European
Commission

Carbon economy

Studies on support to research and innovation policy in the area of bio-based products and services

Independent
Expert
Report

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Research and
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Carbon economy (Lot 1)

Studies on support to research and innovation policy in the area of bio-based products and services

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EUROPEAN COMMISSION

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edited by COWI

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EXECUTIVE SUMMARY

1 Introduction

As a means to unlock the potential that the bioeconomy and in particular the bio-based sector has on achieving the EU's climate targets and the goals set out in the European Green Deal, access to information and comprehensive actions need to be readily available to EU Member States (MS) as key players in the "low carbon economy" transition. The bioeconomy, including the bio-based sector represents a vital source of innovation that can help to mitigate socioe-conomic impacts associated with environmental investments. This study lays out the current state of the carbon economy within the EU as well as the technological and societal challenges that prohibit a sustainable transition to the circular economy. This expansive goal is broken down into bite-sized pieces in order to provide a framework such that knowledge can be shared and concrete actions can be taken by stakeholders at each sectoral level.

According to one estimate, a 61% reduction in waste in landfills through composting and recycling could result in potential mitigation of 72 million tonnes of CO_2eq.[1] In addition, around 60 million tonnes of bio-waste generated across the EU could be recycled through anaerobic digestion and composting.[2] These statistics does not even factor in the benefits that can be generated if the biodegradable waste is then further incorporated into a circular framework. The EU's Circular Economy Action Plan[3], as one of the staples of the European Green Deal[4], stresses the need to decouple economic growth from resource use; applying circular economy principles across the EU could create roughly 700,000 new jobs by 2030 and contribute 0.5% to EU GDP. The bioeconomy is already central to the EU's workforce with a turnover value of € 2.3 trillion and can play a valuable role in improving circularity within the EU.

An integral part of the bioeconomy is the attention to good practices in waste recycling, in particular to high quality recycling. In the most recent update of the EU Waste Framework Directive a target of a 65% recycling rate across MS was set for 2030. For some MS, this target has been surpassed and there are regions or cities heading towards zero-waste and beyond (complete valorisation), while for other MS this target will require significant financial support and effort to reach. The work packages presented in this report highlight the discrepancies across MS while also providing solutions to these discrepancies. Cooperation across MS with different technological capacity or biomass availability would create mutually beneficial outcomes; this is made obvious through the fact that only 20% of biorefineries in the EU are located in Central and Eastern Europe. International coordination is a centrepiece of upscaling the circular and bioeconomy.

Investing in competitive bio-based industries can result in a seismic shift of the circular economy within the EU and will have a positive impact on both the private and public sector. Innovation in the bioeconomy is an efficient method of reducing resource use while simultaneously generating value in waste that would otherwise be lying in a landfill. The work packages are enclosed in this final study report and key findings are summarised below.

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[1] Vogt, R., Derreza-Greeven, C., Giegrich, J., Dehoust, G., Möck, A., & Merz, C. (2015). The climate change mitigation potential of the waste sector. Report by order from the Federal Environment Agency of Germany.

[2] Lee, P., Sims, E., Bertham, O., Symington, H., Bell, N., Pfaltzgraff, L., ... & O'Brien, M. (2017). Towards a circular economy: waste management in the EU; study.

[3] European Commission, (2020). https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf

[4] European Commission, (2019). Communication on the European Green Deal. EUR-Lex - 52019DC0640 - EN - EUR-Lex (europa.eu)

1.1 Work Package 1 – Status Quo: Understanding the Carbon Economy

The objective of WP1 was to provide comprehensive data, analysis and figures on the carbon cycle on several different scopes contained in three chapters. As the anthropogenic carbon cycle is not as extensively studied or conceptualised, this WP fills in an important gap that exists within the currently available research and literature. The study covers the vast majority of economic uses of carbon-based substances through organic compounds and excludes inorganic compounds as they are far less relevant for climate change and therefore not covered in the scope.

In order for a better understanding of the global carbon flow, chapter one is focused on an approach that distinguishes two main natural domains of the carbon cycle (developed by Ciais et. al, 2014[5]). The first is characterised by a rapid exchange of carbon between the reservoirs of the atmosphere, biosphere as well as soil and ocean (hydrosphere). The second domain is the lithosphere for which human-induced extraction of fossil resources have led to a significant acceleration in the lithosphere turnover rate and growth of carbon stock in the atmosphere (CO_2 content).

The technosphere represents the direction and amount of man-made carbon flows within the global carbon cycle. It is found that 41% of fossil carbon resources are used in the transport sector and a quarter of fossil carbon is demanded by the industrial sector. In the residential sector, almost half of the global carbon demand for fossil resources is consumed by space heating. These statistics are significant as both the industrial and heating sector can integrate circular economy principles resulting in a lessened reliance on fossil resources and raw materials.

Following an overarching understanding of the carbon cycle and the impacts that each domain within the organic carbon cycle has on the components of the bioeconomy, the carbon flows in the European economy are considered within chapter two. Carbon supply from biomass and fossil resources as well as within recycled fossil or organic material are shown in the Sankey-diagram below to map the carbon flows of the EU-27 (2018) (Figure 1). It is noticeable, that recycling still makes up a tiny portion of overall C-supply with a heavy reliance on fossil resources. These flows provide a skeleton for the gaps and potentials that already exist within the EU-27 and the future of re-use.

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[5] Ciais, P., Sabine, C., Bala, G., Bopp, L., Brovkin, V., Canadell, J., Chhabra, A., DeFries, R., Galloway, J. and Heimann, M. 2014. Carbon and other biogeochemical cycles. Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press (Ed.).

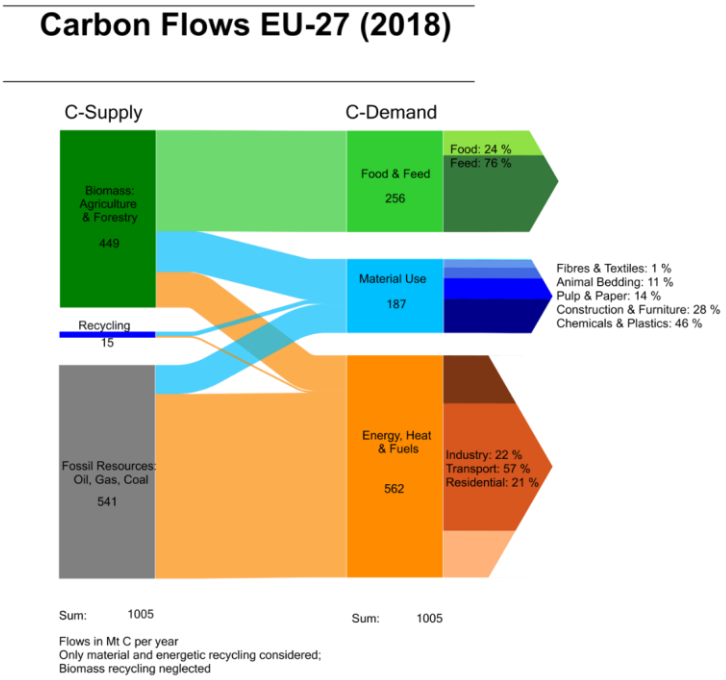

Figure 1. Carbon flows of the EU-27 for 2018 covering C-Supply and C-Demand. Sankey Diagram (own calculations).

The final chapter supports the key focus of the work package as the availability for regional, urban or local data on carbon flows is lacking. In opposition to the common top-down approaches, a bottom-up model containing mass flows of the daily life from an adult living in Germany (age 40-45). The mass flows are analysed and recorded to illustrate material and biogenic carbon flows caused by a single person. This model can be utilised by decision-makers to fill existing gaps in data on carbon flows or verify existing data. The data are broken down into vital processes, household activities, personal hygiene and construction and transformed to kg of carbon/year/person.

The aim was to create a tool that can represent carbon flows on a more detailed and focused level as a function of several pre-selected influencing factors. The simplification of these factors needs to be considered, but the important takeaway is that the waste streams of a single human can be valorised in other sectors but this is only possible if they can be estimated. The results of the model are presented for an average German adult in Figure 2 below.

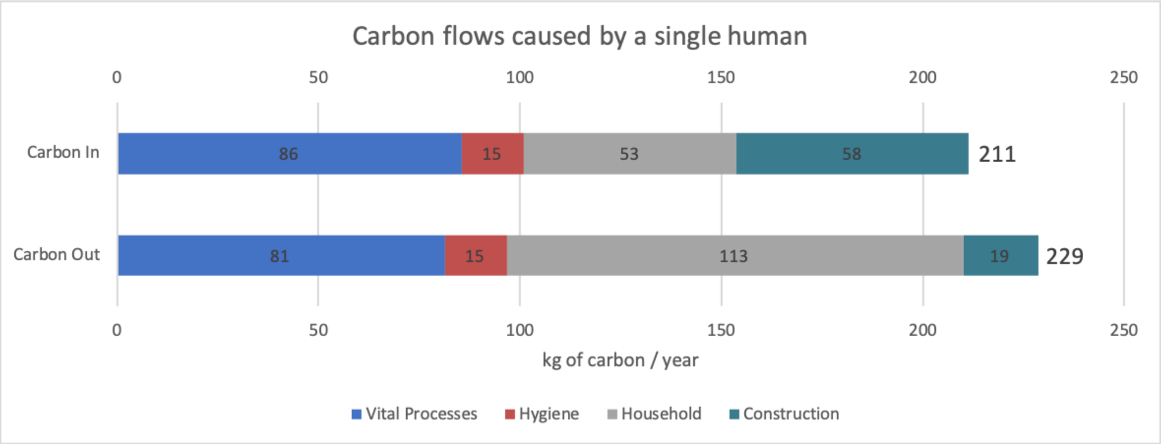

Figure 2. Total biogenic carbon caused by a German adult (own calculations).

1.2 Work Package 2 – Future Scenarios

The main aim of WP2 was to visualise future scenarios for 2050 for the use of carbon in a low carbon economy. To build the scenarios, a number of existing studies were taken into consideration (Mathijs et al. (2015)[6]; European Commission (2018)[7]). Six energy scenarios from the European Commission's study for 2050 (2018) were evaluated to determine overall carbon demand while in parallel two other scenarios on carbon demand from the sectors food & feed and material use for the EU-27 in 2050 were developed due to the absence of reliable and up-to-date future scenarios for those sectors. . These two scenarios are developed using a set of parameters influencing the carbon demand. The six energy scenarios (including power, transport, and industry) are:

- Scenario 1: Business as Usual (BAU)
- Scenario 2: Electrification (ELEC)
- Scenario 3: Hydrogen (H2)
- Scenario 4: Power-to-X (P2X)
- Scenario 5: Energy Efficiency (EE)
- Scenario 6: Circular Economy (CIRC)

The BAU scenario projects the effects of existing or expected MS' policies and projected societal trends. The rest of the scenarios comply with the PA goal of "well below 2 °C." The assumptions surrounding these scenarios (2-6) are based on improvements in energy efficiency and increases in GHG emission reduction targets and biofuel targets as well, among many others.

The approach to develop scenarios for the food, feed and material sector in this study is a hybrid between normative, explorative and predictive scenarios. . The goal of the reduction of GHG emissions and a sustainable economy reflects a normative character of scenarios. Therefore, not all possible situations are determined but only trends that promise sustainability improvements are examined. The scenarios have an explorative character so that a broad range of different possible future situations can be assessed. Furthermore, the approach borrows aspects from predictive scenarios, because it is based on a set of parameters and their future developments can be predicted in some cases. These scenarios are developed in parallel to the first six and are:

- Scenario I: Sufficiency (sufficiency-oriented consumption patterns)

- Scenario II: Technology (strong technological improvements and acceptance)

The conclusions with regard to carbon demand are divided between the energy scenarios (1-6) and the Sufficiency and Technology scenarios (I and II). The main conclusions from the energy scenarios show that carbon demand is significantly lower compared to current carbon demand with the BAU scenario having the highest share of fossil carbon. The demand can be further divided into three sectors (industry, transport, residential). The demand in these sectors can be compared between all six 2050 scenarios and with the current demand (2018), as shown in Figure 4. below.

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[6] Mathijs, E., Brunori, G., Carus, M., Griffon, M., Last, L., Gill, M., Koljonen, T., Lehoczky, E., Olesen, I. and Potthast, A. 2015. Sustainable Agriculture. European Commission, (Ed.)

[7] European Commission 2018. A Clean Planet for all–A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. (Ed.), Download at https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

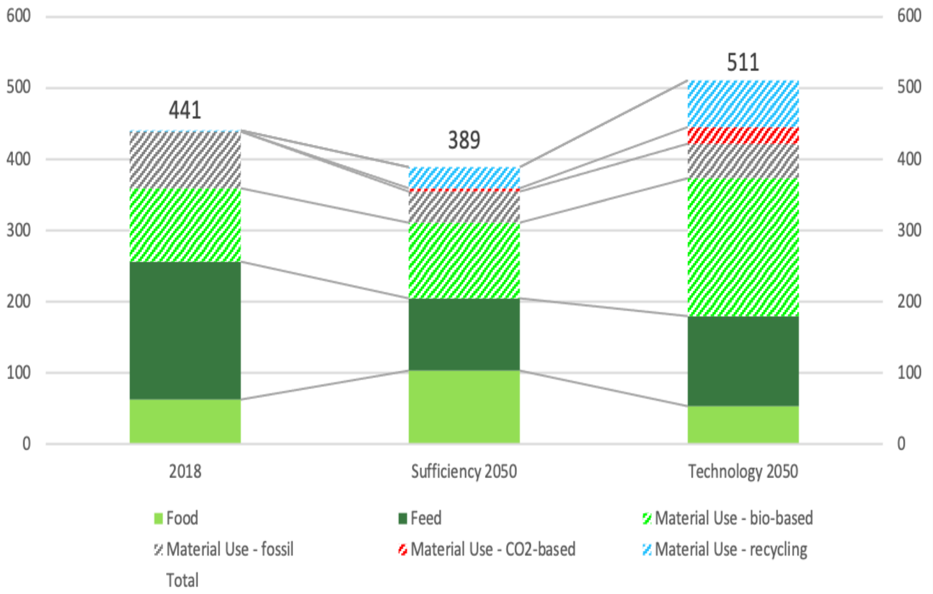

Figure 3. Carbon demand for energetic resources by sector 2018 and by 2050 (own calculations based on European Commission, 2018).

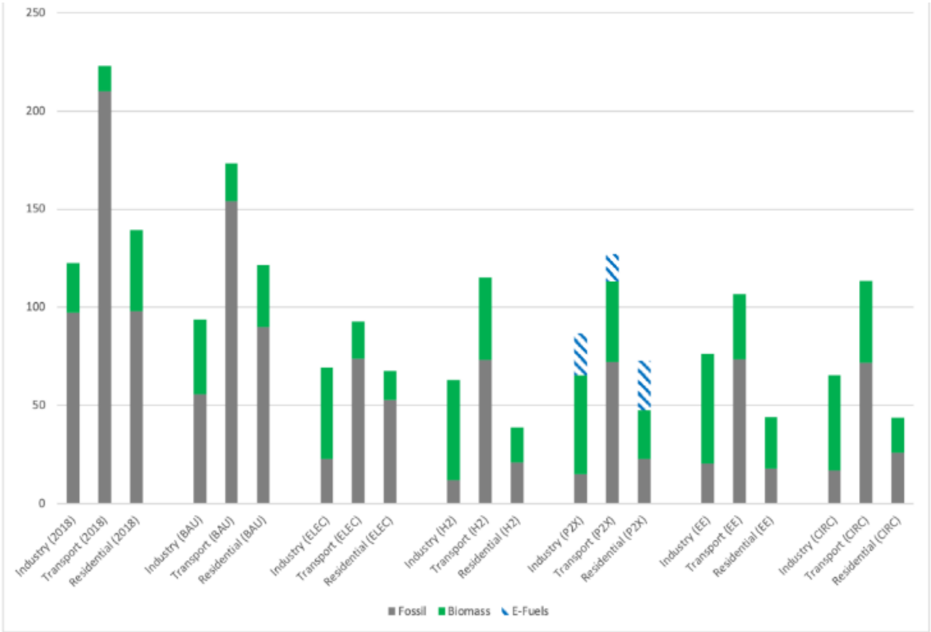

Figure 4. Carbon demand for food, feed and material in EU-27 2018 and by 2050 for both scenarios (own compilation).

For the Sufficiency and Technology scenarios, the carbon demand for food & feed and for the material sector are determined separately. The material sector is further divided between the chemical and plastic sector and other materials (including construction and furniture, pulp and paper, and textiles). In the Sufficiency scenario, the carbon demand is reduced by 12% and in the Technology scenario, the total carbon demand increases by 16% compared to 2018 (Figure 3). While in both scenarios, the carbon demand for food & feed decreases, the decrease is outweighed by the increase in the materials sector in the Technology scenario.

The final chapter of the report covers the sustainability of the considered scenarios based on a selection of indicators for the energy scenarios and impacts for the food, feed and material scenarios. The six energy scenarios are then ranked in a point-based scoring system, 6 being the most sustainable score and 1 the lowest. The highest performing scenario across the indicators was the Circular Economy (CIRC) scenario and the lowest the BAU scenario. The other scenarios had high ranks within various indicators, such as the Electrification (ELEC) scenario with positive evaluation within energy consumption indicator categories and the Hydrogen (H2) scenario in the share of renewable energy source indicator. These results are presented in full within the work package.

For the food, feed and material scenarios, sustainability considerations are focused on impact areas, e.g. carbon demand, land use, circularity rate, material wealth and EU competitiveness. Both scenarios are generally evaluated in all of these areas. In almost every area, both scenarios imply sustainability advantages compared to today. Exceptions are an unchanged land use in the Technology scenario or an unaffected material wealth in the Sufficiency scenario while the material wealth in the Technology scenario increases significantly.

The conclusions from this work package provide a missing piece to previously conducted studies and help to feed into the other work packages of this report. Future scenarios are necessary to outline as reaching the targets set out in the European Green Deal relies on accurate estimations of future carbon demand. The estimations for valorisation and technological improvement towards 2030 are also an integral part of the findings in WP4.

1.3 Work Package 3 – Regulatory Analysis and Assessment of Innovative Technologies

The regulatory analysis undertaken in WP3 is dedicated to the identification of regulatory drivers and obstacles for the production of bio-based products from urban bio-based sources (bio-waste and wastewater sludge). The study builds upon a previous report, "Survey report on regulatory obstacles and drivers for boosting a sustainable and circular bio-based economy" published in 2018[8]. The first part of WP3 updated this report with the current state of regulations as of Q2 2020. Since 2018, 12 EU directives and regulations from the original report had updates that were presented in the first part of WP3 (Table 1).

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[8] Urban Agenda for the EU. (2018). Survey report on regulatory obstacles and drivers for boosting a sustainable and circular urban bio-based. economy https://ec.europa.eu/futurium/en/system/files/ged/analysis_of_regulatory_obstacles_and_drivers_urban_circular_bioeconomy_report_final_version_29.10.19_rv_27.04.2020.pdf

Table 1. Overview of conclusions regarding updates of EU directives and regulations between 2018 and 2020 pertaining to the carbon economy.

EU Directive/Regulation	Update 2020
Landfill Directive	• Calls for stricter measures have been fulfilled by calling for MS to restrict landfilling of recyclable waste • Need for clarification of what constitutes sludge remains relevant and is still excluded from the directive's scope
Nitrates Directive	• Derogations have been filed by MS that ask for exemptions on the nitrogen limits in manure • More derogations add to the earlier analysis that there are too many discrepancies across MS
Fertilisers Regulation	• The new Fertilisers Regulation (2019/1009) takes into consideration the main bottlenecks referring to the point, that organic materials are not considered
REACH Regulation	• Digestate is included to the exemption within the regulation, which eliminates one key bottleneck
Waste Framework Directive	• End of Waste (EoW) criteria is updated, which simplifies the process for determining EoW status • Bio-waste collection is included in directive, which covers many of the main criticisms, but not set to be updated until 2024
Sewage Sludge Directive	• There is an evaluation under way of the directive, so there may be an entirely updated directive
Renewable Energy Directive	• Targets are more ambitious regarding renewable energy percentages (32%) in the final consumption • Barriers remain regarding attention to bio-based materials and there is lack of support for deployment of advanced biofuels
Effort Sharing Decision & Regulation	• Changes are simply proposed not realised and there is a proposed reduction of GHG emissions to 55% which would implicitly support biofuels
The Gas Directive	• New regulation aids non-discriminatory access for green gas • Partnered with the Energy Tax Directive could result in more exemptions for biofuels which are not yet in place
The Plastics Regulation	• New amendments have added new biodegradable substances to the registered list, but still a negligible amount considering the elaborate product list
A European Strategy for Plastics in a Circular Economy	• Still evidence that recycled products take priority over bio-based ones and incentives are lacking for R&D projects for new innovations
Closing the loop – An EU action plan for the Circular Economy	• The main bottleneck of the lack of attention to lifecycle of products has been mostly satisfied by the amendments

The second part of the work package covers the availability of technologies for the material use of carbon and the transformation of processes that will boost resource-efficiency. Innovative technologies in different maturity levels were collected and analysed for their potential contribution to a low carbon economy with the help of multiple indicators. The assessment has been conducted separately for five groups of products (bulk chemicals & fuels, polymers, proteins for food & feed, hydrogen, and fine chemicals).

The evaluation of technologies revealed that electrochemistry is highly promising for polymers, fine chemicals and hydrogen. Microbial systems have potential for bulk chemicals & fuels, proteins, polymers and fine chemicals. Thermochemical conversion and photochemistry are important technologies for bulk chemicals & fuels. Plant systems are key for the production of proteins for food and feed, especially as demand has risen and will continue to rise. Extraction and chemical conversion were deemed the most important for fine chemical production.

By selecting the most promising technologies into a short list, technological gaps and techno-economic challenges can be identified. This is done so that decision-makers are able to direct funds and attention the industries with the highest potential for growth, rather than focus on technologies that may become obsolete. The long list of technologies are found in Annex 6.

1.4 Work Package 4 – Case Studies

WP4 is made up of ten case studies of regions and cities within the EU in order to provide a local perspective at the current state of bio-waste and wastewater sludge valorisation rates. The WP aimed to determine the availability of bio-based resources and their valorisation stage, the presence of the circular economy in local governance as well as existing technological approaches. The selection of cases was conducted in such a way that progressive initiatives could be highlighted with strong potential for value chains.

The final selection centred on diversity (regionally and socio-economically), population size, technological innovation and institutional innovation. This resulted in eight cities and two regions for analysis: Cluj-Napoca (Romania), Emilia-Romagna (Italy), Flanders (Belgium), Łódź (Poland), Maribor (Slovenia), Milan (Italy), Nantes (France), Oslo (Norway), Rotterdam (Netherlands), and Turku (Finland).

Within each case study, municipal data or Eurostat was mined for wastewater and bio-waste data in order to provide a comparison point that can be evaluated across the EU. Stakeholders from clusters, municipal governments, NGOs, academic institutions and public authorities were interviewed in order to gain a closer focus on the goals and future of each region.

The regions and cities examined in this report have taken clear measures to improve the bio-based sector. Cluj-Napoca and Łódź have put considerable effort into encouraging home-composting. Italy is working on expanding existing technologies and its most recent decree announcing the availability of subsidies for biomethane production will support the bio-based sector. The involvement of the private sector in both Milan, through among others the fashion industry, as well as Emilia-Romagna in multiple bio-based production streams, is a major enabling factor. Turku has also introduced its own ambitious recycling targets and has pulled in the private sector through small businesses as well as each level of government.

A key conclusion is the divide between cities that have high levels of bio-waste and no way to maximize its potential (i.e. processing and valorisation) and cities that have the technological capacity to process bio-waste, but not enough input. Enhancing cross-border alliances through cluster networks would result in a well-balanced bio-based sector with sufficient inputs and outputs.

Following the case studies presented in full, a series of recommendations were drafted based on five different barriers to upscaling of the bioeconomy and how these barriers can be tackled through lessons learned from different regions or cities. The lessons learned signify that there are already actions that are pushing the envelope with regards to the

EU's targets, there are still MS that are in need of financial and political support to help the EU achieve the goals within the EU Bioeconomy Strategy and the Circular Economy Action Plan. The barriers and their recommendations are presented in Table 2 below.

Table 2. Barriers and recommendations based on case study analysis within WP4.

Barrier	Recommendations
Data & Reporting	• Reporting at each point of contact • Developing an EU-wide tool • Strict categorisation of what constitutes bio-waste
Financing	• Reward for reduction • Revenues reintroduced to bio-waste streams • Polluter-pays principle
Governance	• Public & private collaboration • Clusters initiated by the government • Consistency between national, international & regional policies
Perception	• Campaigns for waste separation • Incorporating waste separation into school curriculums • Collaboration between research networks
Technologies	• Technological Readiness Level (TRL) transparency • Boosting private sector research through public support • Dissemination of biotechnological knowledge

1.5 Work Package 5 – Communication activities

The transformation towards a low carbon economy, outlined in WP2 requires manifold actions on several levels. The broad dissemination of the results gathered in this study can help foster this transformation. All relevant stakeholders have been identified including policy-/decision-makers, the general public, the industry and scientists. A mixture of communication tools has been used to strategically address each of the stakeholder groups including the following methods:

- Full report including publishable executive summary
- Fact sheet as a short summary of each WP with key findings
- Press Release and dissemination of the press release within nova-Institute's wide network of industry and scientific contacts (newsletter, news portal article, social media channels)
- Video that illustrates the flows of organic carbon caused by a human being and the valorisation potential of waste streams

2 Main conclusions of the study

The information presented in the work packages as part of this study provide a clear window into the current state of the bio-based industry. Engaging stakeholders and upscaling participation in R&I will involve collaboration across MS and at the same time making sure that these stakeholders are very well informed and equipped to make the transition to a low carbon economy. One of the barriers to upscaling the bioeconomy in the case studies was the perception or lack of understanding of the potential and economic benefits that can come from investing in or upscaling the bioeconomy. Building trust and increasing private stakeholder uptake can be solved through information sharing through public and private communication platforms.

Financing the bio-based industry also involves significant upfront investments and resources for those that are involved. Increasing support to municipalities could mitigate the risks that are currently cited within the bioeconomy. By employing a wide variety of well-designed economic instruments such as environmental taxation or tax-exemption for bio-based products, the EU can enable MS to promote circular bioeconomy activities.

The lack of data and reporting within the bio-based industry can further be supported by the anthropogenic carbon cycle model developed in WP1. Alongside enhancing disclosure of environmental data and higher traceability, the benefits of the circular bioeconomy can be more closely tied to and presented through carbon flow data.

The transition to a low carbon economy is an uphill battle that will require cooperation across sectors, geographies as well as industries. The information presented in this summary as well as the work packages provide the bedrock for decision-makers to ramp up their attention to bio-based industries as well as narrow in on the areas with the most potential or those with the largest gaps.

RÉSUMÉ

NOTE DE SYNTHÈSE

1. Introduction

Afin d'exploiter le potentiel de la bioéconomie pour atteindre les objectifs climatiques de l'UE et les objectifs fixés dans le pacte vert pour l'Europe, les États membres de l'UE, en tant qu'acteurs clés de la transition écologique, doivent avoir facilement accès à l'information et à des actions globales. La bioéconomie représente une source vitale d'innovation qui peut contribuer à atténuer les impacts socio-économiques associés aux investissements environnementaux. Cette étude présente l'état actuel de l'économie carbone au sein de l'UE ainsi que les défis technologiques et sociétaux qui interdisent une transition durable vers l'économie circulaire. Cet objectif ambitieux est divisé en petits morceaux afin de fournir un cadre permettant le partage des connaissances et la prise de mesures concrètes par les parties prenantes à chaque niveau sectoriel.

Selon certaines estimations, une réduction de 65 % des déchets biodégradables dans les décharges pourrait entraîner une atténuation potentielle de 74 millions de tonnes d'équivalent CO_2 dans l'UE-27. En outre, cette statistique ne tient même pas compte des bénéfices qui peuvent être générés si les déchets biodégradables sont ensuite intégrés dans un cadre circulaire. Le Plan d'action de l'Union européenne en faveur de l'économie circulaire, qui est l'un des piliers du pacte vert pour l'Europe, souligne la nécessité de dissocier la croissance économique de l'utilisation des ressources. En effet, l'application des principes de l'économie circulaire dans toute l'UE pourrait créer environ 700 000 nouveaux emplois d'ici 2030 et contribuer à hauteur de 0,5 % au PIB de l'UE. La bioéconomie occupe déjà une place centrale dans le monde du travail de l'UE, avec un chiffre d'affaires de 2 300 milliards d'euros, et peut jouer un rôle précieux dans l'amélioration de la circularité au sein de l'UE.

Une partie intégrante de la bioéconomie est l'attention portée aux bonnes pratiques en matière de recyclage des déchets, en particulier au recyclage de haute qualité. Dans la dernière mise à jour de la directive-cadre relative aux déchets, l'objectif d'un taux de recyclage de 65 % dans les États membres a été fixé pour 2030. Pour certains États membres, cet objectif a été dépassé et certaines régions ou villes se dirigent vers le zéro déchet et au-delà (valorisation complète), tandis que pour d'autres États membres, cet objectif nécessitera un soutien financier et des efforts importants pour l'atteindre. Les modules de travail présentés dans ce rapport mettent en évidence les divergences entre les États membres tout en apportant des solutions à ces divergences. La coopération entre des États membres ayant des capacités technologiques ou des disponibilités en biomasse différentes permettrait d'obtenir des résultats mutuellement bénéfiques ; cela est mis en évidence par le fait que seulement 20 % des bioraffineries dans l'UE sont situées en Europe centrale et orientale. La coordination internationale est une pièce maîtresse de la transposition à plus grande échelle de l'économie circulaire et de la bioéconomie.

Investir dans des bio-industries compétitives peut entraîner un changement radical de l'économie circulaire au sein de l'UE et aura un impact positif sur le secteur privé et public. L'innovation dans la bioéconomie est une méthode efficace pour réduire l'utilisation des ressources tout en générant simultanément de la valeur dans les déchets qui, autrement, se trouveraient dans une décharge. Les modules de travail sont inclus dans ce rapport d'étude final et les principales conclusions sont résumées ci-dessous.

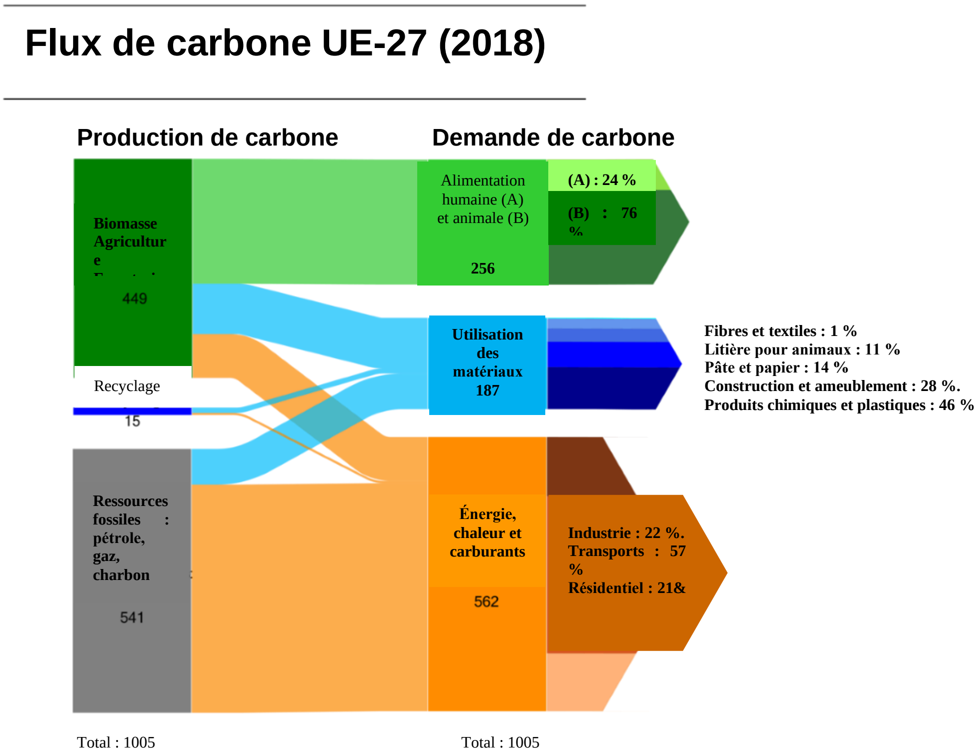
1. Module de travail 1 – Statu quo : comprendre l'économie carbone

L'objectif du module de travail 1 était de fournir des données, des analyses et des chiffres complets sur le cycle du carbone à plusieurs niveaux différents, contenus dans trois chapitres. Le cycle du carbone anthropique n'étant pas aussi largement étudié ou conceptualisé, ce module de travail comble une lacune importante qui existe dans les recherches et la littérature actuellement disponibles. L'étude couvre la grande majorité des utilisations économiques des substances à base de carbone par le biais des composés organiques et exclut les composés inorganiques car ils sont beaucoup moins pertinents pour le changement climatique et ne sont donc pas inclus dans la portée de cette étude.

Afin de mieux comprendre le flux mondial de carbone, le premier chapitre est axé sur une approche qui distingue deux grands domaines naturels du cycle du carbone (élaboré par Cias et al., 2014). Le premier domaine est caractérisé par un échange rapide de carbone entre les réservoirs de l'atmosphère, de la biosphère ainsi que du sol et de l'océan (hydrosphère). Le deuxième domaine est la lithosphère où l'extraction des ressources fossiles par l'homme a entraîné une accélération significative du taux de renouvellement de la lithosphère et de la croissance du stock de carbone dans l'atmosphère (teneur en CO_2).

La technosphère représente la direction et la quantité des flux de carbone produits par l'homme dans le cycle global du carbone. En effet, on constate que 41 % des ressources en carbone fossile sont utilisées dans le secteur des transports et qu'un quart du carbone fossile est demandé par le secteur industriel. De plus, dans le secteur résidentiel, près de la moitié de la demande mondiale de carbone pour les ressources fossiles est consommée par le chauffage des locaux. Ces statistiques sont significatives car le secteur industriel et celui du chauffage peuvent tous les deux intégrer les principes de l'économie circulaire, ce qui permet de réduire la dépendance aux ressources fossiles et aux matières premières.

Après une présentation générale du cycle du carbone et de l'impact de chaque domaine du cycle du carbone organique sur les composantes de la bioéconomie, les flux de carbone dans l'économie européenne sont examinés dans le deuxième chapitre. La production de carbone à partir de la biomasse et des ressources fossiles ainsi que celle provenant de matières fossiles ou organiques recyclées sont présentées dans le diagramme de Sankey ci-dessous afin de visualiser les flux de carbone de l'UE-27 (2018) (figure 1). Il est à noter que le recyclage représente encore une infime partie de la production globale de carbone, avec une forte dépendance aux ressources fossiles. Ces flux fournissent un squelette permettant d'identifier les lacunes et les potentiels qui existent déjà au sein de l'UE-27 et l'avenir de la réutilisation.



Flux exprimés en Mt de carbone par an
Seul le recyclage des matériaux et des énergies est pris en compte
Le recyclage de la biomasse négligé

Figure 1. Les flux de carbone de l'UE-27 (en 2018) couvrant la production et la demande de carbone.

Le dernier chapitre soutient le point central du module de travail, car les données régionales, urbaines ou locales sur les flux de carbone ne sont pas disponibles. En opposition aux approches descendantes communément pratiquées, un modèle ascendant contenant les flux de masse provenant de la vie quotidienne d'un adulte vivant en Allemagne (40-45 ans) y est présenté. Les flux de masse sont analysés et enregistrés pour illustrer les flux de carbone matériel et biogénique causés par une seule personne. Ce modèle peut être utilisé par les décideurs pour combler les lacunes existantes dans les données sur les flux de carbone ou pour vérifier les données existantes. Les données sont ventilées en processus vitaux, activités domestiques, hygiène personnelle et construction et converties en kg de carbone / an / personne.

L'objectif était de créer un outil capable de représenter les flux de carbone à un niveau plus détaillé et plus ciblé en fonction de plusieurs facteurs d'influence présélectionnés. La simplification de ces facteurs doit être envisagée, mais le point important à retenir est que les flux de déchets d'un seul être humain peuvent être valorisés dans d'autres secteurs, mais cela n'est possible que s'ils peuvent être estimés. Les résultats du modèle sont présentés pour un adulte allemand moyen dans la figure 2 ci-dessous.

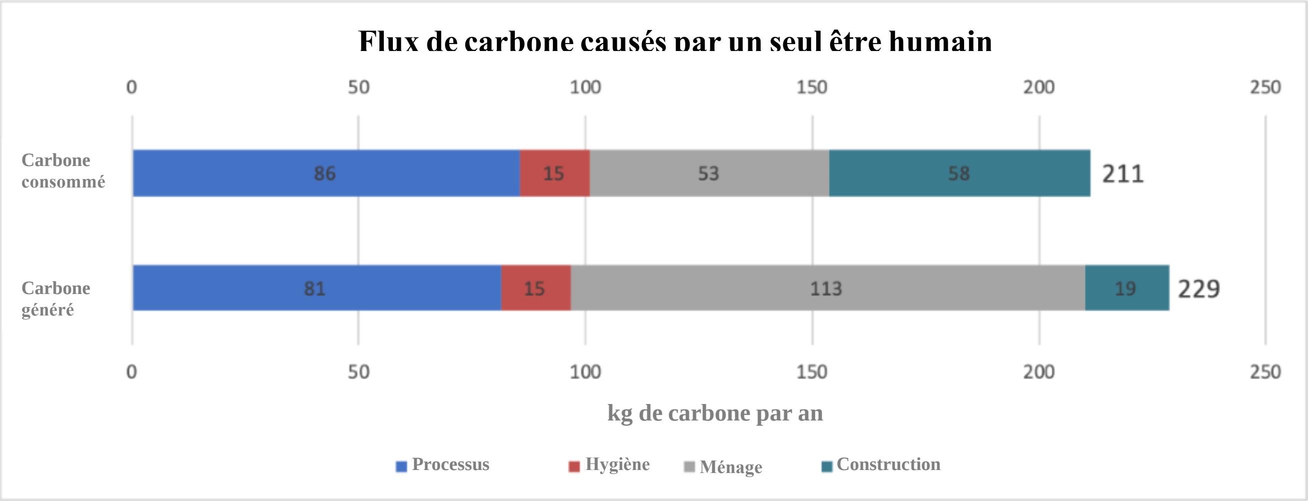


Figure 2. Carbone biogénique total causé par un adulte allemand.

2. *Module de travail 2 – Scénarios d'avenir*

Le principal objectif du module de travail 2 était de visualiser des scénarios futurs pour 2050 concernant l'utilisation du carbone dans une économie à faibles émissions de carbone fossile. Pour élaborer ces scénarios, un certain nombre d'études existantes ont été prises en considération (Mathijs et al. (2015); Commission européenne (2018)). Six scénarios énergétiques issus de l'étude de la Commission européenne pour 2050 ont été évalués afin de déterminer la demande globale en carbone, tandis qu'en parallèle, deux autres scénarios sur la demande en carbone des secteurs de l'alimentation humaine et animale et de l'utilisation des matières premières pour l'UE-27 en 2050 ont été élaborés en raison de l'absence de scénarios futurs fiables et actualisés pour ces secteurs. Ces deux scénarios sont développés à partir d'un ensemble de paramètres influençant la demande en carbone. Les six scénarios énergétiques (comprenant l'électricité, les transports et l'industrie) sont :

- Scénario n° 1 : Scénario de maintien de statu quo
- Scénario n° 2 : Électrification
- Scénario n° 3 : Hydrogène
- Scénario n° 4 : Conversion de l'électricité en un autre vecteur énergétique
- Scénario n° 5 : Efficacité énergétique
- Scénario n° 6 : Économie circulaire

Le scénario de maintien de statu quo prévoit les effets des politiques existantes ou envisagées des États membres et les tendances sociétales projetées. Les autres scénarios sont conformes à l'objectif de l'accord de Paris : "bien en dessous de 2 °C". Les hypothèses sous-jacentes à ces scénarios (2-6) sont basées sur des améliorations de l'efficacité énergétique et des augmentations des objectifs de réduction des émissions de GES et des objectifs en matière de biocarburants, entre autres.

L'approche adoptée dans cette étude pour élaborer des scénarios pour le secteur des denrées alimentaires, des aliments pour animaux et des matériaux est un hybride entre les scénarios normatifs, exploratoires et prédictifs. L'objectif de réduction des émissions de GES et d'une économie durable reflète un caractère normatif des scénarios. Par conséquent, toutes les situations possibles ne sont pas déterminées, mais seules les tendances qui promettent une amélioration de la durabilité sont examinées. Les scénarios ont un caractère exploratoire afin de pouvoir évaluer un large éventail de situations futures possibles. En outre, cette approche emprunte des aspects aux scénarios prédictifs, car elle est basée sur un ensemble de paramètres et leur évolution future peut être prévue dans certains cas. Ces scénarios sont développés en parallèle avec les six premiers et sont les suivants :

- Scénario I : Suffisance (modes de consommation axés sur la suffisance)
- Scénario II : Technologie (fortes améliorations technologiques et acceptation)

Les conclusions concernant la demande de carbone sont réparties entre les scénarios énergétiques (1-6) et les scénarios "Suffisance" et "Technologie" (I et II). Les principales conclusions des scénarios énergétiques montrent que la demande de carbone est nettement inférieure à la demande de carbone actuelle, le scénario de maintien du statu quo présentant la plus forte proportion de carbone fossile. La demande peut encore être divisée en trois secteurs (industrie, transport, résidentiel). La demande dans ces secteurs peut être comparée entre tous les six scénarios 2050 et avec la demande actuelle (2018), comme le montre la figure 4 ci-dessous.

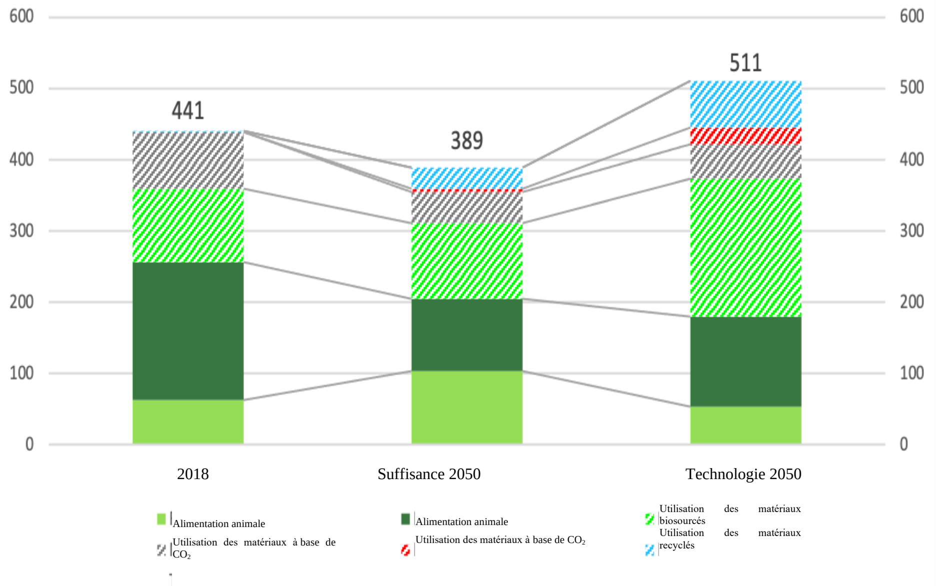


Figure 3. Demande de carbone pour les denrées alimentaires, les aliments pour animaux et les matériaux dans l'UE-27 (en Mt de carbone**)**

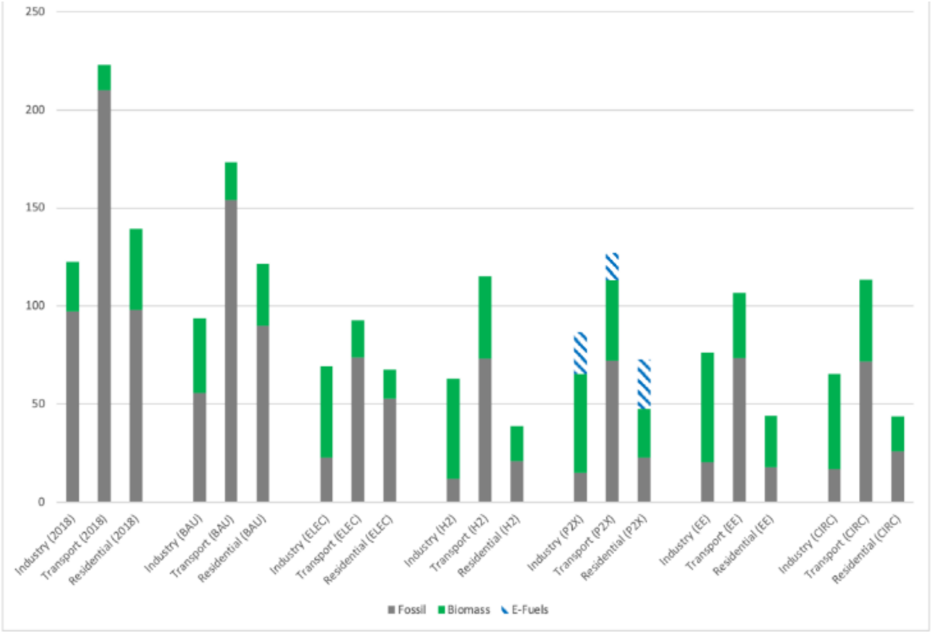


Figure 4. Demande de carbone dans les scénarios énergétiques 2018 et 2050.

Pour les scénarios "Suffisance" et "Technologie", la demande de carbone pour l'alimentation humaine et animale et pour le secteur des matériaux est déterminée séparément. Le secteur des matériaux se répartit en outre entre le secteur chimique et plastique et les autres matériaux (notamment la construction et l'ameublement, l'industrie de pâte et papier et le textile). Dans le scénario "Suffisance", la demande de carbone est réduite de 12 % et dans le scénario "Technologie", la demande totale de carbone augmente de 16 % par rapport à 2018 (figure 3). Si dans les deux scénarios la demande de carbone pour l'alimentation humaine et animale diminue, cette diminution est compensée par l'augmentation du secteur des matériaux dans le scénario „Technologie”.

Le dernier chapitre du rapport couvre la durabilité des scénarios envisagés sur la base d'une sélection d'indicateurs pour les scénarios énergétiques et les impacts pour les scénarios concernant les denrées alimentaires, les aliments pour animaux et les matériaux. Les six scénarios énergétiques sont ensuite classés selon un système de notation par points, 6 étant le score le plus durable et 1 – le plus bas. Le scénario le plus performant parmi les indicateurs était celui de l'économie circulaire et le plus faible celui de maintien du statu quo. Les autres scénarios ont été classés en haut de l'échelle en fonction de divers indicateurs, tels que le scénario "Électrification” avec une évaluation positive au sein des catégories d'indicateurs relatifs à la consommation d'énergie et le scénario "Hydrogène” au sein de l'indicateur relatif à la part des sources d'énergie renouvelables. Ces résultats sont présentés dans leur intégralité dans le module de travail.

Pour les scénarios concernant les denrées alimentaires, les aliments pour animaux et les matériaux, les considérations de durabilité sont axées sur les domaines d'impact, par exemple la demande de carbone, l'utilisation des terres, le taux de circularité, la richesse matérielle et la compétitivité de l'UE. Les deux scénarios sont généralement évalués dans tous ces domaines. Dans presque tous les domaines, les deux scénarios impliquent des avantages en termes de durabilité par rapport à la situation actuelle. Les exceptions sont : une utilisation des terres inchangée dans le scénario "Technologie" ou une richesse matérielle restée inchangée dans le scénario "Suffisance" alors que la richesse matérielle dans le scénario "Technologie" augmente de manière significative.

Les conclusions de ce module de travail fournissent une pièce manquante aux études précédemment menées et contribuent à alimenter les autres modules de travail de ce rapport. Il est nécessaire d'élaborer des scénarios futurs car la réalisation des objectifs fixés dans le pacte vert pour l'Europe repose sur des estimations précises de la demande future de carbone. Les estimations concernant la valorisation et l'amélioration technologique à l'horizon 2030 font également partie intégrante des conclusions du module de travail 4.

3. Module de travail 3 – Analyse et évaluation réglementaires des technologies innovantes

L'analyse réglementaire réalisée dans le cadre du module de travail 3 est consacrée à l'identification des facteurs et des obstacles réglementaires pour la production de produits biologiques à partir de sources biologiques urbaines (biodéchets et boues d'épuration). L'étude s'appuie sur un rapport précédent : "Rapport d'expertise sur les obstacles réglementaires et les facteurs de stimulation d'une bioéconomie durable et circulaire”, publié en 2018. La première partie du module de travail 3 constitue une mise à jour de ce rapport et présente l'état actuel de la réglementation au deuxième trimestre 2020. Depuis 2018, 12 directives et règlements inclus dans le rapport initial ont fait l'objet de mises à jour qui ont été présentées dans la première partie du module de travail 3 (tableau 1).

Tableau 1. Aperçu général des conclusions concernant les mises à jour des directives et règlements de l'UE relatifs à l'économie carbone entre 2018 et 2020.

Directive/Règlement	**Mise à jour 2020**
Directive sur la mise en décharge	• Les appels à des mesures plus strictes ont été satisfaits en demandant aux États membres de limiter la mise en décharge des déchets recyclables • La nécessité de clarifier ce qui constitue des boues reste pertinente et est toujours exclue du champ d'application de la directive
Directive sur les nitrates	• Des dérogations ont été déposées par les États membres qui demandent des exemptions concernant les limites d'azote dans le fumier • D'autres dérogations viennent s'ajouter à l'analyse précédente selon laquelle il existe trop de divergences entre les États membres
Règlement relatif aux engrais	• Le nouveau règlement sur les fertilisants (2019/1009) prend en considération les principaux goulets d'étranglement liés au fait que les matières organiques ne sont pas prises en compte
Règlement REACH	• Le digestat est inclus dans l'exemption du règlement, ce qui élimine un goulet d'étranglement important
Directive-cadre relative aux déchets	• Les critères de fin du statut de déchets sont mis à jour, ce qui simplifie le processus de détermination de la fin du status des déchets • La collecte des biodéchets est incluse dans la directive, ce qui couvre un grand nombre des principales critiques, mais ne devrait pas être mise à jour avant 2024
Directive sur les boues d'épuration	• Une évaluation de la directive est en cours, de sorte qu'il pourrait y avoir une directive entièrement révisée
Directive sur les sources d'énergie renouvelables	• Les objectifs sont plus ambitieux en ce qui concerne les pourcentages d'énergies renouvelables (32 %) dans la consommation finale • Des obstacles subsistent en ce qui concerne l'attention portée aux matériaux biosourcés et le soutien au déploiement des biocarburants avancés est encore insuffisant
Décision et règlement sur la répartition de l'effort	• Des changements sont simplement proposés mais ne sont pas réalisés et il est proposé de réduire les émissions de GES à 55 %, ce qui favoriserait implicitement les biocarburants
La directive sur le gaz	• Le texte révisé favorise un accès non discriminatoire au gaz "vert" • Cette directive – associée à la directive sur la taxation de l'énergie – pourrait entraîner un plus grand nombre d'exonérations pour les biocarburants qui ne sont pas encore en place
Le règlement sur les matières plastiques	• De nouveaux amendements ont ajouté de nouvelles substances biodégradables à la liste enregistrée, mais en quantité encore négligeable compte tenu de la liste de produits élaborée
Stratégie européenne sur les matières plastiques dans une économie circulaire	• Cette stratégie montre que les produits recyclés ont toujours la priorité sur les produits biologiques et les projets de recherche et développement en matière de nouvelles innovations ne sont pas suffisamment encouragés
Boucler la boucle – Plan d'action de l'Union européenne en faveur de l'économie circulaire	• Le principal goulet d'étranglement lié au manque d'attention portée au cycle de vie des produits a été en grande partie éliminé par les amendements

La deuxième partie du module de travail porte sur la disponibilité des technologies pour l'utilisation de matériaux à base de carbone et la transformation des processus qui permettront d'améliorer l'utilisation efficace des ressources. Plusieurs technologies innovantes à différents niveaux de maturité ont été collectées et analysées au regard de

leur contribution potentielle à une économie à faibles émissions de carbone fossile, à l'aide d'indicateurs multiples. multiples. L'évaluation a été menée séparément pour cinq groupes de produits (produits chimiques en vrac et carburants, polymères, protéines pour l'alimentation humaine et animale, hydrogène et produits chimiques plus nobles).
L'évaluation des technologies a révélé que l'électrochimie est très prometteuse pour les polymères, les produits chimiques plus nobles et l'hydrogène. Les systèmes microbiens ont un potentiel pour les produits chimiques en vrac et les carburants, les protéines, les polymères et les produits chimiques plus nobles. La conversion thermochimique et la photochimie sont des technologies importantes pour les produits chimiques en vrac et les carburants. Les systèmes végétaux sont essentiels à la production de protéines pour l'alimentation humaine et animale, d'autant plus que la demande a augmenté et continuera d'augmenter. L'extraction et la conversion chimique ont été considérées comme les plus importantes pour la production de produits chimiques plus nobles.

En sélectionnant les technologies les plus prometteuses dans une liste restreinte, il est possible d'identifier les lacunes technologiques et les défis technico-économiques. Cela a pour but de permettre aux décideurs d'orienter les fonds et d'attirer l'attention sur les industries ayant le plus fort potentiel de croissance, plutôt que de se concentrer sur des technologies qui pourraient devenir obsolètes. La longue liste des technologies se trouve à l'annexe 6.

4. Module de travail 4 – Études de cas

Le module de travail 4 est composé de dix études de cas sur des régions et des villes de l'UE afin de fournir une perspective locale sur l'état actuel des taux de valorisation des biodéchets et des boues d'épuration. Ce module de travail visait à déterminer la disponibilité des bioressources et leur stade de valorisation, la présence de l'économie circulaire dans la gouvernance locale ainsi que les approches technologiques existantes. La sélection des cas a été effectuée de manière à mettre en évidence les initiatives progressistes présentant un fort potentiel pour les chaînes de valeur.

La sélection finale s'est concentrée sur la diversité (régionale et socio-économique), la taille de la population, l'innovation technologique et l'innovation institutionnelle. Cela a donné lieu à l'analyse de huit villes et de deux régions suivantes : Cluj-Napoca (Roumanie), Émilie-Romagne (Italie), Flandre (Belgique), Łódź (Pologne), Maribor (Slovénie), Milan (Italie), Nantes (France), Oslo (Norvège), Rotterdam (Pays-Bas) et Turku (Finlande).

Dans chaque étude de cas, les données municipales ou celles d’Eurostat sur les eaux usées et les biodéchets ont été exploitées afin de fournir un point de comparaison pouvant être évalué dans toute l'UE. Les parties prenantes provenant des clusters, des administrations municipales, des ONG, des institutions universitaires et des autorités publiques ont été interrogées afin de mieux cerner les objectifs et l'avenir de chaque région.

Les régions et les villes examinées dans ce rapport ont pris des mesures claires pour améliorer le secteur de la bioéconomie. Cluj-Napoca et Łódź ont déployé des efforts considérables pour encourager le compostage domestique. L'Italie travaille sur l'expansion des technologies existantes et son dernier décret annonçant la disponibilité de subventions pour la production de biométhane soutiendra le secteur de la bioéconomie. L'implication du secteur privé tant à Milan, par le biais notamment de l'industrie de la mode, qu'en Émilie-Romagne, dans de multiples filières de bioproduction, est un facteur favorable majeur. Turku a également introduit ses propres objectifs ambitieux de recyclage et a fait appel au secteur privé par le biais de petites entreprises ainsi qu'à chaque niveau de gouvernement.

Une conclusion clé est la fracture entre les villes qui ont des niveaux élevés de biodéchets et aucun moyen de maximiser leur potentiel (c'est-à-dire le traitement et la valorisation) et les villes qui ont la capacité technologique de traiter les biodéchets, mais pas assez d'intrants. Le renforcement des alliances transfrontalières par le biais de réseaux de clusters permettrait d'obtenir un secteur de la bioéconomie bien équilibré, avec des intrants et des extrants suffisants.

Après la présentation des études de cas dans leur intégralité, une série de recommandations a été rédigée sur la base de cinq obstacles différents qui entravent l'expansion de la bioéconomie et sur la manière dont ces obstacles peuvent être levés grâce aux leçons tirées par les différentes régions ou villes. Ces leçons signifient qu'il existe déjà des actions qui repoussent les limites en ce qui concerne les objectifs de l'UE et que certains États membres ont encore besoin d'un soutien financier et politique pour aider l'UE à atteindre les objectifs de la stratégie pour la bioéconomie et du plan d'action en faveur de l'économie circulaire. Les obstacles et les recommandations correspondantes sont présentés dans le tableau 2 ci-dessous.

Tableau 2. Obstacles et recommandations basés sur l'analyse d'études de cas au sein du module de travail 4.

Barrière	**Recommandations**
Données et leur communication	• Communication des données à chaque point de contact • Élaboration d'un outil à l'échelle de l'UE • Catégorisation rigoureuse de ce qui constitue des biodéchets
Financement	• Récompense pour la réduction • Revenus réintroduits dans les flux de biodéchets • Principe du pollueur-payeur
Gouvernance	• Collaboration entre les secteurs public et privé • Clusters initiés par le gouvernement • Cohérence entre les politiques nationales, internationales et régionales
Perception	• Campagnes en faveur du tri des déchets • Intégration du tri des déchets dans les programmes scolaires • Collaboration entre les réseaux de recherche
Technologies	• Transparence du niveau de maturité technologique (NMT) • Stimulation de la recherche dans le secteur privé grâce au soutien public • Diffusion des connaissances dans le domaine des biotechnologies

5. Module de travail 5 – Activités de communication

La transition vers une économie à faibles émissions de carbone fossile, décrite dans le module de travail 2, nécessite des actions multiples à plusieurs niveaux. La large diffusion des résultats recueillis dans cette étude peut contribuer à favoriser cette transition. Tous les acteurs concernés ont été identifiés, y compris les responsables politiques/décideurs, le grand public, l'industrie et les scientifiques. Un mélange d'outils de communication a été utilisé pour aborder stratégiquement chacun des groupes de parties prenantes, y compris les méthodes suivantes :

- Rapport complet incluant un résumé publiable
- Fiche d'information sous la forme d'un bref résumé de chaque module de travail avec les principales conclusions
- Communiqué de presse et diffusion du communiqué de presse au sein du vaste réseau de contacts industriels et scientifiques du nova-Institute (bulletin d'information, article sur le portail d'information, canaux de médias sociaux)
- Vidéo qui illustre les flux de carbone organique causés par un être humain et le potentiel de valorisation des flux de déchets

2. Principales conclusions de l'étude

1. Les informations présentées dans les modules de travail faisant partie de cette étude donnent un aperçu clair de l'état actuel de la bio-industrie. L'engagement des parties prenantes et le renforcement de la participation à la R&I impliqueront une

collaboration entre les États membres tout en veillant à ce que ces parties prenantes soient très bien informées et équipées pour effectuer la transition. Dans les études de cas, l'un des obstacles à l'expansion de la bioéconomie était la perception ou le manque de compréhension. L'instauration de la confiance et l'augmentation de la participation des acteurs privés peuvent être résolues par le partage d'informations par le biais de plateformes de communication publiques et privées.

2. Le financement de la bio-industrie implique également d'importants investissements initiaux et des ressources pour ceux qui y participent. Un soutien accru aux municipalités pourrait atténuer les risques qui sont actuellement signalés dans la bioéconomie. En recourant à un large éventail d'instruments économiques bien conçus, tels que la fiscalité environnementale ou l'exonération fiscale des produits biologiques, l'UE peut aider les États membres à promouvoir les activités d'économie circulaire.

3. Le manque de données et de leur communication au sein de l'industrie des produits biologiques peut être encore renforcé par le modèle de cycle du carbone anthropique développé dans le module de travail 1. Outre l'amélioration de la divulgation des données environnementales et une meilleure traçabilité, les avantages de l'économie circulaire peuvent être plus étroitement liés aux données sur les flux de carbone et présentés par le biais de celles-ci.

La transition vers une économie à faibles émissions de carbone fossile est une bataille difficile qui nécessitera une coopération entre les secteurs, les régions et les industries. Les informations présentées dans cette synthèse ainsi que les modules de travail constituent la base sur laquelle les décideurs peuvent s'appuyer pour porter davantage d'attention aux bio-industries et se concentrer sur les domaines présentant le plus grand potentiel ou les lacunes les plus importantes.

INTRODUCTION

This report is made as a final outcome of the work for the DG Research and Innovation (Unit B1 "Circular Economy and Bio-based Systems") services on "Studies on support to R&I policy in the area of bio-based products and services - Carbon Economy (Lot 1)" developed based on the service contract no 2018/RTD/F2/OP/PP-07281/LC-01385837. The study was implemented by the consortium constellated by COWI A/S, nova Institute and Utrecht University. The contract for this assignment was signed on the 5th of December 2019 and the study was running for 14 months and was concluded on the 5th of February 2021. The report covers the findings from all 5 work packages.

PROJECT SYNOPSIS

The main aim of this study was to develop a study to explore the nature and the scale of the challenge of moving towards a low carbon economy. The study investigated the role of research and innovation in addressing this challenge at a global, European, national, regional and urban level. The study delivered material that will allow to devise holistic, multi-level, economy-wide bioeconomy policies that support growth, industrial transition, circular economy and climate change mitigation. The study had also had very practical dimension as it produced 10 regional and urban case studies clearly demonstrating the progress of establishing an element of the circular economy and so-called urban and regional metabolisms system in eight European cities and in two regions. The study also contains a well-developed communication component that illustrated and explained with simplicity the dimensions and derivatives of the circular economy concept to policy-makers, stakeholders, interest groups and the general public. In the chapters below the findings from the each of the work packages are presented.

WORK PACKAGE 1 – STATUS QUO: UNDERSTANDING THE CARBON ECONOMY

1 Carbon Cycle

Carbon is one of the most important chemical elements and building-blocks of life on earth. It can be found in everything and everywhere; in fossil rocks, in oceans, in the atmosphere or in all living organisms. There is carbon in the trees we build houses from, the crops we grow and eat, the animals we rely on and perhaps consume, and in the fuels that we use to heat us and the vehicles we use to transport ourselves. In fact, we have always lived in a carbon economy, which has been powerfully changed by the influence of humans.

Anthropogenic carbon cycles are different from and much smaller than the biogenic and geological carbon cycles. The anthropogenic carbon cycle can be understood as flows and stocks of carbon managed by humans or as carbon stocks and flows from, to and within the technosphere. Through research, the global carbon cycle and the biological and geological cycles within it, have been well understood and quantified, see e.g. Ciais et al. (2014)[9] or Hepburn et al. (2019)[10]. On the other hand, even though the anthropogenic carbon cycle is largely conceptualised, how to quantify and manage the flows and pools without releasing emissions to the atmosphere remains a challenge.

Therefore, the objective of WP1 is to provide comprehensive data, analysis and figures on the carbon cycle on several different scopes. In the first chapter, the global natural and anthropogenic carbon cycle is analysed as a simplified form of the global bio-geological carbon cycle, considering only those carbon flows and stocks, that are relevant for economic activities. Chapter two depicts the carbon economy on the European level. The analysis will focus on biomass and other alternative carbon sources (for details see below) and will investigate their role beside different fossil carbon sources like oil, gas and coal. Chapter three introduces a novel concept of human carbon flows that provides a bottom-up approach to account carbon flows caused by activities of a single human. This model can be used for estimations of carbon flows on various scopes and scales e.g. to fill existing data gaps or to assess top-down derived data.

1.1 Criteria for the inclusion of carbon stocks and flows

As mentioned, carbon can be found in an endless number of forms on the earth. Hence, to follow the aim of this study to analyse the characteristics of current and future carbon economy, a scope must be set to differentiate between relevant and irrelevant forms of carbon to answer the research question.

A suitable approach is the inclusion of organic carbon compounds and the exclusion of inorganic carbon compounds. Within the organic chemistry, carbon can form, inter alia, in:

- compounds with hydrogen (carbohydrates, e.g. found in fossil fuels, petrochemicals, plastics, solvents or lubricants);
- compounds with oxygen and hydrogen (e.g. in sugars, lignans, alcohols or fats);
- compounds containing nitrogen (alkaloids, e.g. in pharmaceutics);
- compounds containing sulphur (e.g. in antibiotics or rubber).

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[9] Ciais, P., Sabine, C., Bala, G., Bopp, L., Brovkin, V., Canadell, J., Chhabra, A., DeFries, R., Galloway, J. and Heimann, M. 2014. Carbon and other biogeochemical cycles. Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press (Ed.).

[10] Hepburn, C., Adlen, E., Beddington, J., Carter, E. A., Fuss, S., Mac Dowell, N., Williams, C. K. (2019). The technological and economic prospects for CO2 utilisation and removal. Nature, 575(7781), 87-97. doi:10.1038/s41586-019-1681-6

Therefore, organic carbon compounds cover the vast majority of economic uses of carbon-based substances. The CO_2 emissions based on these uses are also within the scope of this study, even though the CO_2 molecule is an inorganic compound.

Inorganic carbon compounds on the other hand as well as unbound carbon atoms are part of the inorganic chemistry. Beneath gaseous compounds with oxygen (CO, CO_2, etc.), a very common form are carbon compounds in minerals. Large flows of inorganic carbon are caused by human activities, e.g. carbonic acid due to water use or carbonate rocks like limestone, dolomite or marble for construction material. While some of the uses of inorganic carbon compounds don't include chemical reactions that lead to the emission of greenhouse gases (e.g. the use of natural stone as a construction material), others are sources of GHG emissions (e.g. the calcination process for cement production, see below). All these inorganic carbon compounds are excluded from the scope of the study. Even though, inter alia, the mineral industry is included in the European Union Emission Trading Scheme, the exclusion of these flows seems legitimate since the use of fossil resources is a much more important contributor to EU GHG emissions. Problems associated with resource scarcity are not scope of the study.

Worth mentioning is a number of economic processes that aren't included in this study due to the use of inorganic carbon-based materials but which still emit CO_2. Some important processes are listed below.

- In the calcination process for cement production calcium carbonate ($CaCO_3$) is used. While the emissions for process heating are considered in this study by accounting the fossil energy carriers used, the chemical reaction in the calcination process itself isn't part of the study. However, compared to the total amount of the global carbon supply from fossil resources of 11.3 Gt of carbon per year (see figure world carbon flow) the amount of 0.25 Gt of carbon released to the atmosphere in the calcination reaction is rather low (2%) and the impact even decreases when the carbon offset from the atmosphere in the lifespan of concrete of approximately 43% is considered (Xi et al. 2016)[11]. On the European level, the share of carbon emissions from the calcination reaction on the overall carbon emissions is even lower at 0.4%, according to current emission trade numbers provided by the European Lime Association.

- For the primary production of steel calcinated dolomite is used in blast furnaces to foster the formation of slag. The calcination process uses calcium magnesium carbonate ($CaMg(CO_3)_2$) and is similar to the process for the cement production, discussed above.

- Liming is a process to neutralise soil acidity in agriculture or forestry. Common substances used for liming are calcium carbonate ($CaCO_3$) and calcium oxide (CaO, also known as quicklime or burnt lime). The chemical reaction for the production of the latter releases CO_2.

- In the production of glass, sodium peroxide (NaO) is used to alter the structure of the glass. In the process of the production of sodium peroxide, sodium carbonate (Na_2CO_3, also known as washing soda, soda ash or soda crystals) is used and CO_2 is released. Further feedstocks for the production of glass are potassium carbonate (K_2CO_3) and calcium carbonate ($CaCO_3$). The production of those two materials also releases CO_2.

- Despite the production of glass, sodium carbonate is a raw material for the production of bleach, detergents, soap, paper and pulp.

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[11] Xi, F., Davis, S. J., Ciais, P., Crawford-Brown, D., Guan, D., Pade, C., Shi, T., Syddall, M., Lv, J. and Ji, L. 2016. Substantial global carbon uptake by cement carbonation. Nature Geoscience, Vol. 9 (12), 880-883.

To put into context, organic as well as inorganic stocks of the Earth's spheres are considered in the next chapter.

1.2 Definition of Carbon Economy

The **carbon economy** covers all sectors and systems that rely on resources that contain carbon (organic carbon in animals, plants, micro-organisms and derived biomass, organic waste; organic carbon in fossil resources including coal, oil, gas and gas hydrates and inorganic carbon in various compounds like mineral carbonate rocks), their functions and principles. It includes and interlinks: land and marine ecosystems producing bio-based carbon; deposits of fossil resources in all forms and deposits of mineral carbon, all primary production sectors that use and produce bio-based, fossil or mineral carbon resources; and all economic and industrial sectors that use carbon containing resources and processes (to produce food, feed, chemicals and materials, cement, electric power, heat and fuels) and corresponding services. The sustainable management of carbon resources examines weather a sector's resource demand can be decarbonised or is persistently reliant on carbon inputs and how these carbon demand can become independent of fossil resources. Instead, renewable carbon is used, which entails all carbon sources that avoid or substitute the use of any additional fossil carbon from the geosphere. Renewable carbon can come from the biosphere, atmosphere or technosphere – but not from the geosphere. Renewable carbon circulates between biosphere, atmosphere and technosphere, creating a carbon circular economy. Hence renewable carbon doesn't increase the carbon content of the atmosphere and doesn't contribute to global warming.

Carbon is contained in a cornucopia of everyday products and substances, both, fossil and bio-based (including natural materials like wood or food and synthetic materials like bio-plastics or biofuels). Hence, "decarbonisation" is not the right term for the material use. Instead, the transformation of material use of carbon towards more sustainability means the use of "renewable carbon", which includes carbon from biomass, from direct CO2 utilisation and recycling[12]. In light of this debate, a pragmatic definition of the carbon economy is derived[13]. As described in another section above, the scope of the study is organic carbon. Inorganic carbon is not part of the study.

2 Global natural and anthropogenic carbon flows

A schematic representation of the global natural and anthropogenic carbon cycle including stocks and flows is shown in Figure 5. For each of the Earth's spheres, the carbon stocks as well as their composition have been valuated in gigatons of carbon (Gt C) and the net flows between the spheres in gigatons of carbon per year (Gt C / y).

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[12] The term "renewable carbon" is used in line with the definition given by Carus, M., Dammer, L., Raschka, A., Skoczinski, P., vom Berg, C.. (2020). nova-Paper #12: "Renewable Carbon – Key to a Sustainable and Future-Oriented Chemical and Plastic Industry". nova-Institut (Ed.). Hürth, Germany, see http://bio-based.eu/nova-papers/#novapaper12

[13] The definition is derived from the definition of the European bioeconomy, given in "A sustainable Bioeconomy for Europe: strengthening the connection between economy, society and the environment - Updated Bioeconomy Strategy", European Commission (2018), see https://ec.europa.eu/research/bioeconomy/pdf/ec_bioeconomy_strategy_2018.pdf

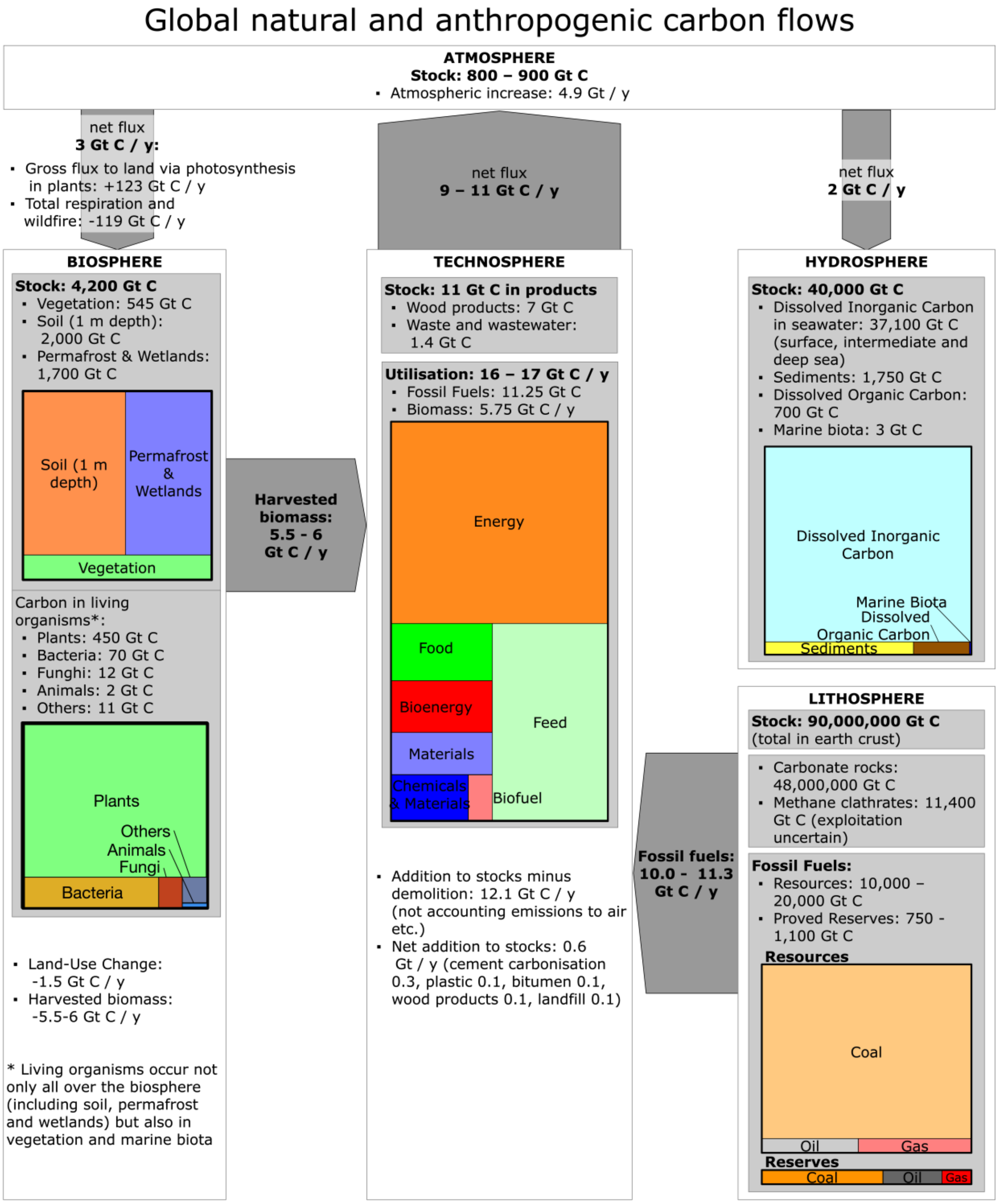

Figure 5. Global anthropogenic carbon cycle. (based on own calculations)

In order for better understanding of the global carbon flow between the spheres, we use the approach of (Ciais et al. 2014)[9], which distinguishes two main natural domains of the carbon cycle.

The first is characterised by a rapid exchange of carbon between the reservoirs of the atmosphere, biosphere as well as soil and ocean. However, it only accumulates a rather small amount of carbon. The second global carbon domain is the lithosphere, which is covered below.

2.1 Atmosphere

In the atmosphere, carbon can be found as carbon dioxide (CO_2). According to (Hepburn et al. 2019)[14] the atmosphere's concentration is about 3,150 Gt CO_2, which is equivalent to 859 Gt C. To convert the specified amount of CO_2 into carbon, it is multiplied by the factor 12/44 in accordance to the molecular weight of carbon in the CO_2 molecule. Other studies state slightly lower values of 750[15], 780[16] or 800 Gt C[17].

2.2 Biosphere

The carbon stock of the biosphere is mainly found in living biomass (500–650 Gt C), but also in dead organic matter and soil (1,500–2,500 Gt C)[18,9,10,19]. In addition, a part of the biosphere carbon stock can also be found in permafrost and wetlands (1,700–2,000 Gt C) [9,10,19].

If we take a look at the carbon content in living organisms, we find that plants make up the biggest share with 450 Gt C[18]. This is mainly due to the fact that plants extract CO_2 from the atmosphere via photosynthesis, which leads to a carbon flux to land of 123 Gt C / year [9]. The bound carbon is built into organic compounds within the plant and after their death, the carbon is decomposed in the soil and then released back into the atmosphere through respiration or other processes such as wildfires (-119 Gt C/year)[19]. A share of the decomposed carbon forms new soil and thereby changes the biosphere's carbon stock. It is worth noting that the carbon uptake by photosynthesis only takes place during the growth phase of the plant, while CO_2 is released in metabolic processes through respiration all year round.

2.3 Hydrosphere

A further exchange of carbon dioxide takes place through diffusion between the atmosphere and the carbon stock of the hydrosphere. How much CO_2 dissolves in water depends on the concentration (pressure difference). A high CO_2 concentration in the atmosphere leads to more dissolving of carbon dioxide into the water, while reverse conditions result in increased CO_2 release from the ocean. Moreover, the ocean's carbon dioxide uptake is temperature dependent. Cold water is able to absorb more CO_2 than warm water[9,20].

The predominant share of carbon in the hydrosphere is present as dissolved inorganic carbon (DIC). DIC includes carbonic acid (dissolved CO_2 in water), bicarbonate and

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[14] Hepburn, C., Adlen, E., Beddington, J., Carter, E. A., Fuss, S., Mac Dowell, N., Minx, J. C., Smith, P. and Williams, C. K. 2019. The technological and economic prospects for CO2 utilisation and removal. Nature, Vol. 575 (7781), 87-97. doi: 10.1038/s41586-019-1681-6

[15] Carlson, C. A. B., N.R.; Hansell, D.A.; Steinberg, D.K. 2001. Carbon Cycle. Encyclopedia of Ocean Sciences (Second Edition), Vol. 477-486. doi: 10.1016/B978-012374473-9.00272-1

[16] Ajani, J. I., Keith, H., Blakers, M., Mackey, B. G. and King, H. P. 2013. Comprehensive carbon stock and flow accounting: a national framework to support climate change mitigation policy. Ecological Economics, Vol. 89 61-72. doi:

[17] Bleam, W. 2012. Natural Organic Matter and Humic Colloids. Soil and environmental chemistry, Vol. 209-256.

[18] Bar-On, Y. M., Phillips, R. and Milo, R. 2018. The biomass distribution on Earth. Proceedings of the National Academy of Sciences, Vol. 115 (25), 6506-6511.

[19] Janowiak, M. C., William J.; Dante-Wood, Karen; Domke, Grant M.; Giardina, Christian; Kayler, Zachary; Marcinkowski, Kailey; Ontl, Todd; Rodriguez-Franco, Carlos; Swanston, Chris; Woodall, Chris W.; Buford, Marilyn. 2017. Considering Forest and Grassland Carbon in Land Management_USDA. United States Department of Agriculture, Forest Service (Ed.), Considering Forest and Grassland Carbon in Land Management. Gen. Tech. Rep. WO-95. Washington, D.C., Download at https://www.fs.usda.gov/treesearch/pubs/54316

[20] Kasang, D. 2020. Der Kohlenstoffkreislauf im Ozean Hamburger Bildungsserver (Ed.), Download at https://bildungsserver.hamburg.de/treibhausgase/2055556/kohlenstoffkreislauf-ozean-artikel/

carbonate ions (37,000–39,000 Gt C)[9,19]. In comparison, the share of dissolved organic carbon (DOC), which is the result of decomposition of dead organic matter, is about 700 Gt C. Other carbon stocks in the hydrosphere are the marine biota, which have a relatively small carbon store of around 3 Gt C and consist mainly of phytoplankton and microorganisms that bind carbon through photosynthesis, as well as ocean floor surface sediments (1700–1900 Gt C)[9,10,19].

2.4 Lithosphere

The second global carbon domain as characterised by Ciais (2013)[21] is the lithosphere – which is rich in carbon, but is characterised by a rather slow turnover rate. The lithosphere consists mainly of rocks and sediments, which store the by far largest amounts of carbon. It is estimated that 90,000,000 Gt carbon can be found in the Earth's crust, including 48,000,000 Gt C in carbonate rocks[16].

The natural extraction from these stocks can take over 10,000 years or longer. This mostly happens by volcanic eruptions, chemical weathering, erosion or sedimentation.[21]

However, since the beginning of industrialisation, the turnover rate of the lithosphere has accelerated significantly. The human-induced extraction of fossil resources from geological deposits and their processing have led to a significant change in the natural carbon cycle. The direction and amount of man-made carbon movement in the global carbon cycle can be summarised in the technosphere. The carbon turnover of the technosphere from fossil sources will be further explained in the following.

2.5 Technosphere

2.5.1 Fossil Fuels

The annual BP-report[22] states that 11.3 Gt of carbon in the form of coal, oil and gas have been extracted from fossil resources into the technosphere in 2018. It should be noted that amount of carbon is not given in the report, but only the sum of the consumption figures for coal, oil and natural gas. These have been converted into carbon by the project team to derive the values for carbon mass (see Table 3 and Appendix 1 for further information on calculation method).

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[21] Ciais, P., C. Sabine, G. Bala, L. Bopp, V. Brovkin, J. Canadell, A. Chhabra, R. DeFries, J. Galloway, M. Heimann, C. Jones, C. Le Quéré, R.B. Myneni, S. Piao and P. Thornton 2013. Ciais et al Carbon and Other Biogeochemical Cycles. (Ed.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[22] Dudley, B. 2019. BP statistical review of world energy 2019. BP (Ed.), London, UK, Download at https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-full-report.pdf

Table 3. Conversion table - global fossil fuel consumption in Gt C in the year 2018

Fossil Fuel	Production of fossil fuels (2018)	Unit	carbon Conversion factor	Carbon mass in produced fossil fuels (Gt C)
Crude oil	998,430,000	barrels per day (bl/d)	0.1166	4.25
Natural gas	3,849 billion	Cubic metres (m^3/year)	0.73	2.81
Coal	3,772	Mln tonnes of oil equivalent (Mtoe)	1.11	4.19
			Total:	11.25

Further, a commonly used distinction can be made between fossil fuel reserves and fossil fuel resources. By the definition of BGR (2019)[23], 'resources' are proven volumes of energy resources, which cannot currently be exploited for technical and/or economic reasons, as well as unproven but geologically possible energy resources, which may be exploitable in the future. Sources state stocks from around 10,000 Gt C to around 20,000 Gt C[16,23,17,14].

'Reserves', on the other hand, are described as proven volumes of energy resources, which are economically exploitable at today's prices and using today's technology (BGR 2019).[23]

The study by BGR uses a conservative approach and accounts the carbon stock for fossil reserves at 747 Gt C, whereas the latest report by BP[22] states a value of 980 Gt C. Some studies differentiate for conventional and unconventional oil and gas resources and reserves. This must be taken into account when comparing stocks between different sources. A relevant study accounts for uncertainties individually for each type of fossil fuel, which adds up to large uncertainties in the sum of all fossil fuels of 1002–1940 Gt C[9]. An explanation is the consideration of methane clathrates. The estimated amount of methane clathrates varies significantly from study to study and it is debatable which share of the resources is exploitable and therefore can be counted as a reserve. The BGR study pursues a conservative approach, therefore considering only those reserves with potential economic production as energy resource, considering "today's understanding and technology". Consequently, the amount of gas hydrates that they consider as a reserve is comparatively low[23]. However, other authors such as Ajani et al. (2013)[16] estimate the carbon mass stored in gas hydrates ("methane clathrates/hydrates") at 11,400 Gt C.

In the following, further examination of fossil fuels in the technosphere are continued with the calculated figure of 11.3 Gt C from the BP report[22].

2.5.2 Sectoral Distribution

Figure 6 shows the distribution of the global energy supply by fossil raw materials (see Figure 7 for calculation). It shows that oil (4.3 Gt C; 38%) and coal (4.2 Gt C; 37%) offer almost the same amount of carbon to the global supply. The proportions for the consumption of fossil fuels per demand sector have been stated by IEA (2020)[24] (Figure 7).

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[23] BGR 2019. BGR Energy Study 2018 – Data and Developments Concerning German and Global Energy Supplies (22). Federal institute for Geosciences and natural Resources (Bundesanstalt für Geowissenschaften und Rohsto e – BGR) (Ed.), Hannover, Germany.

[24] IEA 2020. World Energy Balances Overview 2020. IEA (Ed.).

The biggest consumer with a demand of just under half of the total available fossil carbon (4.63 Gt C; 41%) is the transport sector. In this, almost 90% (4.07 Gt C) of carbon stems from transport by road (Figure 8). The rest is consumed by air, rail and water transportation (0.37 Gt C; 0.09 Gt C; 0.09 Gt C respectively).

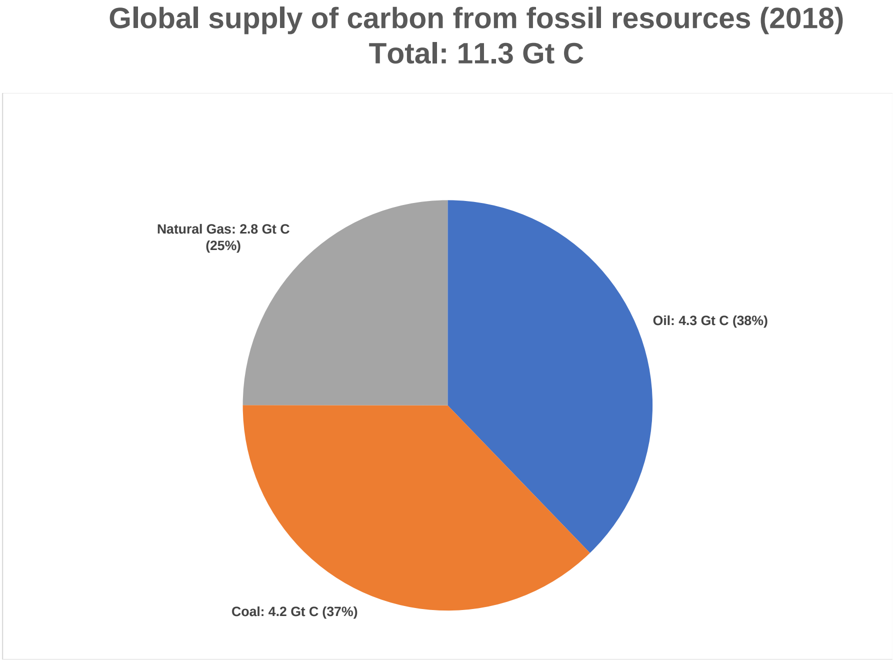

Figure 6. Global supply of carbon from fossil resources (in Gt C) in the year 2018 (own calculations based on IEA, 2020).

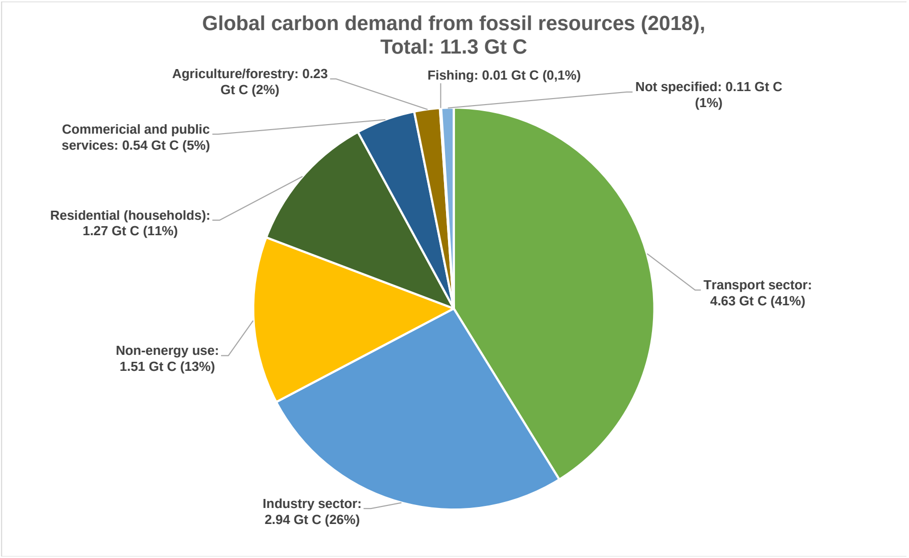

Figure 7. Global carbon demand covered by fossil resources by sectors in 2018 (own calculations based on IEA, 2020)

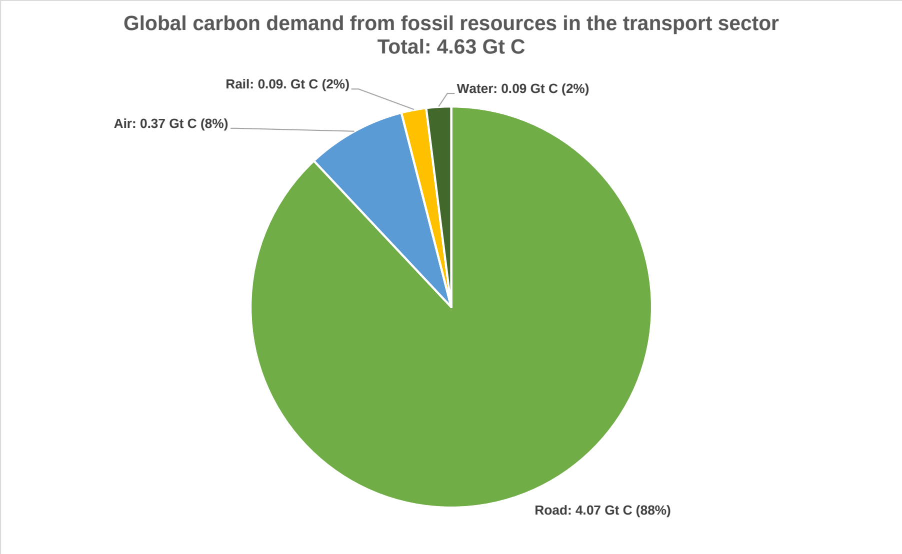

Figure 8. Global carbon demand for fossil resources for energetic use in the transport sector in 2018 (own calculation based on IEA, 2020)

More than a quarter of the carbon from fossil resources goes into the industrial sector (2.94 Gt C; 26%). Figure 9 illustrates the consumption of the industrial sector in more detail[25]. The largest contributor of the industrial consumption is the domain of chemicals and petrochemicals (0.82 Gt C; 28% of the total carbon amount of the industry sector), which is followed by the sector of iron and steel production (0.68 Gt C; 23%).

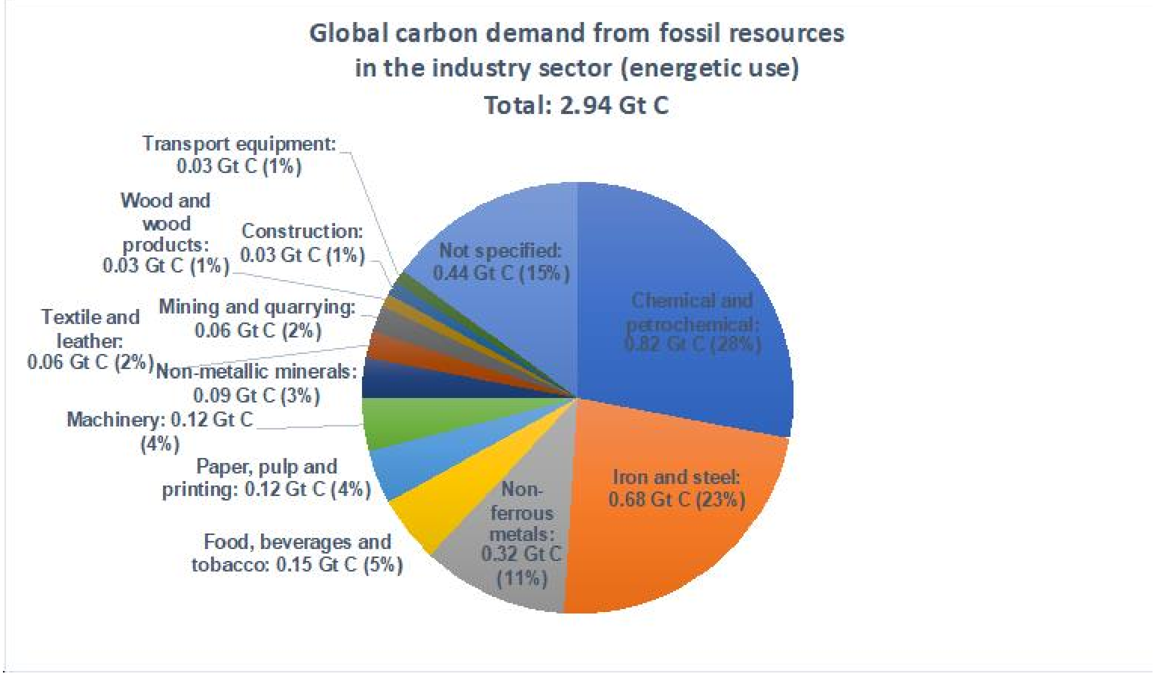

Figure 9. Global carbon demand for fossil resources for energetic use in the industry sector in 2018 (own calculations based on Landolina et al., 2017).

It should be noted that literature defines industry often as a sector of energy-intensive manufacturing[26]. Therefore, only the production of basic chemicals (Inorganic chemicals, organic chemicals (e.g., ethylene propylene), resins, and agricultural chemicals) are accounted for in the chemicals and petrochemicals class. The manufacturing of pharmaceuticals, paint and coatings, adhesives, detergents and other chemical products, which don't require an energy-intensive production, can be found in the 'non-energy-

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[25] Landolina, S. F., Araceli 2017. Global Iron & Steel Technology Roadmap. IEA (Ed.).

[26] EIA 2019. International Energy Outlook 2019. (Ed.), U.S. Energy Information Administration, Office of Energy Analysis, U.S. Department of Energy, Washington, DC 20585, September 2019. Download at https://www.eia.gov/outlooks/ieo/pdf/ieo2019.pdf

sector'[26]. This domain consumes 1.51 gigatons of carbon from fossil resources yearly, which is 13% of the overall demand (Figure 7).

In parallel, private households utilise 1.27 Gt C (11%) accounting for almost the same amount of the global fossil supply. Figure 10 shows that roughly half of the carbon (0.61 Gt C; 48%) is consumed by space heating. The usage of residential appliances as well as water heating consume about 0.50 Gt C together (0.27 Gt C and 0.23 respectively).

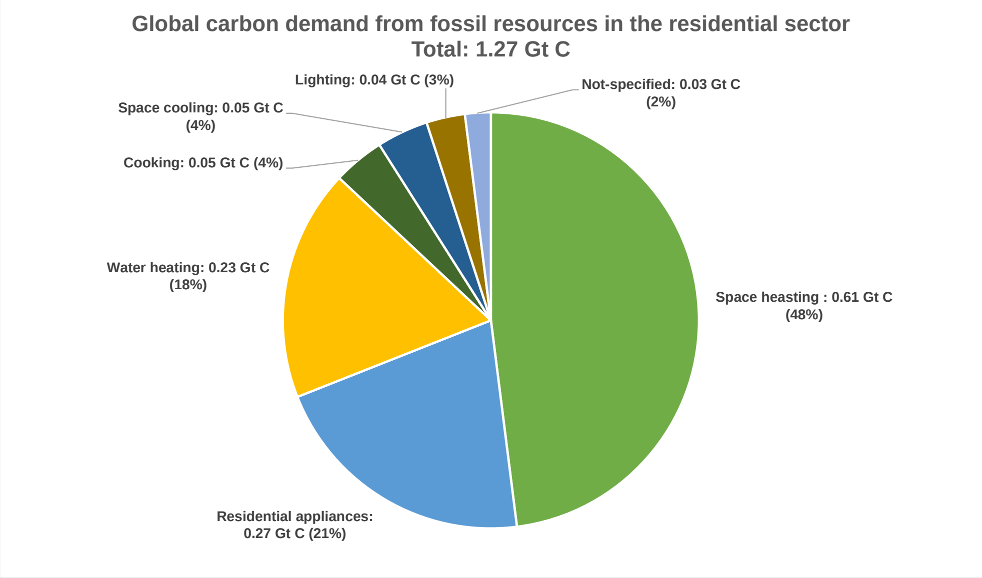

Figure 10. Global carbon demand for fossil resources for energetic use in the residential sector in 2018 (own calculations based on EIA, 2019).

The rest of the carbon goes into sectors of commercial and public services (0.54 Gt C; 5%), agriculture & forestry (0.23 Gt C; 2%) as well as fishing (0.01 Gt C; 0,1%).

2.5.3 Biomass

However, not only fossil fuels from the lithosphere serve as source for the technosphere, but also biomass. Yearly, about 5.5 to 6 Gt carbon are extracted from the biosphere.

These values have been mainly estimated with the global biomass study of Piotrowski et al. (2015)[27]. Within the study the global biomass supply and demand are broken down into the biomass components (such as cellulose, sugar & starch, fat, protein and others). With the knowledge of the approximate carbon content of these constituents, conversion from substance mass to carbon mass can be carried out (see Table 4).

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[27] Piotrowski, S., Essel, R., Carus, M., Dammer, L. and Engel, L. 2015. Nachhaltig nutzbare Potenziale für Biokraftstoffe in Nutzungskonkurrenz zur Lebens- und Futtermittelproduktion, Bioenergie sowie zur stofflichen Nutzung in Deutschland, Europa und der Welt. nova-Institut (Ed.), Hürth, Germany, 2015-08. Download at http://bio-based.eu/markets/#Biomassepotenziale

Table 4. Carbon content of biomass constituents (Piotrowski et al., 2015)

Biomass Constituents	Carbon content [%] in dry matter
Cellulose	44.4%
Sugar (Sucrose)	42.12%
Starch	44.26%
Protein (estimated average value)	55.7%
Fat (estimated average value)	76%

However, it should be noted that the values of the original study refer to data from 2011. In order to get an approximation of current developments, this study was partially updated. In doing so, the figures originating from databases of the Food and Agriculture Organisation (FAO) were updated.

Overall, a total amount of 5.7 Gt of carbon biomass is extracted from the biosphere. The highest supply of carbon originates from harvested agricultural biomass (2.2 Gt C; 39%) and its residues (0.7 Gt C; 13%), followed by grazed biomass (1.7 Gt C; 30%) and wood (1.0 Gt C; 18%) (Figure 11).

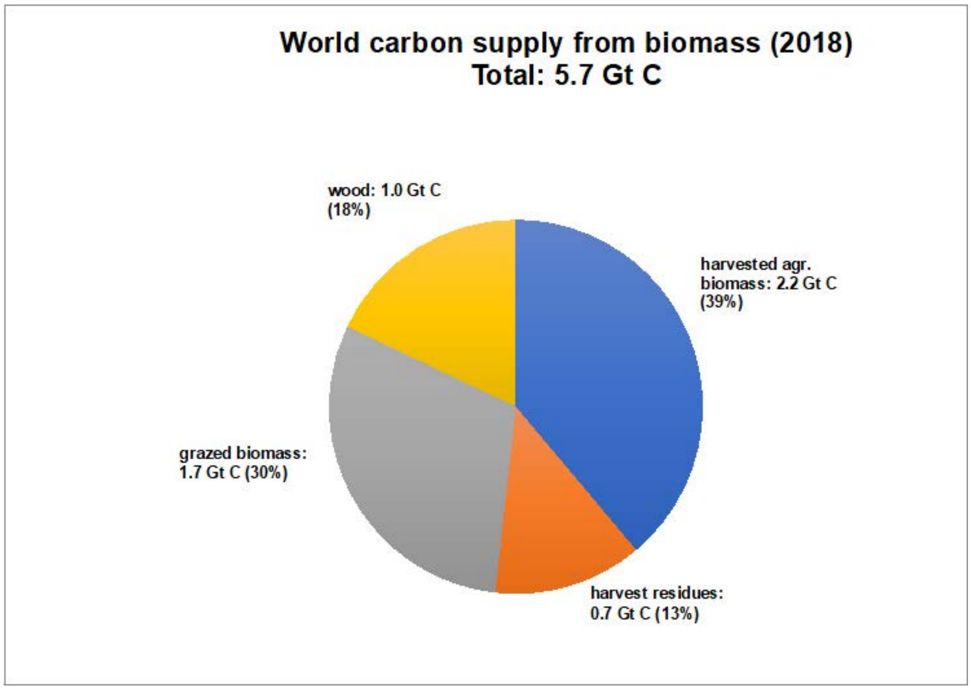

Figure 11. World carbon supply from biomass (in Gt C) in 2018 (based on own calculations)

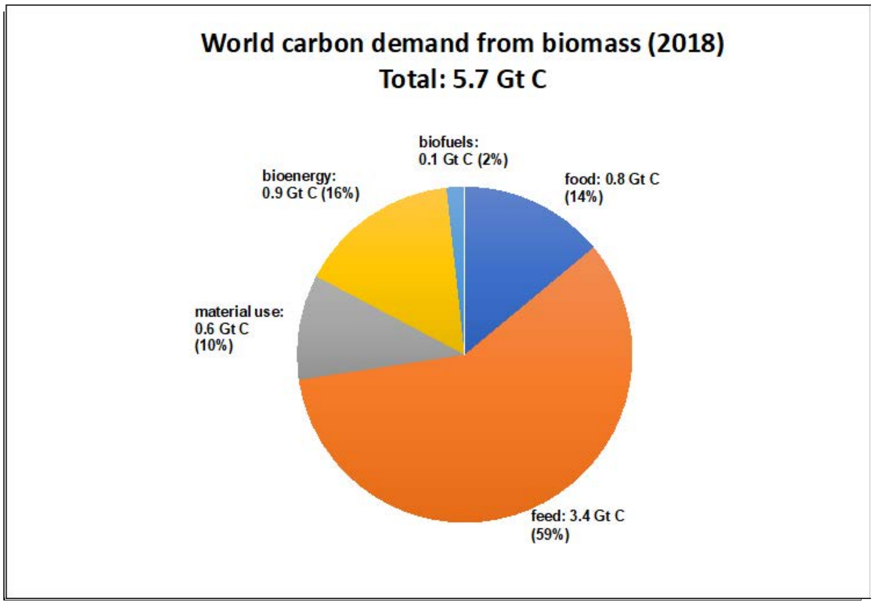

Figure 12. World carbon demand from biomass (in Gt C) in 2018 (based on own calculations)

Almost 60% of this biomass is used as feed (Figure 12). Together with the food sector, food and feed make up about 73% (4,2 Gt C) of the total carbon consumption delivered by biomass.

The demand for biomass-based carbon from the domain of material use (0.6 Gt C) can be further differentiated by individual biomass constituents. About 0.48 Gt C of carbon in the form of cellulose is used for example in the manufacture of paper, chemical pulp or furniture. Furthermore, constituents like fat and oil (0.01 Gt C) as well as sugar and starch (0.01 Gt C) find usage in the chemistry industry (mostly bioethanol production).

Moreover, the consumption of carbon from biomass for the bioenergy sector (heat and power) is around 0.9 Gt C (16%), whereas biofuels consume about 0.1 Gt C (2%).

2.5.4 Carbon Stocks

Overall, the total utilisation of carbon in the technosphere can be determined between 16 and 17 Gt C per year.

Hepburn et al. (2019)[10] estimates the carbon stock in the form of CO_2 and thereby valuates 42 Gt CO_2, which equates to 11 Gt C. This includes 7 Gt carbon in the form of biogenic carbon in wood products, but also 1.4 Gt of carbon is present in global waste and wastewater[10,28]. Further specifications of the technosphere's stock are not available. The annual increase ("without demolition") in carbon storage is estimated at 12.1 Gt C by Haas et al. (2015)[29] (not accounting emissions to air etc.).

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[28] Gómez-Sanabria, A., Höglund-Isaksson, L., Rafaj, P. and Schöpp, W. 2018. Carbon in global waste and wastewater flows – its potential as energy source under alternative future waste management regimes. Advances in Geosciences, Vol. 45 105-113. doi: 10.5194/adgeo-45-105-2018

[29] Haas, W., Krausmann, F., Wiedenhofer, D. and Heinz, M. 2015. How Circular is the Global Economy?: An Assessment of Material Flows, Waste Production, and Recycling in the European Union and the World in 2005. Journal of Industrial Ecology, Vol. 19 (5), 765-777. doi: 10.1111/jiec.12244

At the same time, the technosphere releases carbon to the atmosphere as CO_2 emissions (9–11 Gt C/year), leading to an annual carbon increase of 4.9 Gt C/year in the atmospheric carbon stock[10,30].

3 Carbon Flows in the European Economy

3.1 Fossil Carbon Flow

In order to evaluate the carbon flows at the European level, fluxes from fossil resources are considered in the following. The criteria for the inclusion of carbon stocks and flows mentioned in the introduction also apply for the European level.

Values for production, consumption as well as import and export origin from Eurostat database[31]. The converted data for solid fossil fuels, natural gas as well as oil and petroleum products are shown in Table 5. As for the conversion from world fossil fuel supply, the European fuel volumes are converted to carbon mass, see Table 5 exemplarily (or see Appendix 1 for detailed calculation method).

Table 5. Energetic and material use of fossil resources derived from EU-27 energy balance (in Mt C, 2018)

	Energy balance		Solid fossil fuel		Natural gas		Oil and petroleum products		Total
	EU-27 (2018)								
			Mtoe	Mt C	Mtoe	Mt C	Mtoe	Mt C	Mt C
+	**Primary production**		116.1	128.9	59.2	50.2	24.5	19.3	198.4
+	**Recovered & Recycled products**		0.7	0.7	0.0	0.0	1.1	0.9	1.6
+	**Imports**		104.7	116.2	329.6	279.8	865.2	682.1	1078.1
-	**Exports**		12.9	14.4	59.4	50.4	347.6	274.0	338.8
+	**Change in stock**		1.8	2.0	-4.7	-4.0	4.2	3.3	1.2
=	**Gross available energy**		210.3	233.4	324.6	275.6	547.3	431.5	940.5
-	**International maritime bunkers**		0.0	0.0	0.0	0.0	43.3	34.1	34.1
=	**Gross inland consumption**		210.3	233.4	324.6	275.6	504.1	397.4	906.3
-	**International aviation**		0.0	0.0	0.0	0.0	40.9	32.2	32.2
=	**Total energy supply**		210.3	233.4	324.6	275.6	463.2	365.1	874.1
–	**Transformation input**		212.2	235.5	95.4	81.0	705.1	555.8	872.3
+	**Transformation output**		29.7	32.9	0.4	0.3	688.8	543.0	576.2
-	**Distribution losses**		0.1	0.1	1.4	1.2	0.0	0.0	1.3
-	**Final non-energy use**		1.6	1.8	14.9	12.7	74.6	58.8	73.2
-	**Statistical differences**		2.9	3.2	-0.6	-0.5	2.1	1.7	4.4
=	**Final energy use**		22.5	25.0	200.8	170.5	345.1	272.0	467.5
	+	Industry sector	12.5	13.9	75.2	63.8	25.0	19.7	97.5
	+	Transport sector	0.0	0.0	3.6	3.0	262.6	207.0	210.1
	+	Residential sector	8.1	9.0	78.7	66.8	28.3	22.3	98.1
	+	Other sectors (agriculture, fishery, etc.)	1.9	0.0	43.3	36.7	29.1	22.9	59.7

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[30] Friedlingstein, P., Jones, M. W., O'Sullivan, M., Andrew, R. M., Hauck, J., Peters, G. P., Peters, W., Pongratz, J., Sitch, S., Le Quéré, C., Bakker, D. C. E., Canadell, J. G., Ciais, P., Jackson, R. B., Anthoni, P., Barbero, L., Bastos, A., Bastrikov, V., Becker, M., Bopp, L., Buitenhuis, E., Chandra, N., Chevallier, F., Chini, L. P., Currie, K. I., Feely, R. A., Gehlen, M., Gilfillan, D., Gkritzalis, T., Goll, D. S., Gruber, N., Gutekunst, S., Harris, I., Haverd, V., Houghton, R. A., Hurtt, G., Ilyina, T., Jain, A. K., Joetzjer, E., Kaplan, J. O., Kato, E., Klein Goldewijk, K., Korsbakken, J. I., Landschützer, P., Lauvset, S. K., Lefèvre, N., Lenton, A., Lienert, S., Lombardozzi, D., Marland, G., McGuire, P. C., Melton, J. R., Metzl, N., Munro, D. R., Nabel, J. E. M. S., Nakaoka, S.-I., Neill, C., Omar, A. M., Ono, T., Peregon, A., Pierrot, D., Poulter, B., Rehder, G., Resplandy, L., Robertson, E., Rödenbeck, C., Séférian, R., Schwinger, J., Smith, N., Tans, P. P., Tian, H., Tilbrook, B., Tubiello, F. N., van der Werf, G. R., Wiltshire, A. J. and Zaehle, S. 2019. Global Carbon Budget 2019. Earth System Science Data, Vol. 11 (4), 1783-1838. doi: 10.5194/essd-11-1783-2019

[31] Eurostat 2020. Simplified energy balances [nrg_bal_s] - Last update: 06-06-2020. Eurostat (Ed.), Download at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_bal_s&lang=en

On the one hand, the total energy supply is calculated as domestic production + imports - exports - international marine bunkers - international aviation bunkers - final non-energy use ± stock changes. On the other hand, the total energy consumption reflects the amount of energy delivered to the end-use sectors[24]. Differences between supply and consumption figures can be explained by the fact that products within the energy balance undergo transformations in various processes. This includes for example production of electricity and heat in power plants, refining of crude oil into petroleum products and production of derived coal products[31]. In this way, higher values for the input and output of transformation, especially for oil and petroleum products, can be explained by volumetric gains at the refinery.

However, for the further examination of this study, we will concentrate exclusively on the carbon amount available for the 'final energy consumption' by end-sectors. A further evaluation of carbon use in the non-energetic sector takes place in the chapter 'carbon flow in material use'.

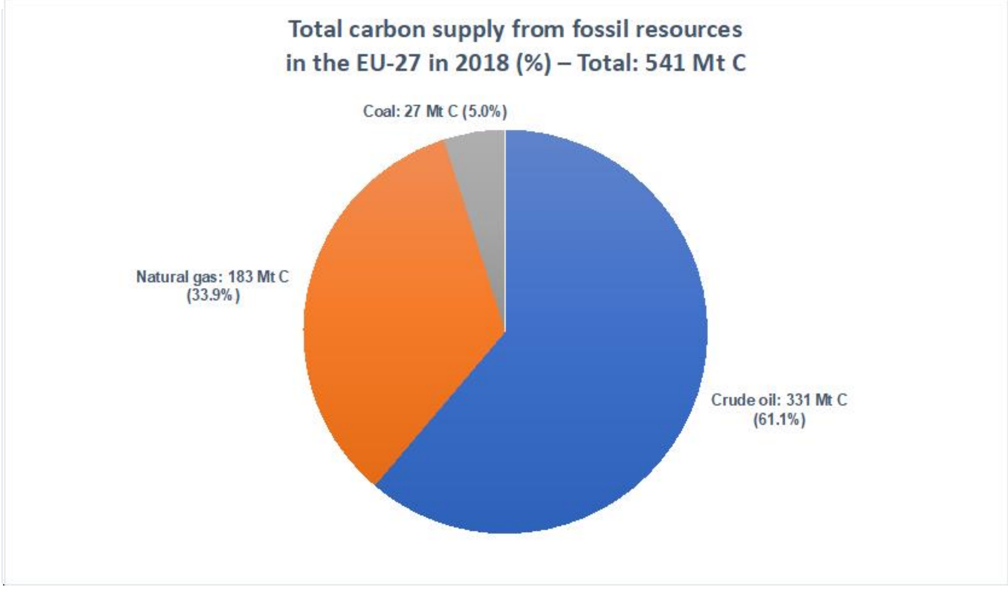

Figure 13. Carbon supply from fossil fuels for energetic and material use in the EU-27 in 2018 (own calculations based on Eurostat, 2020)

Shares of the fossil fuel supply can be seen in Figure 13. Crude oil accounts for the largest share. Figure 14 shows the yearly carbon demand of various sectors aggregated from Eurostat[31].

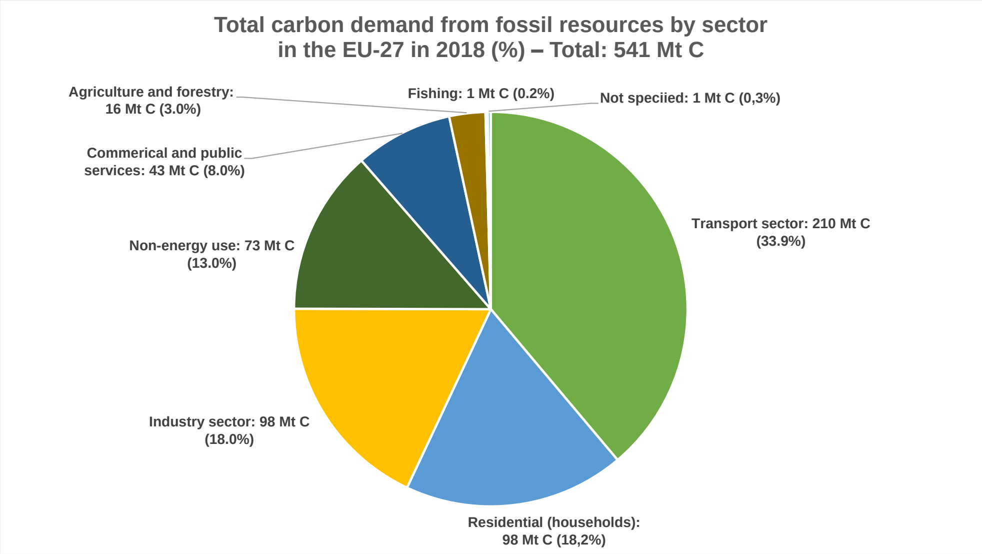

Figure 14. Demand for carbon from fossil fuels by sector in the EU-27 in 2018 (own calculations based on Eurostat, 2020)

As shown for the global level, the European transport sector is the largest consumer, making up almost half of the use of carbon in the energy sector. Here, the largest share is consumed by road transport (199 Mt C; 94.7%) (Figure 15).

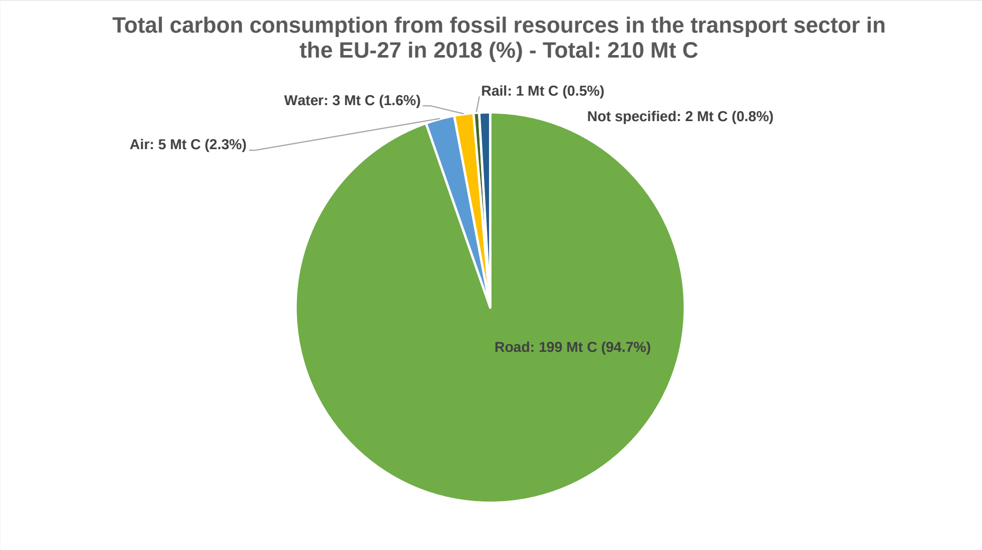

Figure 15. Carbon demand from fossil sources for energetic use in the EU-27 transport sector (in Mt C, in 2018) (own calculations based on Eurostat, 2020)

Unlike at the world level, it appears that the residential sector has a similar share of fossil fuel consumption in the EU as the industrial sector (98 Mt C; 20.9% to 98 Mt C; 20.8% respectively).

Within the residential sector, space heating in particular accounts for 64% (62 Mt C), well over half of the carbon demand from fossil sources for energetic use (Figure 16). Water heating (15 Mt C; 15%) and lighting (14 Mt C; 14%) have a similar share and make up one third of the total demand.

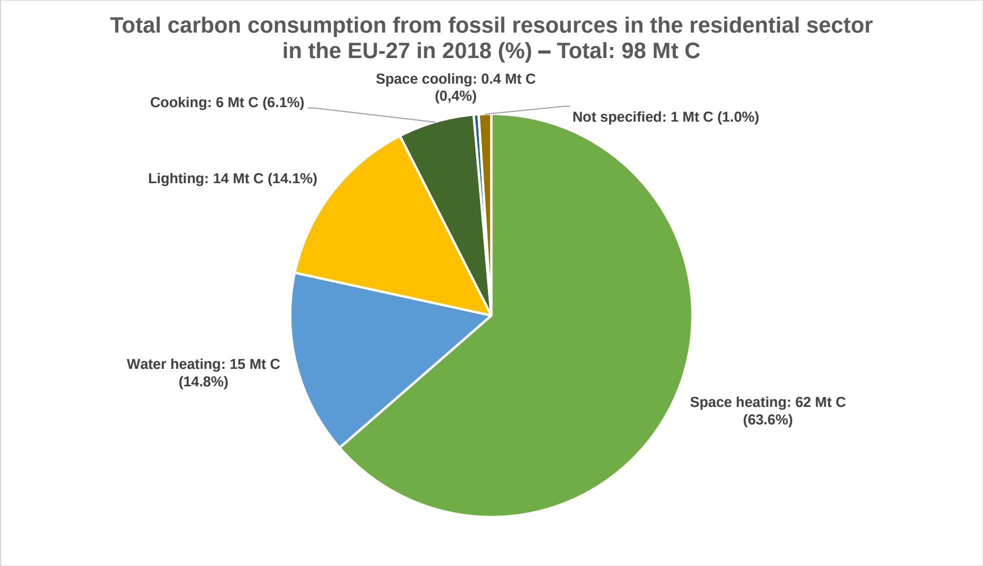

Figure 16. Carbon demand from fossil sources in the European residential sector (in Mt C, in 2018) (own calculations based on Eurostat, 2020)

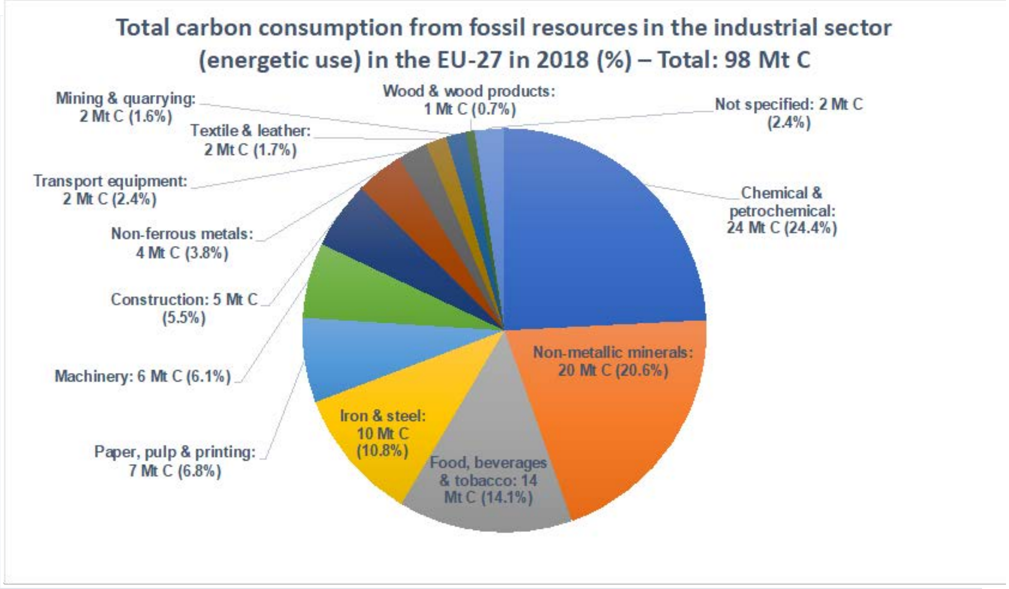

Figure 17. Carbon demand from fossil sources in the EU-27 industrial sector (in Mt C, 2018) (own calculations based on Eurostat, 2020)

The distribution of energy demand between the different industrial sectors is shown in Figure 17. Similar to the global level, the domain of chemicals and petrochemicals is the largest consumer of carbon from fossil resources, utilising 24.4% (24 Mt C) of the total industry demand for energetic use. However, in comparison to the global industrial energy consumption it is worth mentioning, that the production area of non-metallic minerals makes up the second-largest consumer with a fifth (20 Mt C; 20.6%), whereas the iron and steel sector makes up a smaller portion (10 Mt C; 10.8%).

The remaining carbon demand from fossil fuels for energetic use is divided between commercial and public services, agriculture and forestry as well as fishery (43 Mt C (9.2%); 16 Mt C (3.4%) and 1 Mt C (0.2%) respectively).

3.2 Biogenic Carbon Flow

In order to determine the carbon flows from biomass in the next section, primarily JRC's data on European biomass flows from their DataM database is used as a basis[32]. In order to set a base for valid results, the latest data provided by JRC are taken into account[33]. However, in order to convert the substance flows to carbon flows, data on the respective biomass constituents is needed, which the existing data from JRC (2020) do not provide. This is why this study is based mostly on the Piotrowski et al. (2015)[27] study on biomass potentials to realise the conversion to carbon, or at least an approximation. Completely accurate results will not be reached, since the matching of categories is not fully possible, as different methodologies have been used to collect and utilise data.

First, it should be noted that generalisations are needed to separate the harvested biomass into its main components (carbohydrates, proteins and fats), as these vary from culture to culture. To convert the agricultural crops, Piotrowski et al. (2015)[27] have used data and values from the FAO, which lists the composition of all crops that can be used for human nutrition. This data covers 99% of the total volume of harvested biomass. Those lists are used to calculate averages for cellulose, sugar / starch, proteins and fats from these cultures in dry matter, which can be seen in Table 6. Average constituents in crops, dry matter, in % (Piotrowski et al. (2015)

Table 6. Average constituents in crops, dry matter, in % (Piotrowski et al. (2015)

Biomass Constituents	**Average share of dry matter in crops**
Protein	11.83
Fat	11.72
Sugar & Starch	34.74
Cellulose	23.33
Others	18.39

Hence, the proportions of the biomass constituents of the harvested biomass as well as their residues can be determined, as shown in Figure 18.

The assumptions of Piotrowski et al. (2015)[27] are adopted for the dry matter of the pasture biomass: 65% cellulose / hemicellulose, 20% protein, 10% minerals / vitamins and 5% fat.

The amount of wood produced can be separated into the main components cellulose, hemicellulose and lignin. A division of the dry wood mass into 80% cellulose / hemicellulose and 20% lignin are assumed. When summarising this information, the following supply of biomass constituents is derived for the European domestic production:

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[32] DataM; Gurría, P. G.-H., H; Ronzon, T; Tamošiūnas, S; López-Lozano, R; García-Condado, S; Ronchetti, G; Guillén, J; Banja, M; Fiore, G; M'barek, R (European Commission) 2020. Biomass flows in the European Union - EU Biomass Flows tool, version 2020. Last access 24.11.2020. https://datam.jrc.ec.europa.eu/datam/mashup/BIOMASS_FLOWS

[33] See JRC report on "Biomass flows in the European Union" available at: https://ec.europa.eu/jrc/en/publication/biomass-flows-european-union

Biomass supply

259.6	Mt C harvested crops
172.4	Mt C carbohydrates
thereof:	
30.0	Mt C cellulose
142.4	Mt C sugar and starch
36.7	Mt C fat
35.9	Mt C protein
14.5	Mt C others

46.8	Mt C harvest residues
32.7	Mt C carbohydrates
thereof:	
30.2	Mt C cellulose
2.6	Mt C sugar and starch
3.8	Mt C fat
1.1	Mt C protein
9.1	Mt C others

46.0	Mt C grazed biomass
27.5	Mt C carbohydrates
thereof:	
27.5	Mt C cellulose
0.0	Mt C sugar and starch
3.6	Mt C fat
10.6	Mt C protein
4.3	Mt C others

150.9	Mt C wood
120.4	Mt C carbohydrates
thereof:	
120.4	Mt C cellulose
0.0	Mt C sugar and starch
0.0	Mt C fat
0.0	Mt C protein
30.5	Mt C others

Figure 18. Carbon supply from biomass in Europe (EU-27) (in Mt C, 2017) (own calculations based on Piotrowski et al., 2015 and JRC, 2020)

On the demand side, for the food and feed sectors the values given by JRC (2020)[32] and Piotrowski et al. (2015)[27] are very similar, so that the use of the same, or at least similar method for the determination can be assumed. Hence, the shares for the biomass constituents can easily be adopted.

Piotrowski et al. (2015)[27] assumes, that the biomass for the feed demand consists of an average of 70% carbohydrates (39% cellulose / hemicellulose, 31% sugar / starch), 15% protein, 5% fat and 10% other things (minerals etc.).

For the food demand, it is assumed that the composition of available nutrients (3549 kcal/capita*day), which are available after deducting losses in agricultural production, corresponds to the harvest volume recorded by the FAO, that enters the value chain for food production. According to the FBS, in 2011 the average nutrient supply in the EU was divided into 50% carbohydrates, 38% fat and 12% protein. In addition, the FBS indicate that this supply was divided into plant (95% carbohydrates, 48% fat and 42% protein) and animal food (5% carbohydrates, 52% fat and 58% protein).[27]

Determining the share of biomass constituents for the demand for material use, bioenergy or biofuels is somewhat more difficult. Since these values from Piotrowski et al.'s study (2015) are based on several studies with partly adpoted results, a quick update is not possible. Therefore, we continue examination with the orginal procentual shares from 2015 combined with the values of the JRC (2020) flowchart. However, it should be noted that, for example the use of biomass in chemistry may have changed in recent years.

Figure 19 shows the biomass demand scheme resulted from the outlined approach with assumptions based on data from Piotrowski et al. (2015)[27] and the JRC (2020)[32] biomass flow-chart.

Biomass demand

45.7	Mt C plant based food
23.6	Mt C carbohydrates
8.3	Mt C fat
6.1	Mt C protein
7.7	Mt C others

16.6	Mt C animal based food
1.4	Mt C carbohydrates
8.9	Mt C fat
5.1	Mt C protein
1.2	Mt C others

194.2	Mt C feed demand for domestic consumption
126.1	Mt C carbohydrates
thereof:	
89.0	Mt C cellulose
37.1	Mt C sugar and starch
15.5	Mt C fat
34.2	Mt C protein
18.4	Mt C others

103.1	Mt C for material use
89.3	Mt C carbohydrates
thereof:	
86.7	Mt C cellulose
2.6	Mt C sugar and starch
1.7	Mt C fat
10.3	Mt C lignin
1.0	Mt C natural rubber (chem. ind.)
0.3	Mt C glycerin
0.4	Mt C others

89.8	Mt C for bioenergy (heat and power)
51.5	Mt C carbohydrates
thereof:	
40.9	Mt C cellulose
10.6	Mt C sugar and starch
3.0	Mt C fat
3.3	Mt C protein
32.0	Mt C lignin and others

3.8	Mt C for biofuels
2.8	Mt C plant oils for biodiesel
1.0	Mt C sugar and starch for bioethanol

Figure 19. Carbon demand from biomass in Europe (EU-27) (in Mt C, 2017) (own calculations based on Piotrowski et al., 2015 and JRC, 2020).

In addition to the intra-European production and demand of biomass, the imported and exported amount of biomass are also determined. Nevertheless, it should be noted that a conversion from EU-28 to EU-27 (accounting for the withdrawal of the United Kingdom from the EU) for international trade is not easily possible with the help of the JRC (2020) data. This is because the EU-27&UK-data only considers extra EU imports and exports, while a Member State trade includes all trade from any other country, regardless of whether EU or not. Therefore, it is not possible to calculate the EU-27 value by simply deducting the UK in the DataM-sankey tool (2020). In addition, this database includes the international trade in agricultural raw materials as well as the trade in animal products and a further category for processed products (Products mainly from biomass). However, the composition of these categories is not apparent from the database.

This is why we choose to use the same approach as Piotrowski et al. (2015) for determining the amount of imported and exported plant and animal products. This calculation method is based on data from the SITC (Standard International Trade Classification). However, this method also refers to EU-28 figures. In order to achieve a conversion to EU-27, we determined a value of around 10% of the UK in the total biomass supply of EU-28, which we offset against the import and export figures for plant and animal products. For foreign trade in wood biomass, we use the stated values of the JRC (2020) and also deducted the 10% of the UK.

The converted values can be seen in Figure 20.

Imports
51.8 Mt C imported plant products
18.1 Mt C carbohydrates
thereof:
5.0 Mt C cellulose
13.1 Mt C sugar and starch
16.2 Mt C fat
14.0 Mt C protein
3.5 Mt C others

6.0 Mt C feed for imported animal products
3.9 Mt C carbohydrates
thereof:
2.8 Mt C cellulose
1.2 Mt C sugar and starch
0.5 Mt C fat
1.1 Mt C protein
0.6 Mt C others

9.7 Mt C imported wood
7.7 Mt C carbohydrates
thereof:
7.7 Mt C cellulose
0.0 Mt C sugar and starch
0.0 Mt C fat
0.0 Mt C protein
1.9 Mt C others

Exports
24.7 Mt C exported plant products
13.6 Mt C carbohydrates
thereof:
1.7 Mt C cellulose
11.9 Mt C sugar and starch
5.6 Mt C fat
4.4 Mt C protein
1.1 Mt C others

15.0 Mt C feed demand for exported animal products
9.7 Mt C carbohydrates
thereof:
6.9 Mt C cellulose
2.9 Mt C sugar and starch
1.2 Mt C fat
2.6 Mt C protein
1.4 Mt C others

3.8 Mt C exported wood
3.0 Mt C cellulose
0.8 Mt C lignin

Figure 20. Carbon imports and exports from biomass in Europe (EU-27) (in Mt C) (own calculations based on Piotrowski et al., 2015 and JRC, 2020).

Finally, the total biomass supply and demand as well as their composition can be seen in Figure 21.

Biomass supply *(domestic production & imports)*	Biomass demand *(domestic uses & exports)*
571,2 Mt C	496,7 Mt C
353,4 Mt C carbohydrates thereof: 208,4 Mt C cellulose 145,0 Mt C sugar and starch	293,8 Mt C carbohydrates thereof: 218,9 Mt C cellulose 74,9 Mt C sugar and starch
44,2 Mt C fat	31,4 Mt C fat
47,6 Mt C protein	43,6 Mt C protein
58,5 Mt C others	67,9 Mt C others

Figure 21. Total carbon supply and demand from biomass in Europe (EU-27) (in Mt C, 2017) (own calculations based on Piotrowski et al., 2015 and JRC, 2020)

With the help of the conversion factors, which are based on the carbon content of the biomass ingredients, which have already been established in this report, the biomass supply and the demand in megatons of carbon can be shown (Figure 22 and Figure 23).

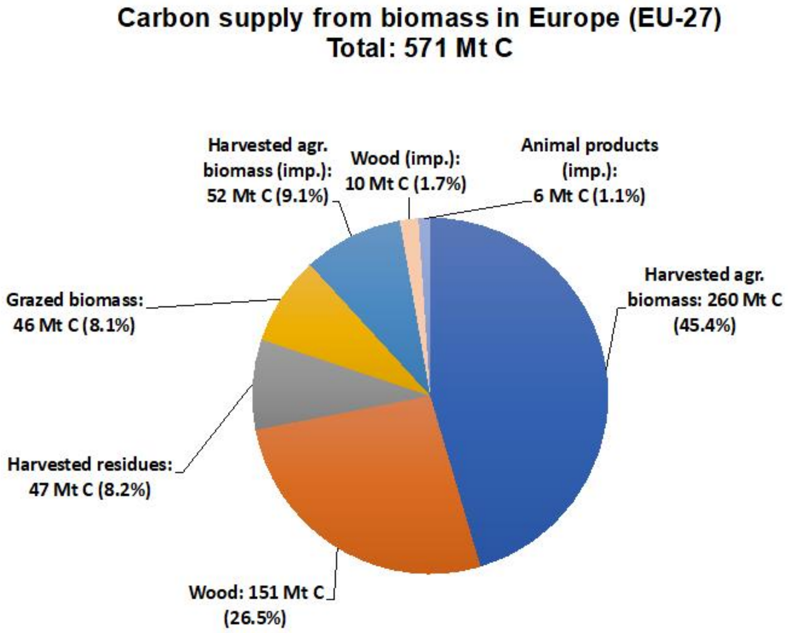

Figure 22. Carbon supply from biomass (in Mt C, 2017) (based on own calculations)

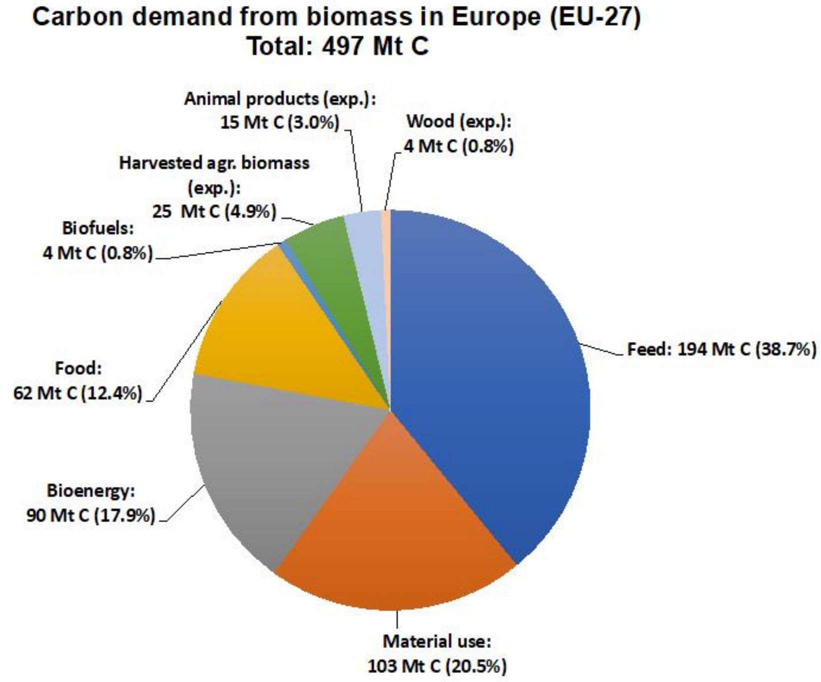

Figure 23. Carbon demand from biomass (in Mt C, 2017) (based on own calculations)

Overall, a total amount of 571 Mt of carbon from biomass is available in the EU. The highest supply of carbon, contributing more than half of the supply from biomass originates from domestic harvested agricultural biomass (45.4%; 260 Mt C) and its residues (47 Mt C; 8.2%). Wood alone account for about one third of the carbon biomass (151 Mt C; 26.5%), whereas grazed biomass makes up 8.1% (46 Mt C). 10.2% of the total biomass is imported into the EU-27. These include plant and animal-based biomass (52 Mt C (9.1%); 6 Mt C (1.1%) respectively) and wood products (10 Mt C; 1.7%).

On the consumption side, feed consumes the biggest share of carbon from biomass (194 Mt C; 38.7%). However, unlike at world level, the JRC (2020)[32] numbers suggest that the consumption of carbon from biomass in the material use and bioenergy sectors are higher than for food. The material use consumes 103 Mt C (20.5%) and food 62 Mt C (12.4%).

Furthermore, 25 Mt C of harvested biomass (4.9%), animal products (15 Mt C; 3.0%) and wood products (4 Mt C; 0.8%) are exported. All in all, the figures show that the EU is a net importer of biomass, whose imports of wood as well as animal and plant products outweigh the amount of biomass exports.

3.3 Carbon Flow for Material Use

In addition to the energetic consumption of fossil raw materials and biomass as fuel, the non-energy consumption describes the utilisation of fuels as raw materials (for example, wood for furniture, fossil resources in chemical reactions or bitumen for road construction).

Table 5 shows that 73.2 Mt C from fossil resources is consumed in the non-energy sector. It is worth noting that according to the VCI[34], the non-energy use of oil and coal can be fully attributed to the chemical industry, since there are no other branches that use carbon as a material. As the figure for the energy balance, the value for non-energy-use from fossil sources originates from the Eurostat database[31].

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[34] Verband der Chemischen Industrie e.V., personal communication with Benzing, T. 2020.

The shares and distribution of biogenic resources in the material sector, based on Piotrowski et al. (2015)27, as well as its conversion to carbon, is listed in

Table 7.

Table 7. Material use of carbon covered by carbon from biomass (in Mt C, 2017) (own calculations based on Piotrowski et al., 2015)

Material use from Biomass (in Mt C)								
	Cellulose	Starch/Sugar	Fat	Natural rubber	Lignin	Glycerin	Others	Total
Chemical industry	0,5	1,8	1,7	1,0	0,0	0,3	0,4	**5,8**
Plant oil			1,3					1,3
Animal fat			0,4					0,4
Chemical pulp	0,5							0,5
Sugar and starch (chem. Ind.)		0,9						0,9
Bioethanol		0,9						0,9
Natural rubber				1,0				1,0
Glycerin						0,3		0,3
Others							0,4	0,4
Construction and furniture	45,2				5,3			**50,6**
Pulp and paper	24,4	0,8			0,9			**26,1**
Paper starch		0,8						0,8
Paper	24,4				0,9			25,3
Animal bedding	15,5				4,1			**19,6**
Textiles	0,9							**0,9**
Total	86,6	2,6	1,7	1,0	10,3	0,3	0,4	**103,0**

It becomes clear that since cellulose and lignin make up the biggest share in the material use, wood is the biggest supplier, especially for the sectors of construction and furniture (45.2 Mt C) as well as pulp and paper (24.4 Mt C). About 5.8 megatons of carbon are used in the chemical industry.

So, when the non-energy consumption from fossil raw materials (73.2 Mt C) is added to biomass (5.8 Mt C), it can be seen that about 79.0 Mt of carbon is consumed by the field of chemical industry (Figure 24).

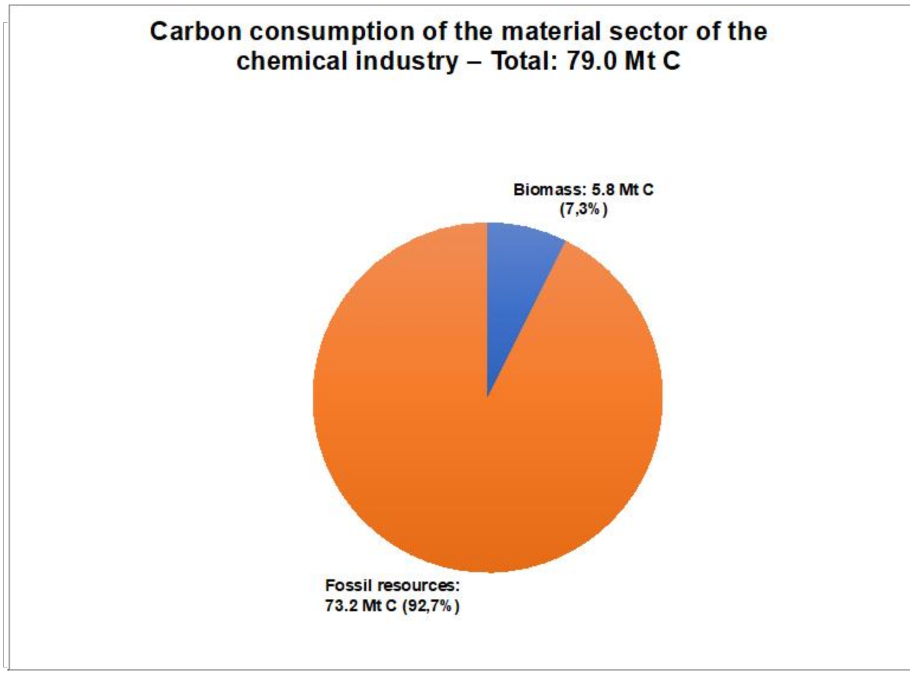

Figure 24. Demand for carbon for material use in the European chemical industry (EU-27) (based on own calculations).

The distribution of carbon used in the EU-27 material sector between fossil-based carbon and bio-based carbon can be compared to findings of other studies. Therefore, the scope of the different studies as well as the study's approach have to be considered (e.g. weather production volumes, carbon flows or monetary values are analysed). Porc et al. (2020)[35] assesses the share of bio-based products on the EU-28 NACE division 20 ("Manufacture of chemicals and chemical products"). The share of bio-based product value in 2017 is stated to be 7.5 %, or 14.9 %, when only organic parts of chemicals are considered. In this study, also only organic chemicals are considered so the difference between the 14.9 % found by Porc et al. (2020)[35] and the 7.3 % found in this study has to be explained. On the one hand, the study by Porc et al. (2020)[35] assesses product values where the share of bio-based products could be overrepresented compared to their production value due to their higher price (referred to as "green premium", see e.g. Partanen et al. (2020)[36]. On the other hand, the mass share of carbon is different for bio-based and fossil-based products. While for example petroleum has a carbon content of 85 %, the carbon content of starch in dry matter material is only 44 %, see Annex for details. Therefore, the share of bio-mass products is further reduced, when carbon content is determined instead of product mass. This is an important finding, because the substitution of one Mt carbon from fossil resources with carbon from bio-based resources requires a higher mass of bio-based virgin material compared to fossil-based virgin material. Further inconsistencies between the studies can be derived from different timescales and underlying data sets with slightly diverging product definitions.

To gain a further and deeper look into the material sector, the yearly bioeconomy study by nova-Institute is used[35]. This study examines the macroeconomic effects that come from the bioeconomy, for example turnover and employment. For this purpose, in addition to fully bio-based sectors like agriculture or forestry, also partly bio-based areas like chemical industry are considered. For these partly bio-based sectors, so called "bio-based shares" have been defined by nova-Institute in collaboration with industry experts and are applied on product level. Further, the study looks at the contribution of industry classes according to the NACE standard and contributions of products to the total product volume of bio-based chemicals. According to Table 8, animal and vegetable fertilisers alone contribute 6.4 mln t to the bio-based production volume of division 20 according to the PRODCOM standard[37] for industrial products in 2017.

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[35] Porc, O., Hark, N., Carus, M., Dammer, L., Dr. Carrez, D. and BIC 2020. European Bioeconomy in Figures 2008–2017. nova-Institute (Ed.), September 2020. Download at https://biconsortium.eu/sites/biconsortium.eu/files/downloads/BIC%20%26%20nova-Institute%20-%20Bioeconomy%20in%20figures%202008-2017.pdf

[36] Partanen, A., Carus, M., Piotrowski, S., Dammer, L. and Küppers, M. 2020. nova-Paper #13: "Bio-based products: Green premium prices and consumer perception of different biomass feedstocks". nova-Institut (Ed.), Hürth, Germany, 2020-09. Download at http://bio-based.eu/nova-papers/#novapaper13

[37] Prodcom (2020). Statistics on the production of manufactured goods (prom) - Sold production, exports and imports by PRODCOM list (NACE Rev. 2) - annual data (DS-066341)

Table 8. The 20 partly or fully bio-based chemical products with the highest bio-based production volume in the EU-27, 2017 (Prodcom (2020)

PRODCOM-code	**Name**	**Bio-based production volume (mln tons)**
20.15.80.00	Animal or vegetable fertilisers	6.43
20.14.23.33	D-glucitol (sorbitol)	2.70
20.59.59.94	Other chemical products, n.e.c.	1.22
20.14.71.20	Activated natural mineral products; animal black	0.78
20.59.20.00	Animal or vegetable fats and oils chemically modified	0.69
20.41.10.00	Glycerol (glycerine), crude; glycerol waters and glycerol lyes	0.61
20.14.23.60	Glycerol (including synthetic; excluding crude, waters and lyes)	0.54
20.14.31.95	Industrial monocarboxylic fatty acids distilled (excluding stearic, oleic tall oil)	0.53
20.52.10.80	Prepared glues and other prepared adhesives, n.e.c.	0.45
20.14.34.73	Citric acid and its salts and esters	0.44
20.16.59.40	Cellulose and its chemical derivatives, n.e.c., in primary forms	0.43
20.14.71.30	Tall oil; whether or not refined	0.41
20.14.22.65	Lauryl alcohol; cetyl alcohol; stearyl alcohol and other saturated monohydric alcohols (excluding methyl, propyl and isopropyl, n-butyl, other butanols, octyl)	0.36
20.14.71.50	Rosin and resin acids; and derivatives; rosin spirit and oils; run gums	0.35
20.14.64.70	Enzymes; prepared enzymes (not elsewhere specified or included) (excluding rennet and concentrates)	0.34
20.14.32.80	Lauric acid and others; salts and esters	0.32
20.53.10.75	Mixtures of odoriferous substances of a kind used in the food or drink industries	0.32
20.14.72.00	Wood charcoal whether or not agglomerated (including shell or nut charcoal)	0.30
20.16.59.60	Natural and modified natural polymers, in primary forms (including alginic acid, hardened proteins, chemical derivatives of natural rubber)	0.30
20.14.21.00	Industrial fatty alcohols	0.28

To determine the contribution of NACE classes and products to the total production volume of non-bio-based chemicals, the "bio-based-shares" are reversed and used in the calculation.

Table 9 shows that mineral and chemical fertilisers contribute the highest share of the non-bio-based chemicals, which is about 12 mln tons.

Table 9. The 20 non- bio-based chemical products with the highest bio-based production volume in the EU-27, 2017 (Prodcom, 2020)

PRODCOM-code	**Name**	**Non-bio-based production volume (mln tons)**
20.15.71.00	Mineral or chemical fertilisers containing the three fertilising elements nitrogen, phosphorus and potassium (excluding those in tablets or similar forms, or in packages with a gross weight of <=†10 kg)	12.05
20.14.11.30	Ethylene	11.37
20.16.51.30	Polypropylene, in primary forms	11.19
20.59.59.94	Other chemical products, n.e.c.	11.19
20.14.11.40	Propene (propylene)	10.07
20.41.32.50	Washing preparations and cleaning preparations, with or without soap, p.r.s. including auxiliary washing preparations excluding those for use as soap, surface-active preparations	8.31
20.16.10.50	Polyethylene having a specific gravity of >=†0,94, in primary forms	6.20
20.14.12.23	Benzene	6.05
20.15.51.00	Potassium chloride (excluding in tablets or similar forms or in packages of a weight of <=†10 kg)	6.00
20.16.30.10	Polyvinyl chloride, not mixed with any other substances, in primary forms	5.96
20.16.10.39	Polyethylene having a specific gravity <†0,94, in primary forms (excluding linear)	5.45
20.52.10.80	Prepared glues and other prepared adhesives, n.e.c.	4.29
20.30.22.60	Non-refractory surfacing preparations for facades, indoor walls, floors, ceilings or the like	4.00
20.14.12.50	Styrene	3.90
20.16.55.50	Urea resins and thiourea resins, in primary forms	3.73
20.16.53.90	Acrylic polymers, in primary forms (excluding polymethyl methacrylate)	3.72
20.30.11.50	Paints and varnishes, based on acrylic or vinyl polymers dispersed or dissolved in an aqueous medium (including enamels and lacquers)	3.58
20.14.73.40	Naphthalene and other aromatic hydrocarbon mixtures (excluding benzene, toluene, xylene)	3.41
20.15.10.75	Anhydrous ammonia	2.99
20.14.11.60	Buta-1,3-diene and isoprene	2.78

In addition to that, the following Figure 25 and Figure 26 show how much carbon from biogenic and fossil sources is approximately consumed by the chemical industry, divided into NACE classes.

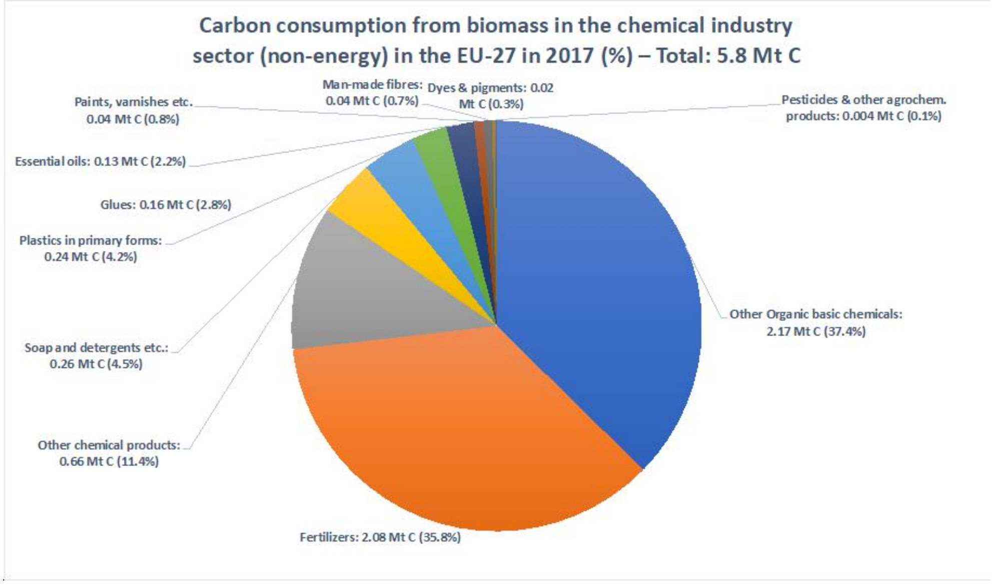

Figure 25. Carbon consumption from biomass in the EU-27 chemical industry (non-energy) in 2017 (based on own calculations)

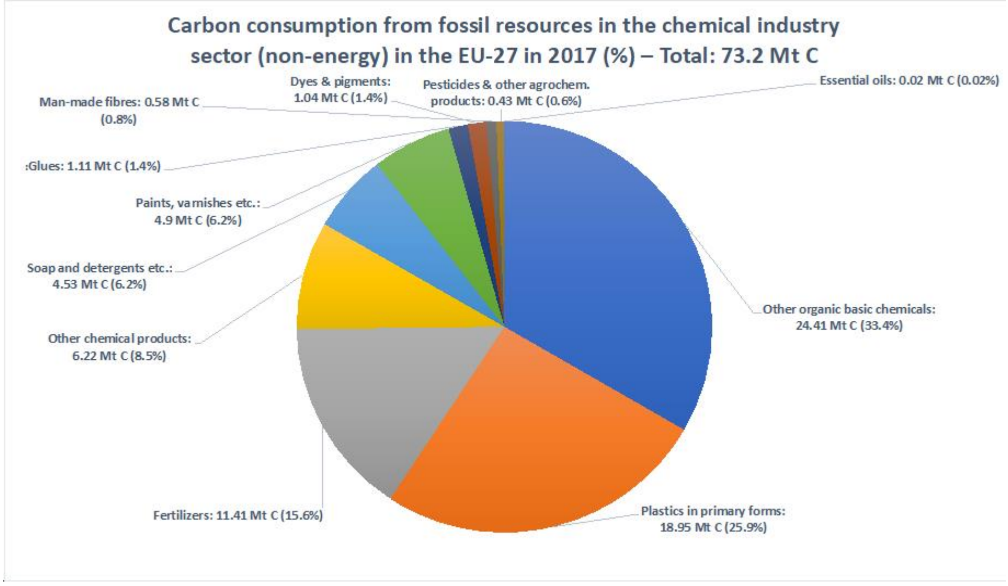

Figure 26. Carbon consumption from fossil resources in the EU-27 chemical industry (non-energy) in 2017 (based on own calculations)

3.4 Circular Material Use Rate

In addition to domestic production, consumption and import and export, some of the carbon from fossil or organic material is recycled. With the circular material use rate, the European Commission[38] describes the contribution of recycled material to the overall material usage. In 2017, the total rate has been 11.2%, which means that over 11% of the feedstock for materials used in the EU came from recycled products. However, the circular rate varies strongly between different materials. 8.7% of biomass (including paper, wood, tissue and other) and 2.5% of fossil-based materials (plastics) used in the EU has come from recycled products and materials. In contrast, metal ores have the highest circularity rate with 21.8%.

The European Commission[38] claims a rather small potential for both sectors to achieve higher rates, since fossil fuels are mostly utilised for energy production and most biomass isn't available for recycling due to the use of agricultural products for food and feed or

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[38] Eurostat 2020. EU circular material use rate. (Ed.), Download at https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20200312-1

wood for energy. In our case we can estimate that 0.008 Gt C from biomass-materials and 0.001 Gt C from fossil-based material are recycled.

3.5 The role of trade

The European economy depends on trade to meet the material demand. According to Eurostat, 24.0% of the material made available for the EU-27's economy comes from EU imports. This share varies by product group with the lowest import dependency in non-metallic ores (3.3%) and biomass (12.0%), higher import dependency for metal ores (53.1%) and the highest import dependency in for fossil energy materials (70.0%).[39]

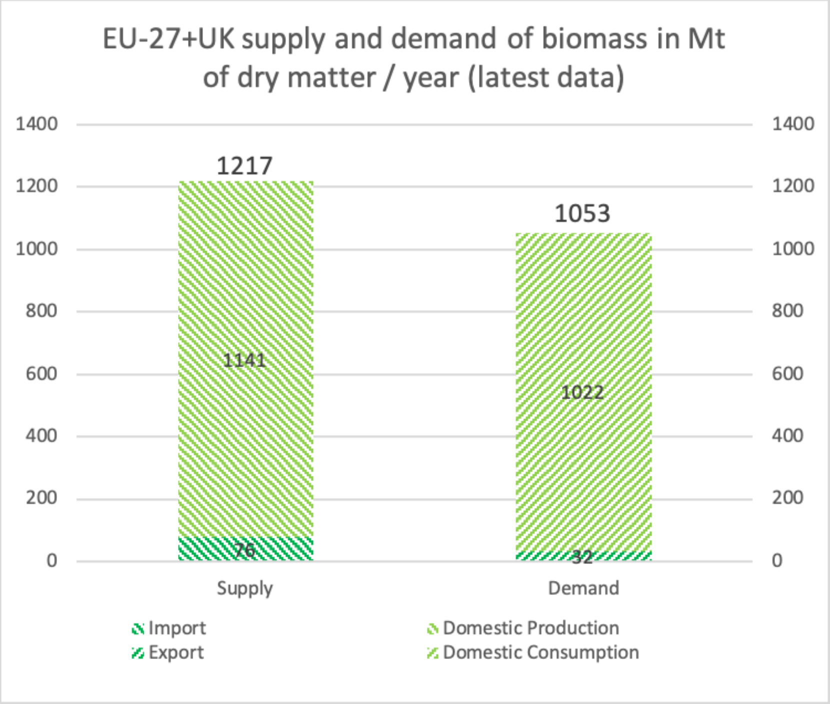

Figure 27. Annual supply (extra-EU imports and domestic production) and demand (extra-EU exports and domestic consumption) of biomass according to JRC biomass flow data (2020).

Figure 27 shows data for supply and demand of biomass in the EU-27+UK, divided into imports/exports and domestic production/consumption, according to the JRC biomass flow data. When dry matter is considered, the import share of the biomass supply is around 6.3%. The share of exported biomass is 3.1% of the total demand. The difference between total demand and supply is cause by estimation errors, stock changes, waste and/or loss of biomass or differences in the data sources used.

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[39] Eurostat data base (2019), online code: env_ac_mid

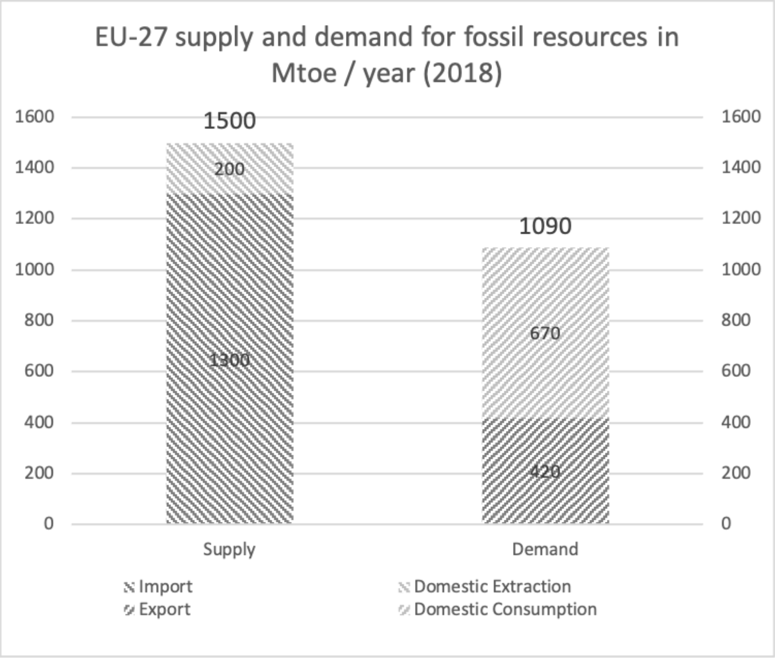

Figure 28. Annual supply (extra-EU imports and domestic extraction) and demand (available for final consumption, extra-EU exports and domestic consumption) of fossil resources (coal, natural gas, oil) according to Eurostat database (2020), online code: nrg_bal_c

Figure 28 shows data for supply and demand divided into imports/exports and domestic extraction/consumption of fossil resources, according to Eurostat data base (2020). For the supply, the primary production of fossil resources is considered. Hence, 86,7% of the fossil resources are imported into the EU-27. For the demand side, the energy from fossil resources available for final consumption is considered. According to this, 38.5% of the energy resources are exported. The large differences between supply and demand in the diagram above can be explained with energy transformation and distribution losses and self-consumption in the energy sector.

The figures stated above show the import dependency of carbon containing resources (biomass, fossil resources), as well as the relevance of exports of carbon-based products (bio-based and fossil-based products). To obtain insights of the situation for carbon imports and exports, the material flows of biomass (measured in tonnes of dry matter) and the energy flows of fossil resources (measured in million tonnes of oil equivalent) would have to be considered in detail and their respective carbon content would have to be determined (on a product level). Due to the lack of such detailed data, the further investigation of trade is not conducted in this study. Nevertheless, the import and export shares stated above provide a general overview.

3.6 Sankey Diagram

With the help of the previous determined results, a Sankey flow chart is compiled, which states carbon flows within the EU-27 economy (Figure 29). The width of the flows represents the size of the annual flows.

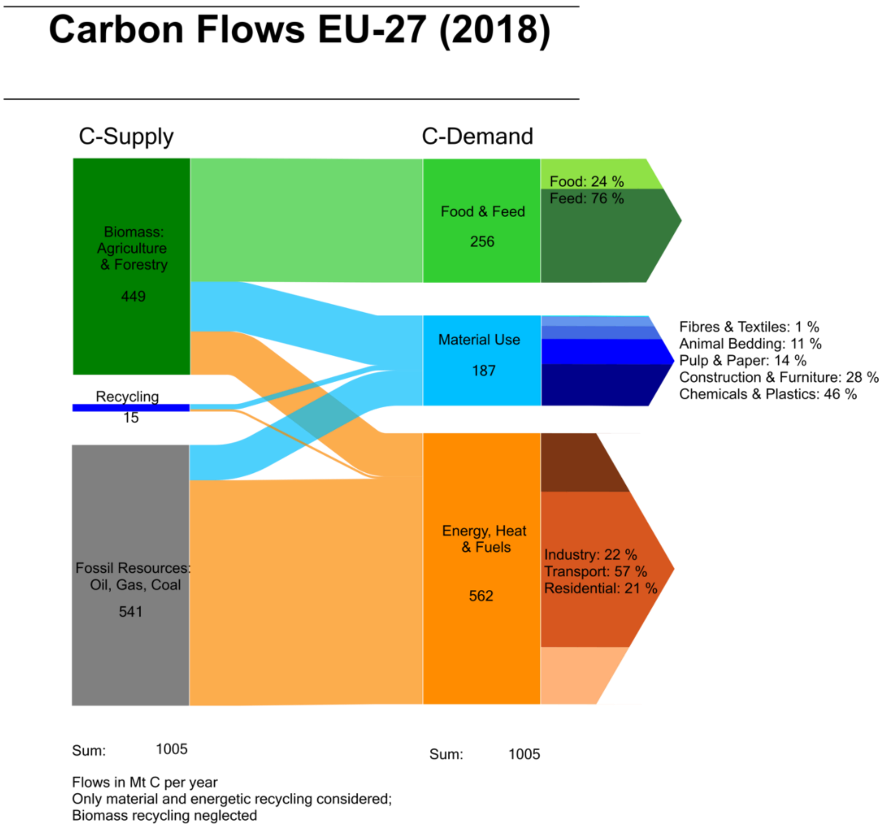

Figure 29. Carbon flows in the EU-27 economy (2018) - Sankey Diagram (own calculations)

To reduce complexity trade is not included in the diagram. The figures for the carbon demand for food & feed, material use, and energy, heat & fuels accord to the assessment carried out in this study but do not include exports. For the compilation of the graphic the figures for the carbon supply from biomass, recycling, and fossil resources are derived from the demand-side and do not include imports. Therefore, the supply does not represent the domestic production.

Recycling is only considered for the recycling of products from material sector including material and energetic recycling. Recycling and use of resources from the food & feed sector (such as bio-waste stream or sewage sludge) is not included.

4 Human Carbon Flow

4.1 Introduction

The carbon cycle of the earth is attracting more and more attention. Not only with regard to the advancing climate change, but also to the possible sequestration and utilisation without further degrading and minimising the earth's long-term storage capacity. Most approaches are based on the carbon flow of countries, continents or large global acting companies. From these carbon streams with ridiculous large numbers the currently known emissions and environmental footprints for individual cities, households or inhabitants are derived. The aim of this report is to gain a better and more comprehensive understanding of carbon flows not only on global and European levels but also on regional and urban levels. Unfortunately, the availability of data for smaller levels is lacking, as the assessment in Work Package 4 shows. Therefore, a novel approach is used to value carbon flows on those regional scales.

The present approach choses a different path and starts with the human being itself (bottom-up approach). The mass flows of the daily life from an adult living in Germany are analysed and recorded. Including flows of vital processes, households, hygiene, construction and more the model is illustrating material and one step further carbon flows caused by a single person. The system boundary for this report is an average middle-aged

German citizen (40-45 years). In addition, only biogenic flows are considered at the present time, as possible resources for carbon-dependent industries are to be identified. These possible sources could serve as sustainable stocks for the production in industries that rely on carbon.

For the overall consideration of all carbon flows emanating from an individual, fossil sources could be supplemented retrospectively to cover, for example, primary production, heating and transport.

Moreover, such a model is an instrument that can be used by decision-makers, to fill data gaps or the assess existing data but also by our fellow human beings, to change the future of politics and everyday life. To achieve this, we must first create the basis for an awareness that even small carbon flows have an impact on the system as a whole. Once such a basis is established, the whole issue of carbon flows will become more tangible and the debate on it will be stimulated.

4.2 Model of carbon flows on the level of a single human

The mind map (Figure 30) below displays all sources of carbon flows on the level of a single human accounted for in the model. As a reference point, an average German at the age of 41-45 years is set. Starting from there, modifications can be applied to the model to adjust it to regional or demographical conditions.

Figure 30. Mind map of the current state of included data. Size of bubbles are indicating the carbon amount. Colour code shows data availability (green: good, yellow: fair, red: poor) (own composition)

4.3 Consumption and waste stream data for Germany

The collected data are subdivided into categories which are vital processes, households, hygiene and construction. Each of these categories contains the most important factors regarding carbon flows. Data from different sources are collected and considered sufficiently accurate if there is a maximum deviation of 20%. Data on leisure activities and behaviour at work cannot be generalised to form an average and therefore are neglected.

4.4 Vital Processes

Every human consumes food and beverages primarily to supply the body with nutrients, energy and hydration. Therefore, these are the first factors to be considered.

According to the Bundesanstalt für Landwirtschaft und Ernährung (BLE) (2019)[40] Germans are consuming 99.6 kg vegetables, 65.1 kg fruits, 14.5 kg eggs, 33.8 kg sugar, 78 kg cereals and 57.9 kg potatoes per person and year. Inedible parts of food, such as vegetable and fruit peelings, are treated as separate flows for the overall balance.

Additionally, the BLE is presenting the mean meat consumption of a person living in Germany (2017) with 87.7 kg per year. The given meat consumption displays the total amount of meat including not edible parts like bones. Excluding these parts, the amount decreases to 59.73 kg / person a year. FAOSTAT (2018)[41] provided corresponding data on human consumption for Germany.

Data provided by the Fisch-Informationszentrum e.V. (2019)[42] present a consumption of 1.14 million tonnes of fish and fishery products eaten in Germany in 2018. That is 13.7 kg (catch weight) per inhabitant. The given data are matching with the ones FAO supplied. The Deutscher Fleischer-Verband e.V. (2019)[43] is giving lower values for the meat consumption because they've already deducted bones and other losses due to industry or animal feed. They state 60.1 kg meat per person and year which confirms the value of BLE above.

The given data sources for the mean food consumption in Germany are consistent in their amounts.

Regarding beverages, a typical German person is drinking 148 L sparkling water, 165 L coffee, 28 L black/green tea, 33 L fruit juices, 119 L soft drinks and 110 L beer per year according to the Barmer e-Magazin (2016)[44] with data derived from Federal Statistical Office of Germany. Apart from the listed beverages above[44], Germans are drinking 52.2 L milk per person yearly[40]. The Deutscher Kaffeeverband (2020)[45] and the Deutscher Teeverband (2018)[46] are confirming the data from Barmer e-Magazin (2016)[44] on coffee and tea. Furthermore, the published data on sparkling water consumption from Verband Deutscher Mineralbrunnen (2020)[47] indicate almost equal amounts.

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[40] Bundesanstalt für Landwirtschaft und Ernährung (BLE) 2019. Pro-Kopf-Verbrauch ausgewählter Lebensmittel in Deutschland (in kg). Bundesanstalt für Landwirtschaft und Ernährung (Ed.), Download at https://www.ble.de/SharedDocs/Downloads/DE/BZL/Informationsgrafiken/ProKopfLebensmittel.html

[41] FAOSTAT 2018. New Food Balances. (Ed.), Download at http://www.fao.org/faostat/en/?#data/FBS

[42] Fisch-Informationszentrum e.V. 2019. Wo werden welche Fischprodukte gekauft? (Ed.), Download at https://www.fischinfo.de/index.php/markt/114-infografiken

[43] Deutscher Fleischer-Verband e.V. 2019. Jahrbuch 2019. (Ed.), Frankfurt, Germany, Download at https://www.fleischerhandwerk.de/fileadmin/content/03_Presse/Geschaeftsbericht/DFV_Jahrbuch_2019_72dpi.pdf

[44] Barmer e-Magazin 2016. Getränke-Konsum in Deutschland. (Ed.), Download at https://magazin.barmer.de/tipps/getraenke-konsum-in-deutschland/

[45] Deutscher Kaffeeverband 2020. Deutscher Kaffeemarkt 2019 erneut gewachsen - Trend setzt sich auch während Corona-Pandemie weiter fort. 20-05-17. Download at https://www.kaffeeverband.de/de/presse/deutscher-kaffeemarkt-2019-erneut-gewachsen

[46] Deutscher Teeverband 2018. Tee als Wirtschaftsfaktor. (Ed.), Hamburg, Germany, Download at https://www.teeverband.de/files/bilder/Presse/Marktzahlen/Tee_als_Wirtschaftsfaktor_2018.pdf

[47] Verband Deutscher Mineralbrunnen 2020. Mineralwasser-Absatz 2019. 20-01-16. Download at https://www.vdm-bonn.de/oeffentlichkeitsarbeit/news-detail/article/mineralwasser-absatz-2019.html

Additional data supplied by the Bundesverband der Deutschen Spirituosen-Industrie und -Importeure (2018)[48] giving values for 2017. Germans have drunk averagely 101.1 L of beer, 20.9 L of wine and 9.1 L of other alcoholic beverages which is again confirmed by FAOSTAT (2018)[41]. Data from the Bundesverband der Deutschen Spirituosen-Industrie und -Importeure (2018)[48] corresponds to the data stated by Barmer e-Magazin (2016)[44] with the exception of the milk consumption. For the latter, the mean value of the two sources is formed.

Most of the data for beverage consumption in Germany coming from different sources are matching very well. The conversion from litre to kilogram is set to 1:1 (water) for all drinks, neglecting minor deviations in density.

Continuing with vital processes, data for excretion are collected. Humans are urinating approximately 5 times a day and defecating between 0.5 – 3 times daily[49,50]. Every day there is excreted an amount of 1.5 – 2 L urine and 100 – 250 g faeces per person[51,52]. On top a volume of 0.5-2 L intestinal gas per day and person is released[53]. Intestinal gas includes just very small amounts of carbon overall and is mentioned only for the sake of completeness.

Moreover, humans release biomass into the environment through cell regeneration. Factors to mention are the loss of hair and skin. Hair are usually growing around 12 cm per year[54]. With an average of 120,000 hair per person, a mean thickness of 0.07 mm and a weight of 1.3 g/m^3 [55,56,57,58] this results in an annual hair production of 72 g. Daily there is a loss of around 10 g[59] of skin which leads to 3.65 kg per year and person. Both skin and hair are converted with a carbon amount of 50 % which stands for the carbon content of keratin[60].

With regards to vital processes breathing is another factor to take into account. Humans are breathing 12-18 times per minute[61]. Every breath has a volume of roughly 0.5 L[62]. This

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[48] Bundesverband der Deutschen Spirituosen-Industrie und -Importeure 2018. Pro-Kopf-Verbrauch der verschiedenen alkoholhaltigen Getränke nach Bundesländern 2017. (Ed.), Download at https://www.spirituosen-verband.de/fileadmin/introduction/downloads/Pro-Kopf-Verbrauch_nach_Laendern-2017.pdf

[49] Krammer, H., Kolac, C., Köhler, U. and Bischoff, S. 2009. Tabuthema Obstipation: Welche Rolle spielen Lebensgewohnheiten, Ernährung, Prä-und Probiotika sowie Laxanzien. Aktuelle Ernährungsmedizin, Vol. 34 (01), 38-46.

[50] Rheinische Post Online 2002. WC-Gewohnheiten der Deutschen - Wie der Deutsche sein "Geschäft" erledigt. Rheinische Post Online, Vol. 2002-02-19.

[51] Gressner, A. and Gressner, O. 2019. Stuhlfeuchtgewicht. Lexikon der Medizinischen Laboratoriumsdiagnostik. Springer (Ed.).

[52] Schönemann, J. 2017. Thema Niere: Veränderte Urinmenge. Apotheken Umschau (Ed.), Download at https://www.apotheken-umschau.de/Niere/Urinmenge-veraenderte-98631.html

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[54] Schwichtenberg, U. 2020. Der Haarzyklus. (Ed.), Download at https://www.haarerkrankungen.de/grundlagen/haarzyklus.htm

[55] Ley, B. 1999. Diameter of the human hair. (Ed.), Download at http://hypertextbook.com/facts/1999/BrianLey.shtml

[56] Lochhead, R. 2012. Practical modern hair science. Allured Pub Crop, Washington, Vol. 75-110.

[57] Schwichtenberg, U. 2020. Der Haarzyklus. (Ed.), Download at https://www.haarerkrankungen.de/grundlagen/haarzyklus.htm

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[59] Sterry, W. 2011. Kurzlehrbuch Dermatologie. Unter Mitarb. von Czai.

[60] Gallert, J., Engelhardt, M. and Süslü, B. (Bayreuth, U.) 2016. Haare aus der Sicht des Chemikers. (Ed.), Download at http://daten.didaktikchemie.uni-bayreuth.de/umat/haare/haare_chemie.htm

[61] Lindh, W. Q., Pooler, M., Tamparo, C. D., Dahl, B. M. and Morris, J. 2013. Delmar's comprehensive medical assisting: administrative and clinical competencies.

[62] DocCheck 2016. Tidal volume. (Ed.), Download at https://flexikon.doccheck.com/en/tidal_volume

leads to a total volume of 3,153,600 – 4,730,400 L air / year. As the daily routine and the activity of individual persons varies greatly, these values are just approximately in line with reality. For example, a small, unathletic person emits much less CO_2 over the course of his or her life than an active, large person. 1000 L of air are weighing roughly 1.2 kg for the required conversion to kilogram[63]. The ambient air contains around 0.04 % of carbon dioxide[64]. Metabolic processes enrich the air with CO_2 by factor 100. When exhaled the air contains a relatively constant amount of 4% CO_2 [65]. The amount of carbon released through respiration is between 41.3 and 61.9 kg/year. For further estimations the mean value of the given range is formed, resulting in 51.6 kg/year.

4.5 Hygiene

Hygiene accounts for another important mass flow produced by man. In this section, we will mainly focus on paper-based products as they create large amounts of waste. However, for the sake of completeness, water for personal hygiene and body care products such as shampoos should not be neglected, even though they are low in carbon.

Energy provider Energis (2020)[66] states that bathing results in a water consumption of 140 – 200 l/bath. One bath per week is assumed to be representative for citizens living in Germany. Further on, 30 – 80 L water are consumed per shower[66]. 60% of the Germans are showering every day[67]. Therefore, showering every second day is assumed for calculations. If we also assume that a shampoo bottle with a content of 250 ml lasts one month, we would have a consumption of 3,000 ml, i.e. 3 kg per person per year.

Germans are washing their hands approximately 6 – 10 times a day[68]. For every time washing hands around 2 L of water is needed[69] which results in a daily water consumption of 12 – 20 L and 4,380 – 7,300 L per year.

Usually German people flush their toilets 6 times a day[50] with an approximate water consumption of 6 L/flush[69], which leads to a daily water consumption of 36 L. A typical German has a usage of 15 kg toilet paper per year[70], making it one of the most important streams in the hygiene sector beside the elusive body care products.

Twice a day brushing tooth is set as an average based on own assumption. Per brush around 1 litre of water is consumed[69], which results in 730 L water per year. Along with the given water consumption 330 - 370 ml toothpaste is used per person each year[71].

In total the water consumption per person accounting for hygiene is within the range of 31,005 – 46,170 litre per year.

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[63] Deutscher Wetterdienst 2020. Wetterlexikon: Luftdichte. (Ed.), Download at https://www.dwd.de/DE/service/lexikon/Functions/glossar.html?lv2=101518&lv3=607748

[64] Deutscher Wetterdienst 2020. Climate gases (CO2, CH4, N2O). (Ed.), Download at https://www.dwd.de/EN/research/observing_atmosphere/composition_atmosphere/trace_gases/cont_nav/climate_gases.html

[65] DocCheck 2016. Atemluft. (Ed.), Download at https://flexikon.doccheck.com/de/Atemluft

[66] Energis 2020. So lässt sich der Wasserverbrauch beim Duschen senken. (Ed.), Download at https://www.energis.de/ratgeber/wasser/wasserverbrauch_duschen

[67] jocalvi 2018. 6 interessante Fakten zum Thema Duschen. (Ed.), Download at https://jocalvi.de/fakten-duschen/

[68] Krankenhausgesellschaft Nordrhein-Westfalen 2018. Tag des Händewaschens am 15.10.2018. (Ed.), Download at https://www.kgnw.de/presse/2018_10_12_keine_keime_haende_waschen_tag_umfrage/

[69] arche noVa 2020. Wasserprotokoll. (Ed.), Download at https://www.sachsen.schule/~sud/methodenkompendium/dokumente/ansatz1/wa/A09_1.pdf

[70] Badratgeber 2018. Wie viel Toilettenpapier verbraucht ein Mensch im Durchschnitt? (Ed.), Download at https://www.badratgeber.com/wie-viel-toilettenpapier-verbraucht-ein-mensch-im-durchschnitt/

[71] Nielsen, A. 2007. Verbrauch von Zahnbürsten und –pasten, Zahnseide und Interdentalbürsten im Vergleich. (Ed.), Download at https://www.colgate.de/OralHealthMonth/DE/2008/arch/2007/gallery/MdM-Presseinfo_2007_infografiken_verbrauch.pdf

A big factor to consider are families with babies and their potential of waste accumulation. One baby alone produces over 51 kg waste in shape of diapers and wet wipes per year[72]. It should be noted that the consumption of baby products of course occurs through babies and consequently does not fit into the presented model of an average adult citizen age 41-45. Therefore, a conversion factor is needed, which describes how many babies (0-2 years old) are there per average citizen. In Germany there has been 2.3 million babies per 4.8 million adult between 41 and 45 years old in the year 2019[73]. With a calculated factor of 0.5, we would get a consumption of about 25 kg per person age 41-45 per year.

Furthermore, feminine hygiene products like tampons or sanitary napkins make up a big share in the hygiene waste. About 152 kg of these products are consumed within the life of a women in western societies (Fuhr et al. 2019). With the average lifespan of a women in Germany of 83 years[74] that accounts for 1.8 kg of waste per year per women or 0.9 kg of waste per year per average adult.

4.6 Households

The data collected for human mass flows in German households contain the water consumption of selected machines such as dishwashers and washing machines, which can be found in almost every household. In this context, we also estimate the detergent consumption per year.

Furthermore, it is shown how much waste is accumulated over the course of a year.

In a typical household the washing machine runs twice a week for each person[75] and uses 80 litres of water for every run[69]. In this context, we assume that around 50 ml of detergent is used per wash. Projected over the whole year, this would be over 10 kg detergent used per household.

A dish washer runs around about 5 times a week (own assumption) with a water consumption of 25 L/run[69].

A survey done by Westdeutsche Zeitung (2019)[76] states that Germans are cleaning 3 h per week. Every time they do cleaning a demand of 10 litres water is used up[69]. In nova-Institute’s estimation people are cooking around 4 times a week on average using approximately 5 L of water every time[69].

Apart from the water demand in the hygiene part this leads to a water consumption in German households of 9720 litres per year.

The accumulated waste produced by households is one of the main carbon flows from the present model. It’s of special interest because it could serve as a carbon source for the industry in the future. Since the municipal waste contains some non-biogenic and elusive components, just organic, food and pulp and paper waste were considered. In Germany municipal waste amounts to 535 kg per year and adult with a share of organic waste of

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[72] Miller-Wilson, K. 2020. How Many Diapers Does a Baby Use in a Year? (Ed.), Download at https://baby.lovetoknow.com/baby-care/how-many-diapers-does-baby-use-year

[73] Eurostat (EU) 2020. Bevölkerung am 1. Januar nach Alter und Geschlecht. Last access 19.11.2020. https://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do

[74] Destatis (Statistisches Bundesamt) 2020. Deaths, life expectancy. (Ed.), Download at https://www.destatis.de/EN/Themes/Society-Environment/Population/Deaths-Life-Expectancy/_node.html;jsessionid=F522753B154FC9E6E112E790C82D5F32.internet8721

[75] LG Clothing Care 2016. Studie zur Wäschepflege in Deutschland 2016. (Ed.), Download at https://presse.lg.de/wp-content/uploads/2016/10/LG-Electronics_Studienauszug_Wäschepflege-in-Deutschland.pdf

[76] Westdeutsche Zeitung 2019. Jeder Achte putzt erst bei sichtbarem Schmutz. Westdeutsche Zeitung, Vol. 2019-11-28

9.9%[77]. Of this, the total amount of organic waste (brown bin) collected from households is 4398.4 thousand tonnes per year, resulting in 53.6 kg / person every year.

Personal recordings from nova-Institute's employees recorded amounts of 1014.3 g of organic waste per week and person, resulting in 52.7 kg a year. The Umweltministerium NRW (2017)[78] and Umweltbundesamt (2016)[79] conducted studies, which found slightly lower amounts of around 40 kg / person for German cities. According to those studies rural regions produce more organic waste per person than cities.

Moreover, municipal waste includes 12.5% organic materials which originate from gardening and public parks[78]. This organic waste stream results in 5553.5 thousand tonnes nationwide and 67.7 kg per person. On top Bundesministerium für Umwelt (2020)[80] states that 39.3% of the household waste (black bin) is organic waste. According to this publication this results in 50.3 kg per person and year. Summarising these three organic waste streams a total amount of 171.6 kg/person/year is resulting.

According to a study on food waste in Germany, food waste in total were 12 million tons from which 1.4 million tons are coming from primary production, 2.2 million tons are from processing of food, 0.5 million tons are from wholesale and retail, 6.1 million tons are waste from private households and 1.7 million tons are from out of home catering[81]. Since food waste from private households is already considered in the section on organic waste in general, it is not considered again to avoid duplication. The other mentioned food waste streams are included.

To conduct a proper conversion to carbon, the composition of the food waste is necessary. Since the Verbraucherzentrale NRW (2020)[82] and Schmidt et al. (2019)[81] presenting numbers that deviate strongly from each other, the reference value was taken from the database Phylis (2020)[83]. Phyllis states a carbon amount of 42% for food waste.

The pulp and paper waste stream is another important flow to consider. According to Umweltministerium NRW (2017)[78] pulp and paper are accounting for 17% of the German municipal waste. In total this is 7508.3 thousand tonnes, accounting for 91 kg of pulp and paper waste per person and year.

Data for urban areas (e.g. Cologne) indicate lower values of around 60 kg pulp and paper waste per person in 2017, as seen for organic waste streams[78].

Bundesministerium für Umwelt (2020)[80] gives recent data for 2018. According to that, 5.2 % of the household waste (black waste bin) is pulp and paper. This estimation leads to 6.7 kg pulp and paper waste per person and year. Pulp and paper which is separated by the

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[77] Statistisches Bundesamt 2017. Abfallbilanz 2017. (Ed.), Download at https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Umwelt/Abfallwirtschaft/Tabellen/abfallbilanz-kurzuebersicht-2017.html

[78] Umweltministerium NRW 2017. Abfallbilanz Nordrhein-Westfalen für Siedlungsabfälle 2017. (Ed.), Düsseldorf, Germany, Download at https://www.umwelt.nrw.de/fileadmin/redaktion/Broschueren/abfallbilanz_2017.pdf

[79] Umweltbundesamt 2016. Abfallwirtschaft - Nationales Abfallaufkommen an Haushaltsabfällen und nationale und internationale Verbringung von Abfällen. (Ed.), Download at http://gis.uba.de/website/apps/abf/

[80] Bundesministerium für Umwelt, N. u. n. S. 2020. Infografik - Zusammensetzung des Hausmülls in Deutschland. (Ed.), Download at https://www.bmu.de/media/zusammensetzung-des-hausmuells-in-deutschland/

[81] Schmidt, T., Schneider, F., Leverenz, D. and Hafner, G. 2019. Lebensmittelabfälle in Deutschland – Baseline 2015.

[82] Verbraucherzentrale NRW 2020. Lebensmittel: Zwischen Wertschätzung und Verschwendung. (Ed.), Download at https://www.verbraucherzentrale.de/wissen/lebensmittel/auswaehlen-zubereiten-aufbewahren/lebensmittel-zwischen-wertschaetzung-und-verschwendung-6462

[83] Phylis (Ecn.Tno) 2020. Phyllis2, database for (treated) biomass, algae, feedstocks for biogas production and biochar. (Ed.), Download at https://phyllis.nl/

consumer is not included here. Anyways, this amount should nevertheless be included and leads to a total of pulp and paper waste of 97.7 kg/year.

For the present model based on a single person given amounts for whole Germany were divided by the population of 82 million.

4.7 Construction

Since the focus of the study lies on biogenic carbon streams, wood is the main construction material to be considered. Wood in general has a carbon content of around 50%[84]. For conducted calculations the share mentioned above is used for wood, neglecting differences between various wood species.

The building industry is the sales sector with the greatest capacity for wood products in Germany. In 2012 13.4 million m^3 of wood were utilised in the construction sector. Until a wooden product is installed in construction, there is wood waste in production and application in construction. For the supply of 13.4 million m³ of wood, 16.6 million m³ of wood were originally required. The waste thus accounts for 19.3% or 3.2 million m³ of wood. The originally required wood converted to solid cubic metre equivalent leads to 16.3 million m^3 [85].

Coniferous woods account for the largest share with 85.6%, followed by hardwoods with 12.6% and tropical woods with 1.8%. To calculate the total weight of utilised wood in tonnes mean weight conversion factors for the three wood types mentioned were defined[86]. Coniferous woods with a factor of 550 kg/m^3, hardwoods with 720 kg/m^3 and tropical woods with 900 kg/m^3.

This leads to a total wood amount originally required of 9.44 million tonnes. Divided by the German population of 82 million a single person consumes 115.2 kg of wood annually for construction.

The total amount of wood waste coming from the construction sector including the demolition of old buildings is 3 million tonnes[87]. This leads to an annual out flow of 37.2 kg per person.

Due to the different orientations of the studies referred to in this section, the proportion of wood waste on the construction site itself may have been calculated twice. This would in reality slightly reduce the annual carbon stock built up by timber construction.

4.8 Conversion to Carbon

A detailed document, stating and explaining conversion factors, is attached to this report. The carbon content of the most important biomass products like protein, fat, cellulose and starch or virgin sugar is determined within every compound, as stated above. The data used to define the different carbon contents are derived from various sources. These sources are listed in the attached document.

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[84] Diestel, S. and Weimar, H. 2014. Der Kohlenstoffgehalt in Holz-und Papierprodukten: Herleitung und Umrechnungsfaktoren. Thünen Working Paper (Ed.).

[85] Weimar, H. and Jochem, D. 2013. Holzverwendung im Bauwesen: Eine Marktstudie im Rahmen der" Charta für Holz".

[86] Engineering ToolBox 2004. Density of Various Wood Species. (Ed.), Download at https://www.engineeringtoolbox.com/wood-density-d_40.html

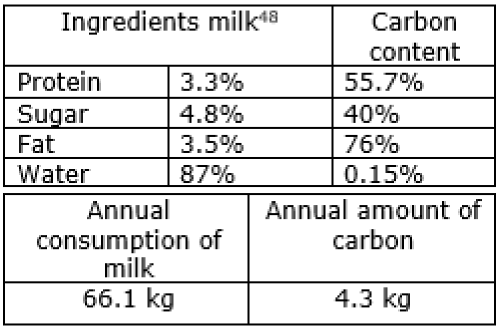
[87] Statistisches Bundesamt 2017. Umwelt - Abfallentsorgung. (Ed.), Download at https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Umwelt/Abfallwirtschaft/Publikationen/Downloads-Abfallwirtschaft/abfallentsorgung-2190100177004.pdf?__blob=publicationFile

If data from multiple sources diverge, the mean value is taken to conduct the carbon conversion. All the presented data above are transformed to kg/year/person and recorded in the conversion table. As an example, the conversion table for the consumption of milk is presented in Table 10.

In the following section, the methodology of carbon conversion is explained using two examples (milk and potatoes). As previously shown, the methodology refers to the carbon content of biomass constituents.

Table 10 shows the composition of ingredients of milk and their respective carbon content. With an annual milk consumption of 66.1 kg (see above), the consumed carbon is 4.3 kg/year/person.

Table 10. Carbon conversion of milk with regard to the annual consumption (own calculations based on Barmer e-Magazin, 2016)



Ingredients milk[48]		Carbon content
Protein	3.3%	55.7%
Sugar	4.8%	40%
Fat	3.5%	76%
Water	87%	0.15%

Annual consumption of milk	Annual amount of carbon
66.1 kg	4.3 kg

A second example shows the annual consumption of potatoes converted to carbon. In order to determine the carbon content of a specific food, the composition of it must be known. For this, the 'Nutritive factors' table by FAO are used[88], which lists almost all agricultural products that can be used for human consumption. Furthermore, losses in meal preparation are taken into account. For example, fruits, vegetables or eggs have peels or other parts, which are waste material, that are removed before eaten. Percentages of these peeling losses have been estimated or taken from various sources. For potatoes, we assume that 80% is consumed and the rest is waste (peel). Table 11 shows the consumption of potatoes per capita and its conversion to carbon.

Table 11. Carbon conversion of potatoes with regard to the annual consumption (own calculations based on BLE, 2019)

Ingredients potatoes		**Carbon content**
Protein	1.6%	55.7%
Sugar/Starch	2.5%	40%
Fat	0.1%	76%
Cellulose	0.04%	44.4%
Water	78.7%	0.15%
Annual consumption of potatoes (gross)	Annual consumption of potatoes (net)	Annual amount of carbon (net)
57.9 kg	46.3 kg	4.4 kg

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[88] Fuhr, L., Buschmann, R. and Freund, J. 2019. Plastikatlas 2019. Daten und Fakten über eine Welt voller Kunststoff.

The following Figure 31 shows the annual carbon consumption of one person living in a city, distinguished into inflow and outflow. Further, the data is divided into four main domains (vital processes, hygiene, households and construction), which are assumed to have the biggest carbon turnover rate for a human. These values per capita are converted for a one-million-inhabitant-city, afterwards.

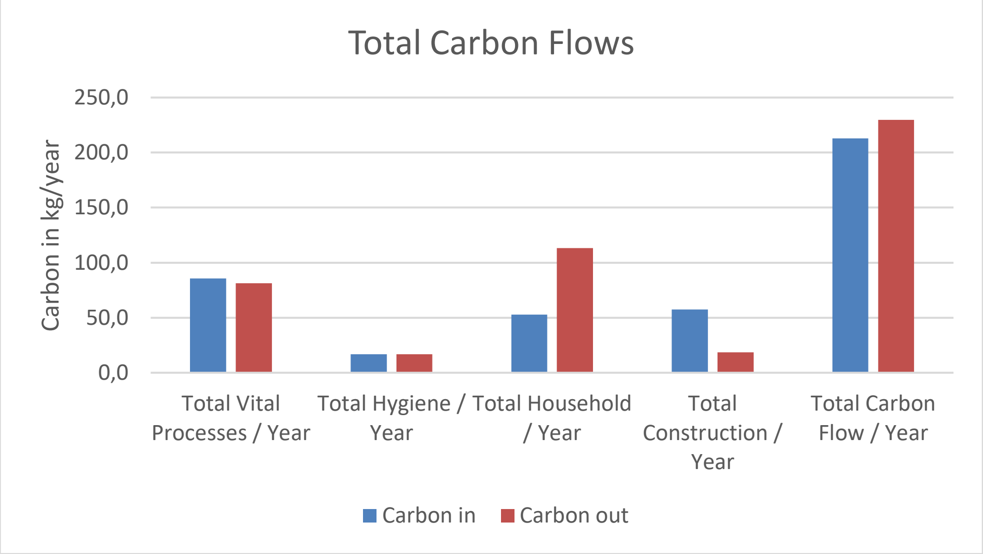
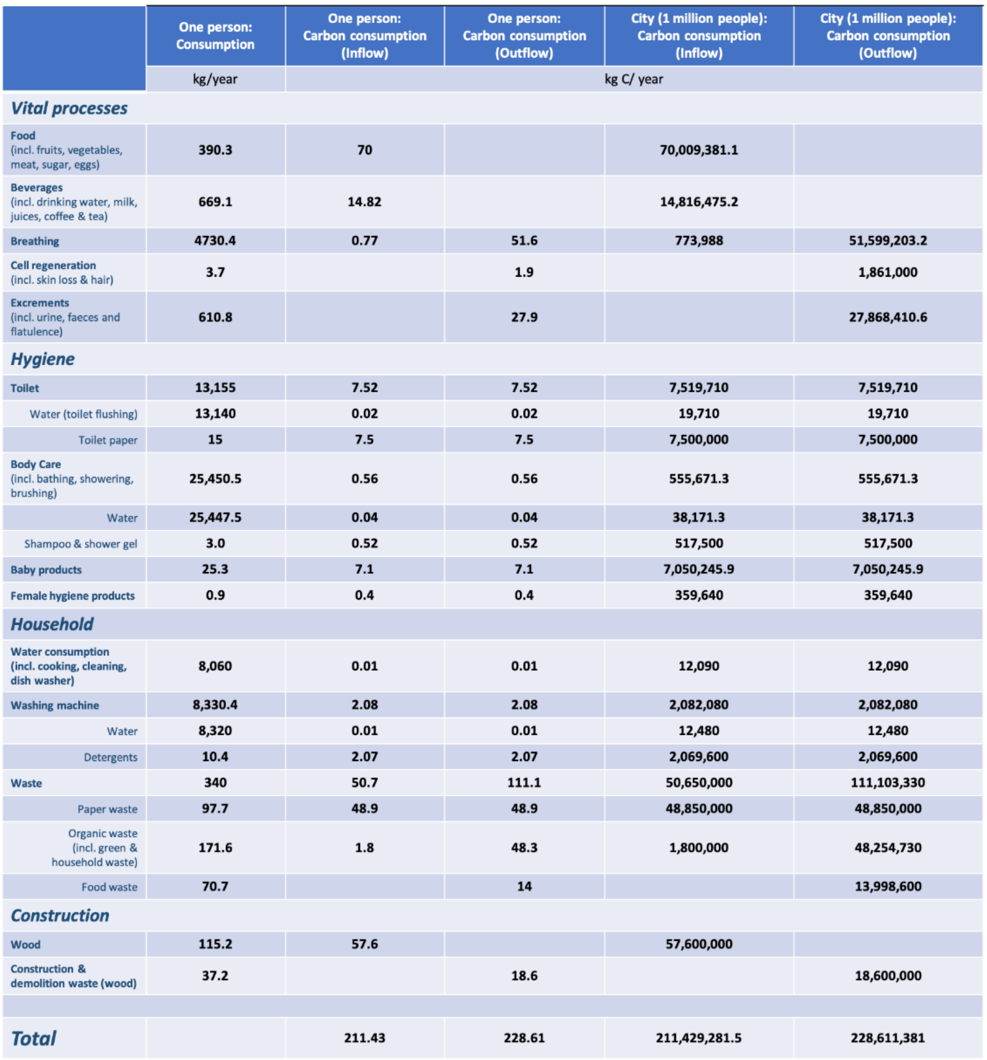


Figure 31. Total carbon in- and outflows in kg/year/person (own calculations)

Table 12. Summary of carbon flows accounted on a single human level and scaled-up for a city level (own calculations)



	One person: Consumption	One person: Carbon consumption (Inflow)	One person: Carbon consumption (Outflow)	City (1 million people): Carbon consumption (Inflow)	City (1 million people): Carbon consumption (Outflow)
	kg/year	kg C/ year			
Vital processes					
Food (incl. fruits, vegetables, meat, sugar, eggs)	390.3	70		70,009,381.1	
Beverages (incl. drinking water, milk, juices, coffee & tea)	669.1	14.82		14,816,475.2	
Breathing	4730.4	0.77	51.6	773,988	51,599,203.2
Cell regeneration (incl. skin loss & hair)	3.7		1.9		1,861,000
Excrements (incl. urine, faeces and flatulence)	610.8		27.9		27,868,410.6
Hygiene					
Toilet	13,155	7.52	7.52	7,519,710	7,519,710
Water (toilet flushing)	13,140	0.02	0.02	19,710	19,710
Toilet paper	15	7.5	7.5	7,500,000	7,500,000
Body Care (incl. bathing, showering, brushing)	25,450.5	0.56	0.56	555,671.3	555,671.3
Water	25,447.5	0.04	0.04	38,171.3	38,171.3
Shampoo & shower gel	3.0	0.52	0.52	517,500	517,500
Baby products	25.3	7.1	7.1	7,050,245.9	7,050,245.9
Female hygiene products	0.9	0.4	0.4	359,640	359,640
Household					
Water consumption (incl. cooking, cleaning, dish washer)	8,060	0.01	0.01	12,090	12,090
Washing machine	8,330.4	2.08	2.08	2,082,080	2,082,080
Water	8,320	0.01	0.01	12,480	12,480
Detergents	10.4	2.07	2.07	2,069,600	2,069,600
Waste	340	50.7	111.1	50,650,000	111,103,330
Paper waste	97.7	48.9	48.9	48,850,000	48,850,000
Organic waste (incl. green & household waste)	171.6	1.8	48.3	1,800,000	48,254,730
Food waste	70.7		14		13,998,600
Construction					
Wood	115.2	57.6		57,600,000	
Construction & demolition waste (wood)	37.2		18.6		18,600,000
Total		211.43	228.61	211,429,281.5	228,611,381

As can be seen, an average German person consumes over 211,4 kg carbon per year and releases about 228,6 kg. Extrapolated to a city of millions, we get a carbon inflow of 211,4 million and an outflow of 228,6 million carbon per year. The gap between the in- and outflow can be explained by the fixation of carbon, for example into the human body by food and beverages or the transformation through wood into wood products like furniture.

4.9 Interpretation

This model was prepared with the intention of presenting biogenic carbon flows from a single person. It is not intended to and cannot replace current models of the entire carbon cycle, which, inter alia, also include fossil sources. However, the aim is to create a tool that can represent carbon flows on a smaller scale and at regional level as a function of various influencing factors. The values derived from the global carbon flows are often very inaccurate, as no regional differences can be considered. In addition, individual categories from everyday life are less well broken down, so that the individual itself can hardly make use of the data provided. With a more detailed breakdown, the values are much more tangible for citizens and an adaptation of behaviour is more realistic. However, this tool is not primarily intended to help citizens understand the data, but to identify regionally available biogenic carbon sources in order to utilise them and reduce the use of fossil carbon.

The analysis of the listed carbon in- and outflows shows different patterns. In the category vital processes, for example, slightly more inflow than outflow was found. Assuming that the considered individual does not gain weight and that the human body releases everything it absorbs back into the environment in various ways, this slight surplus is probably due to the collection of data from studies of various kinds. In general, an attempt was made to eliminate as far as possible the different frames of reference of the studies referred to. These variations are within the acceptable range, at less than 10%. It can be said that apart from excrements no relevant amounts of carbon are released for utilisation, since exhaled air cannot be realistically collected. However, human excrement could become even more of a focus of interest once the technical solutions for reuse are fully developed, as this outflow is present in large quantities everywhere, especially in densely populated regions.

As the hygiene section only contains products and water for external use, which are disposed of in the drain or waste bin without being consumed, the inflow here is equivalent to the outflow. Since water contains very little carbon amounts, it can be neglected as a possible source for carbon dependent industries. The main carbon streams are generated by toilet paper, baby products and menstrual products. Overall, the carbon flow from hygiene is the lowest within the four categories and is fed into the wastewater and solid waste system anyway. Therefore, the recycling of hygiene products, including for the recovery of carbon, must be ensured by the existing systems. Nevertheless, it is important to consider the hygiene sector as well in order to get an overall view of the carbon flows.

In the household section, the analysis focuses on household chores, such as cooking and cleaning, household appliances, including their water consumption and the waste generated in households. Since water plays a minor role in respect of carbon flows, as mentioned above, it will not be discussed further here. The streams that contain much more carbon and can therefore be of high interest for recycling are organic waste, paper waste and food waste. Only this waste together results in an output of 62.3 kg of pure carbon per person annually, which is completely biogenic. In Germany in particular, a high proportion of waste streams is already being recycled, but a lot is still landfilled and left unused. In addition, a share of organic waste ends up in incineration plants.

Nevertheless, there will be enough options to make these waste streams usable for other sectors if decision-makers recognise the many positive benefits in terms of dwindling resources and climate change and if technological progress continues to mature.

The surplus in outflows in the household sector is due to the fact that inflows cannot be clearly distinguished. In addition, organic waste from gardens and parks for which there is no definite inflow equivalent is considered.

The construction sector is fixing more carbon through the application of wood than it is released due to demolition. It is important here that only the raw material wood was considered. Other building materials or materials that are necessary in timber construction were not taken into consideration, as materials, such as concrete, do not have a biogenic origin. Many other organically produced materials are not included at this time but could still change the balance if they were included. Overall, it is clear that in the building industry wood is creating a carbon stock in the technosphere, since there is more construction going on than demolition. The wood used in buildings lingers too long for it to be useful as a resource. However, the waste generated by the demolition of wooden constructions could be recycled. After all, this is a respectable 18.6 kg of pure carbon per inhabitant per year.

Certainly, the model does not yet include all biogenic carbon flows that occur in total, but existing gaps could be gradually closed through continuous optimisation. For example, leisure time and work activities have not been given special consideration so far and no distinction has been made between age groups. Such adjustments could be made in the future. When applied in other regions, the available data should always be examined and used to draw conclusions at local level. In this way, the conversion factors for carbon content remain the same, but the respective base quantities in kilograms per year may differ significantly.

The model thus presents the annual carbon flows of an average person living in Germany based on the current situation of available data.

5 Conclusions

The aim of this work package was to retrieve a better understanding of the carbon economy in a qualitative and quantitative manner. A graphical presentation of carbon sources and flows was to goal in order to gain information on various levels of the carbon economy.

To achieve these goals on a global level, the Earth's global bio-geological carbon cycle is assessed. Data from various studies of multiple scientific disciplines from geology to climate science to empirical economics are collected. Hence, the global carbon cycle is simplified in accordance with the scope of the study and the definition of "carbon economy" to get a better understanding of the relevance of global carbon stocks and flows. This (simplified) "global anthropogenic carbon cycle" is presented in a comprehensive graphic.

In the assessment, the Earth's spheres are divided by four natural spheres (atmosphere, hydrosphere, lithosphere and biosphere) and one man-made sphere (technosphere). Total carbon stocks and their composition are identified and the net carbon flows between the spheres are stated. The analysis shows that the by far largest carbon stocks are contained in the lithosphere (90,000,000 Gt C), which is dominated by carbonate rocks. Other important stocks in the lithosphere are methane clathrates with their exploitation being uncertain and large resources of fossil fuels with coal providing the largest share of fossil resources. The hydrosphere also has a large stock reservoir compared to the other remaining spheres. 40,000 Gt C are stocked in the hydrosphere with the vast majority being dissolved inorganic carbon in seawater. The biosphere has a carbon stock of 4,200 Gt C with the largest share in soil (up to 1m depth), closely followed by permafrost and wetlands and a rather small share stored in vegetation. Considering only carbon in living organisms, plants make up the by far largest share, followed by bacteria. While fungi are also relevant, the share of carbon in living animals is very low comparatively. The technosphere is defined by anthropogenic activities. The determination of the total carbon stock in the technosphere is not possible due to the lack of data. However, the carbon stored in products used by humans is 11 Gt C. The annual utilisation is 16 to 17 Gt C provided by flows from the lithosphere (10.0 to 11.3 Gt C per year in fossil fuels) and flows from the biosphere (5.5 to 6.0 Gt C per year in biomass). The most relevant sector for the use of carbon is the energetic use, followed by feed and food. Furthermore, carbon is used for bioenergy, materials, chemicals and biofuels. Apart from the flows of biomass and fossil resources to the technosphere, net flows to and from the atmosphere are determined. Those are especially relevant because net flows of carbon from the technosphere to the atmosphere (9 to 11 Gt C / year) contribute to global warming, while net flows from the atmosphere to the biosphere or the hydrosphere (3 Gt C and 2 Gt C / year respectively) compensate the anthropogenic greenhouse gas emissions partly.

The results emphasise the large dependency of human economic activities on fossil fuel extraction. Furthermore, it is shown, that fossil resources in the lithosphere are huge, compared to the annual consumption. This underlines the necessity of a phase-out of fossil fuels before deposits are fully exploited. Additionally, the graphic shows the major difference between carbon sourced from fossil resources and from biomass. While there are emissions from the technosphere to the atmosphere, there is a net flow from the atmosphere to the biosphere and from there back to the technosphere. Hence, while fossil carbon from the lithosphere is contributing to global warming, carbon from the biosphere is kept in a circular flow and not leading to an increasement of carbon in the atmosphere (in form of CO2).

For the European level, for all sectors with relevant uses of carbon, current data from various sources on material input flows are assessed. For each product group, the carbon content is determined to transfer the material flows to carbon flows. In doing so, the carbon demand of the European economy is determined. Apart from the total demand, the source of carbon (bio-based, fossil or from recycling) for each application is tracked, in order to draw conclusions on the overall composition of carbon supply (divided into carbon from fossil resources, from biomass and from recycling).

Apart from detailed depictions for several sectors and product groups, a comprehensive overview of the EU-27’s current carbon demand and supply is derived. The results show, that the most important source to meet the EU-27’s carbon demand are fossil resources (54% of the total carbon supply), followed by biomass (46%). The role of energetic and material recycling is comparatively low (1.5%, only considering recycling for the material sector and energetic recycling, not including recycling of biomass flows). On the demand side, the largest carbon flow is consumed in the energy sector (51%, including power, heat and transport). Food and feed is the second biggest sector regarding the carbon demand (23%), followed by chemicals and materials (17%). These findings emphasise the strong dependency of the current European carbon demand on fossil resources, especially in the energy sector, where 85% of the carbon is derived from fossil resources. Furthermore, possible opportunities for future transformation are revealed, e.g. with a comparatively large share of carbon for food and feed being used for feed (76%) and only a much smaller share being used directly for food (24%).

Apart from the global and the European level, a novel bottom-up model is introduced to account for urban carbon flows. It is designed to fill data gaps or assess existing data, with special regard to urban biogenic carbon waste streams that could be valorised. In its current state, the model depicts activities of an average German adult and accounts all relevant carbon flows caused by daily activities. Starting from this point, the model can be adopted to other geographical regions or extrapolated the account for an EU average. Within the scope of the model, household activities (including paper waste and the organic shares of household waste, bio-waste and green waste) play the biggest role in carbon outflows (50%), followed by vital processes (36%, including breathing, excrements and cell regeneration). Together with hygiene measures and private construction activities, the carbon outflow amounts to around 230 kg per person per year.

WORK PACKAGE 2 - FUTURE SCENARIOS

1 Introduction

To mitigate climate change, a deep transformation of the European economy lays ahead. A move towards a "low-carbon economy" with greatly reduced net carbon emissions is ongoing with regards to the COP21 Paris Agreement[89] and a policy framework outlined in the European Green Deal. As the results of Work package 1 of this study outlined, carbon is included in a massive variety of natural substances and manufactured products. On the other hand, humankind has a multitude of carbon sources at its disposal, some fossil and some renewable. While in the energy sector an extensive decarbonisation is possible, in the case of food and feed production and in the production of materials and chemicals, this decarbonisation is not possible since carbon compounds are the key molecules in these products and therefore unavoidable. Hence, pathways to sustainable sourcing and use of carbon must be developed and evaluated. In this study the authors attempt to develop and evaluate future scenarios for the European carbon economy in 2050. Moreover, the scenarios were assessed regarding their implications for sustainability. In this study the six different variations of Scenarios for the Energy Sector were analysed. Additionally, the two scenarios for Food and Feed and for Material use were created and evaluated. The scenarios were based on the best available data in the report and available literature.

2 Description of Future Scenarios on Supply and Demand of Carbon

2.1 Development of explorative scenarios

Work package 1 provides an understanding of the current state of carbon flows and description of where carbon appears in European economy. Relevant material flows are gathered, and their relative carbon content is determined. Hence, current carbon supply and demand are assessed and summarised to compile a Sankey flow diagram, as shown in Figure 29. As described previously, the demand refers to demand by the EU population as well as the demand from the industry. Therefore, both, domestic consumption and exports are considered for the carbon demand. Also, the supply is considered as the sum of demand for biogenic or fossil carbon or carbon from recycling. For simplification it is not considered if the carbon resources are derived from domestic production or imported. Furthermore, losses aren't regarded separately but are included in a sector's demand, e.g., the carbon demand from the food and feed sector includes losses in the food production chain.

As depicted in Figure 29, the carbon supply is dominated by carbon from fossil resources (oil, gas and coal) and carbon from biomass (agriculture and forestry). On the demand side, the most relevant sector is energy, heat and fuels with approximately 85% of carbon derived from fossil resources. The second biggest sector demand for carbon demand is food & feed with exclusively bio-based carbon[90]. The material use sector is more balance, with a share of around 40% carbon from fossil resources, 55% bio-based carbon and the rest coming from recycling.

In order to determine possible pathways towards a sustainable future for supply and demand of carbon within the European economy the scenarios were developed and assessed using the insights gathered for the current situation. To do this, scenarios were developed to illustrate some potential pathways and future possibilities for the European economy and their implication for sustainable development.

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[89] United Nations Treaty Collection – Chapter XXVII Environment. 7. d Paris Agreement. Paris, 12 December 2015. Available at https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-d&chapter=27&clang=_en

[90] While all the carbon contained in food and feed products is biogenic, fossil carbon products are used in the food production chain (e.g. fuel for agricultural machinery, gas heating in the production of fertilisers). Those fossil carbon products are accounted for in the energy, heat and fuels sector and not in the food & feed sector.

For the energy sector the well-regarded study "A Clean Planet for all - A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy" by European Commission (2018)[91] is used to derive scenarios for 2050. This study covers supply and demand of energetic resources (fossil and bio-based) for the European energy sector (including residential, transport and industry). The study covers a Business as Usual scenario as a baseline, five scenarios that explore the intensive use of a certain technological pathway and three additional scenarios that cover combinations of other scenarios. From this study, the Business as Usual scenario is adopted along with five scenarios for different technological pathways. Detailed descriptions for the scenarios are given in the following chapter. The figures for EU-28 stated in the study are adapted to EU-27 by reducing the flows by the UK's share of energy consumption in 2018. Apart from that, all assumptions are adapted equally in order to use the data for the energy flows provided in the study to derive the corresponding carbon demand and supply following the methodology introduced in Work package 1.

For demand of carbon from the sectors food & feed and material use, no comprehensive studies are known that can be used to gather insights on future European carbon demand and supply for those sectors. For the food and feed sector, Mathijs et al. (2015)[92] offers a promising approach, but the database from 2015 requires an update and there is no information included on the material use sector. Hence, based on the knowledge base created in Work package 1, explorative scenarios for 2050 are developed. In order to do that, a set of parameters is gathered with influence on type and quantity of carbon demand. For those parameters, possible future developments are depicted for two different scenarios. For those two scenarios the resulting overall carbon demand for each scenario is derived following the methodology introduced in Work package 1.

2.2 Scenarios for the Energy Sector

Scenarios for the energy sectors 1 to 6 are based on the study by European Commission (2018)[93]. Those include:

- Scenario 1: Business as Usual (BAU)
- Scenario 2: Electrification (ELEC)
- Scenario 3: Hydrogen (H2)
- Scenario 4: Power-to-X (P2X)
- Scenario 5: Energy Efficiency (EE)
- Scenario 6: Circular Economy (CIRC)

The main assumptions used to create the original scenarios are depicted in Table 13.

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[91] European Commission 2018. A Clean Planet for all–A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. (Ed.), see: https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

[92] Mathijs, E., Brunori, G., Carus, M., Griffon, M., Last, L., Gill, M., Koljonen, T., Lehoczky, E., Olesen, I. and Potthast, A. 2015. Sustainable Agriculture. European Commission, (Ed.)

[93] European Commission 2018. A Clean Planet for all–A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. (Ed.), Download at https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

Table 13. Overview of main energy scenario building blocks, Source: European Commission (2018)[94]

	Scenario 2: Electrification (ELEC)	**Scenario 3: Hydrogen (H2)**	**Scenario 4: Power-to-X (P2X)**	**Scenario 5: Energy Efficiency (EE)**	**Scenario 6: Circular Economy (CIRC)**
Main Drivers	Electrification in all sectors	Hydrogen in industry, transport and buildings	E-fuels in industry, transport and buildings	Pursuing deep energy efficiency in all sectors	Increased resource and material efficiency
GHG target in 2050	80% GHG (excluding sinks) ["well below 2°C" ambition]				
Major Common Assumptions	• Higher energy efficiency post 2030 • Deployment of sustainable, advanced biofuels • Moderate circular economy measures • Digitalisation • Market coordination for infrastructure deployment • BECCS present only post-2050 in 2°C scenarios • Significant learning by doing for low carbon technologies • Significant improvements in the efficiency of the transport system.				
Power sector	Power is nearly decarbonised by 2050. Strong penetration of RES facilitated by system optimisation (demand-side response, storage, interconnections, role of prosumers). Nuclear still plays a role in the power sector and CCS deployment faces limitations.				
Industry	Electrification of processes	Use of H2 in targeted application	Use of e-gas in targeted application	Reducing energy demand via Energy Efficiency	Higher recycling rates, material substitution, circular measures
Buildings	Increased deployment of heat pumps	Deployment of H2 for heating	Deployment of e-gas for heating	Increased renovation rates and depth	Sustainable buildings
Transport sector	Faster electrification for all transport modes	H2 deployment for HDVs and some for LDVs	E-fuels deployment for all modes	Increased modal shift	Mobility as a service
Other Drivers		H2 in gas distribution grid	E-gas in gas distribution grid		

The Business as Usual scenario (BAU) is the baseline scenario which projects the effects of existing or expected Member States' policies and objectives until 2050. It also projects generally expected and accepted societal trends. The GHG reduction efforts lead to a decrease of 48% by 2050 compared to 1990.

Scenarios 2 to 6 comply with the Paris agreement's goal of "well below 2°C" for global warming. Each of the six scenarios depict a characteristic set of decarbonisation options in

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[94] European Commission, A Clean Planet for all, A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy, 2018, see: com_2018_733_analysis_in_support_en_0.pdf (europa.eu)

the energy sector. Some basic assumptions and properties apply for each of those scenarios, including:

- GHG reduction of 80% by 2050 compared to 1990 (excluding the LULUCF sector);
- strong improvements in energy efficiency;
- deployment of renewable energies combined with a slightly increased share of nuclear power and a (limited) installation of CCS technologies at remaining fossil-based power plants;
- increased electrification in the final energy demand, especially in transport and buildings;
- improvements in transport system efficiency;
- consideration of technologies found in mainstream research and in innovation, not considering options with low technology readiness levels (> TRL4);
- consideration of cost-effectiveness with special regard of the emission trade sector.
- the stated changes are realised, inter alia, by the deployment of the following technical measures:
- balancing capacities for electric energy (demand response) by fostering self-consumption, smart appliances, energy storage;
- increase of resource efficiency and improving of waste management;
- increase of the mandate of biofuels in transport fuels to at least 25%.

While scenarios 2 to 4 (Electrification, Hydrogen and Power-to-X) are characterised by a deployment of energy carriers that don't rely on fossil carbon. In other words, these scenarios require significant change in the energy supply sectors. The transformation in scenarios 5 and 6 (Energy Efficiency and Circular Economy) is driven by a reduction of GHG emissions on the demand side of the energy sector.

2.2.1 Energy Scenario 1: Business as Usual (BAU)

In the BAU Scenario the Member States' recent policies are considered.[95] A number of pieces of relevant policies and Commission proposals from 2018 are incorporated in the BAU scenario, namely in the fields of emission trading, LULUCF (land use, land use change and forestry), energy performance of buildings, renewable energy, energy efficiency, combined transport and clean vehicles, and high and low duty vehicles.

The achievement of the energy and climate targets for 2030, as adopted by the EU Leaders on October 2014, is foreseen. Those targets include a reduction of GHG of 40% (compared to 1990), at least 27% of RES consumption, and an increase of energy efficiency of 27%.[96,97]

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[95] Capros, P., De Vita, A., Tasios, N., Siskos, P., Kannavou, M., Petropoulos, A., Evangelopoulou, S., Zampara, M., Papadopoulos, D. and Nakos, C. 2016. EU Reference Scenario 2016-Energy, transport and GHG emissions Trends to 2050. (Ed.)

[96] European Council 2014. Europe leads the way in the fight against climate change and Ebola, 23-24 October 2014. (Ed.), Download at https://www.consilium.europa.eu/en/meetings/european-council/2014/10/23-24/

[97] Since the publication of the by the European Commission (2018), the European Green Deal has been announced by the European Commission tightening the emission reduction goals. The aims include a reduction of GHG emissions of 50% towards 55% by 2030 and climate neutrality by 2050. A revision of existing legislation as

The projection of trends beyond 2030 shows significant improvements in energy efficiency and a growth of the share of renewable energies. Nuclear power production remains stable, natural gas use in power generation grows slightly while the share of other fossil fuels decreases. The overall transport activity grows significantly while the efficiency in this sector intensifies.

2.2.2 Energy Scenario 2: Electrification (ELEC)

The main characteristic of this scenario is the electrification of the energy demand, leading to a higher demand for electricity supply. Aside from the general measures described in section 2.2, special actions are taken in sectors where emissions are harder to abate. Those include strict CO_2 standards for light duty vehicles, battery electric heavy-duty vehicles for short distances and overhead lines for heavy duty vehicles for long distances. In contrast, the electrification of inland navigation (inland waterways and national maritime) and aviation remains low. In the buildings sector, efficient heat pumps are deployed. In the industry sector, all possible processes are electrified, including high-temperature process heating.

2.2.3 Energy Scenario 3: Hydrogen (H2)

The main characteristic of this scenario is the deployment of hydrogen in the energy sector, leading to increased hydrogen production on the supply side. Hydrogen is mainly produced in electrolysers powered with renewable energy (green hydrogen)[98]. Aside from the general measures described in section 2.2, hydrogen is used for final uses in transport, buildings and industry. The gas distribution and heating equipment is adjusted to allow for a share of 50% hydrogen in gas distribution. Additionally, biogas is blended in to provide gas with a low fossil carbon footprint for heating of buildings, for industry and for heat generation. Industrial furnaces use hydrogen locally produced in electrolysers. For transport, hydrogen powered vehicles are used where battery electric vehicles are not an option (e.g. long-distance light duty cars, coaches, trucks). Therefore, a new fuelling infrastructure is established to acquire high shares of hydrogen use.

The required demand for electric energy to operate the electrolysers is high. On the other hand, the gas grid is used to store excessive energy from the volatile renewable energy production.

2.2.4 Energy Scenario 4: Power-to-X (P2X)

Aside from the general measures described in section 2.2, in this scenario e-fuels are deployed in the energy sector, leading to increased e-fuel production on the supply side. E-fuels (e-gas and e-liquids) are synthetic fuels that are produced using hydrogen and carbon. Electrolysers are used to produce hydrogen, methanation plants for e-gas and various chemical routes for e-liquids (methanol route and Fischer-Tropsch process). E-gas is used for industry appliances and for heating of buildings while e-fuels replace fossil fuels in transport. The scenario is partially similar to the hydrogen scenario with the difference that hydrogen is used as an intermediate feedstock to produce e-fuels. While e-fuels largely share the chemical properties with fossil fuels, their production is energy intensive, because another transformation step is required after the production of hydrogen in electrolysers. For the transformation of hydrogen into e-fuels, carbon is needed. The carbon sources considered in this scenario are (the burning of) biomass and direct air capture (not

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well as an introduction of new policies is planned regarding the fields of circular economy, building renovation, biodiversity, farming and innovation. Also, new goals for renewable fuels in the transport sector have been set in the RED II legislation from 2018. Because the concretisation debate is ongoing, the specific effects for the industrial, transport and building sector is not clear yet. Therefore, the legislative stand of the study by the European Commission (2018) is remained for the business as usual scenario in this report.

[98] While “green” hydrogen is seen as the preferred option, “blue” hydrogen (hydrogen produced from natural gas with CCS) is also mentioned as an alternative if the constrains of CCS technology can be lifted.

considering the use of remaining fossil carbon airborne emission sources like lime, bricks, ceramics, clinker). The gas grid is used to provide a mixture of e-gas and biogas to the end users. For transport, e-liquid powered vehicles are used, where battery electric vehicles are difficult to deploy or require significant changes. Therefore, no change in the refuelling infrastructure is needed as for the hydrogen scenario. Since e-fuels are used for the transport sector, less biofuels are needed here, leaving the biomass capacities for heat, electricity and as a feedstock.

The required electricity demand for hydrogen generation and e-fuel transformation is even and substantially higher than in the hydrogen scenario. On the other hand, the gas grid also allows the storage of excessive energy from volatile renewable energy production.

2.2.5 Energy Scenario 5: Energy Efficiency (EE)

The main characteristic of EE scenario is the fostering of energy efficiency in buildings, industry and transport sector. The efficiency gains are the highest in buildings, achieved by strong improvements in energy performance through extensive and in-depth renovations, improvements in heating and cooling equipment and building automation. In the industry sector, high efficiency furnaces, technologies with low enthalpy heat uses and the use of waste heat recovery are fostered. For transport, the share of battery electric vehicles is very similar to the electrification scenario combined with a shift of transport modes (modal shift) towards waterborne freight transport and collective transport modes in urban areas.

2.2.6 Energy Scenario 6: Circular Economy (CIRC)

This scenario is characterised by a strong circularity in the industry, as well as (partly) in the transport sector. Hence, the scenario is similar to the energy efficiency scenario with the difference that the GHG savings aren’t only driven by energy savings, but rather by the general concept of resource and material efficiency. Main drivers are, inter alia, recycling and re-use, innovation in products and processes innovation, improved waste management or material substitution. In the industry sector, a high share of secondary materials leads to a lower demand of virgin materials, thereby reducing energy and carbon demand. While the primary industrial output is reduced, new processes are added to the value chain focussing on recycling and re-use and associated services. In the transport sector, shared mobility as well as mobility-as-a-service are deployed leading to smaller vehicle fleets with higher utilisation, higher occupancy rates and faster renewal rates. The circular approach leads to a shift from long-distance freight to near sourcing, combined with a shift in favour of rail and waterborne transport. Biomass supply that is not needed for the industry sector, is used for fuel production. In the energy sector, waste heat recovery is implemented in addition to the conversion of remaining waste material to heat, electricity or fuel. Furthermore, an improved collection system for organic waste is deployed together with biomass cascading to provide a feedstock to produce biogas. In general, the use of biomass in this scenario is higher than in the energy efficiency scenario where the share of electricity consumption is higher.

2.3 Scenarios for Food, Feed and Material Use

While for the energy sector, reliable and appropriate scenarios as a basis for future European carbon demand exist, this is not the case for the sectors food & feed and the material use of carbon-based substances.

A promising approach is provided in the study by Mathijs et al. (2015)[99], where a set of parameters is analysed to deploy explorative scenarios for European agriculture, forestry and fisheries. However, the parameters considered are based on values from 2015 or older

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[99] Mathijs, E., Brunori, G., Carus, M., Griffon, M., Last, L., Gill, M., Koljonen, T., Lehoczky, E., Olesen, I. and Potthast, A. 2015. Sustainable Agriculture. European Commission, (Ed.)

and do not cover the entirety of aspects considered in this report, since the material use of carbon-based resources is not covered by the study. Therefore, the parameters are updated, refined and expanded.

According to Börjeson et al. (2006)[100], there are different types of scenarios with different underlying research questions: predictive, normative and explorative. The first category of scenarios is used to predict future states of socio-economic systems, often with complex modelling. The second category is used for changes in baseline assumptions or parameters like new policy measures that influence the outcomes. The third category of scenarios is used in situations where a target is known and pathways to reach the target are to be examined. This category is useful to help develop the policy framework needed to foster a, e.g. energy efficient economy.

The approach to develop scenarios for the food, feed and material sector in this study borrows aspects from each of the scenario categories. The goal of the reduction of GHG emissions and a sustainable economy reflects a normative character of scenarios. Therefore, not all possible situations are determined but only trends that promise sustainability improvements are examined (e.g. carbon supply strongly based on fossil resources is out of scope). However, no goal has been set for the amount and origin of carbon used in the future of the European economy. Hence, the scenarios developed need to be explorative, so that they allow to derive knowledge regarding the sustainability of possible future states of carbon supply and demand within the European economy. Many parameters, trends and constraints influence the future European carbon demand and supply. Some of them are already analysed in a variety of studies and their future development has a low uncertainty. Therefore, some aspects of the scenarios have a predictive character. Generally, the scenarios developed are vehicles to gain insights and to help for decision-making by assessing them from a variety of perspectives. Therefore, the scenarios are:

- explorative (situations that are possible to happen),
- plausible (based on solid data and assumptions), and
- consistent (consistency with current targets, consistency between industrial sectors of supply and demand).

Next to the six energy scenarios, two more scenarios on food, feed and material use sectors are developed parallelly. Two different developments are examined that are characterised by the following general principles:

1. **Scenario I: Sufficiency (sufficiency-oriented consumption patterns)**
2. **Scenario II: Technology (strong technological improvements and acceptance)**

Sufficiency and Technology, reflecting two very different alternative futures regarding the socio-economic and technological developments. The material use includes the chemicals and plastics sector, construction and furniture, pulp and paper, and textiles sectors.

For the two scenarios, a number of parameters that influence the carbon demand are considered (see

and

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[100] Börjeson, L., Höjer, M., Dreborg, K.-H., Ekvall, T. and Finnveden, G. 2006. Scenario types and techniques: towards a user's guide. Futures, Vol. 38 (7), 723-739. doi: 10.1016/j.futures.2005.12.002

Table 15 for summaries). Each of the parameters are regarded individually. Depending on the parameter, the analysis is based on the current values, 2050 forecasts, or on the expected relative growth rates. Combined, the estimations for each parameter result in an estimation of the total carbon demand in 2050.

The following sections present description of the two scenarios on food, feed and material use, and the methodological approach to scenario development, including presentation of parameters and carbon supply.

2.3.1 Scenario I: Sufficiency Scenario for Food, Feed and Material Use

The transformation process in this scenario is driven by changes in preferences and consumer behaviour towards more environmentally friendly lifestyles.

In the agricultural sector, yields rise slightly due to moderate improvements in agricultural technologies (e.g. new breeds). Eating habits experience drastic change with a reduction of the consumption of meat and dairy products in general, and a rising share of vegetarian and vegan diets. The feed for the remaining livestock is partly produced from new protein sources that use insects or CO_2 (bacterial protein with CO_2 from the burning of biomass or remaining fossil emission point sources) as a carbon source. A strong demand for organic food leads to a rise in the corresponding production share, which is much more land extensive. Losses in the food production chain are reduced drastically due to a raised awareness of the stakeholders. The utilisation of the remaining food waste improves (e.g. for animal food or home composting). Those effects result in a moderate decrease of the carbon demand with the trend towards plant-based diets and moderate reduction of food waste as the main drivers.

In the material use sector, non-fossil material sources are well established due to the positive image regarding climate aspects. Plastics are partly replaced in favour of other materials owing to their negative reputation. While there is no significant growth in the chemicals and plastics sector, the circularity and recycling rate rises driven by consumer demands. The general change in values leads to a reduced demand of packaging materials and overall reduced consumption patterns. Those effects result in an unchanged demand for carbon compared to 2050 despite a slightly growing economy.

2.3.2 Scenario II: Technology Scenario for Food, Feed and Material Use

The transformation process in this scenario is driven by technology improvements and their appreciation by consumers and the general public.

In the agricultural sector, yields rise due to strong improvements in agricultural technologies (e.g. precision farming or gene editing). Eating habits experience moderate change with a slight reduction of the consumption of meat and dairy products in general, and a slightly rising share of vegetarian and vegan diets due to climate aspects of nutrition. Insects and CO_2 (bacterial protein) play an important role as protein sources for the remaining livestock as those technologies are regarded favourably. The demand for organic food rises moderately. Losses in the food production chain are reduced drastically due to new technologies (e.g. precision farming, urban farming) or new business models (e.g. meal kit shipping). The remaining food waste is extensively used with improved recycling technologies (e.g. microbial systems or electrochemistry). Those effects result in an even stronger decrease of the carbon demand than in the Sufficiency scenario with the strong reduction of food waste and the moderate trend towards plant-based diets as the main drivers.

In the material use sector, alternative material sources extensively replace fossil sources. With new production technologies, biomass, CO_2, and recycling provide feedstocks for high quality materials. The use of plastics increases in new appliances where their properties are technologically beneficial. Therefore, the growth in the chemicals and plastics sector continues. With new technologies (e.g. chemical recycling), the circularity and recycling rates rise. The demand for packaging decreases slightly due to digitalised services and improvements in logistics. On the other hand, the growth of the material use sector in general remains stable, leading to a significantly higher demand for carbon.

2.3.3 Parameters influencing the carbon demand for food and feed

In the following, the parameters influencing the carbon demand for food & feed sector are explained. A general explanation for each parameter is given, the sustainability implications for the parameters are depicted and the values determination of concrete values is explained. Consequently, the resulting carbon demand is stated.

The population growth rate in Europe is neglectable (+2% for 2050) according to the UN DESA's "medium projection"[101]. Hence, population growth is neglected for both scenarios.

Yield improvements in agricultural systems

Yield (also agriculture productivity) measures the amount of produced food, feed or wood per unit area of land. The yield depends on environmental parameters (e.g. climate and weather conditions, soil conditions, pest infestation) and manageable parameters (crop cultivated, irrigation, soil cultivation, use of pesticides and fertilisers).

A high yield is important for the supply of a growing global population with food, livestock with feed and the economy with feedstock. High yields implicate smaller areas used for cultivation or fewer imports. Measures to obtain high yields like monocultures can have negative implications for biodiversity, while lower yield cultivation methods like organic farming lead to a higher demand for agricultural area.[102]

In the "sufficiency" scenario, yields increase due to moderate technology improvements like new breeds (without gene editing). High increases in the "technology" scenario are realised with strong technologic improvements like precision farming or gene editing (e.g. CRISPR/Cas9).

Protein feed from alternative sources (CO_2 / insects)

Today, the consumption of animal-based protein (22 kg per EU citizen per year) exceeds the consumption of plant-based protein (16 kg).[103] Both the global livestock and fish production have a significant impact on the environment being responsible for 12% of the greenhouse gas emissions and 30% of the terrestrial biodiversity loss.[104]

Alternative protein sources like insect meal, microbial-derived single-cell protein, microalgae, and protein hydrolysates are coming into focus.[105] New focus areas can also be identified for food protein sources in the field of plant-derived proteins, insects, algae, and muscle protein sources from stem cell-based in vitro fish and meat production[106]. Studies find advantages of insect-based protein in higher feed-efficiency, lower GHG

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[101] UN DESA 2019. World Population Prospects 2019. United Nations. Department of Economic and Social Affairs.

[102] zur Strassen, T., Scharf, A., Carus, G., Carus, M.. (2020). nova-Paper #14: Are new food and biomass technologies more sustainable?. nova-Institut (Ed.). Hürth, Germany, see http://bio-based.eu/nova-papers/#novapaper14

[103] FAOSTAT Food Supply - Crops Primary Equivalent (2018), see:http://www.fao.org/faostat/en/#data/CC

[104] Westhoek, H., Rood, T., van den Berg, M., Janse, J., Nijdam, D., Reudink, M. and Stehfest, E. 2011. The Protein Puzzle - The consumption and production of meat, dairy and fish in the European Union. PBL Netherlands Environmental Assessment Agency (Ed.), The Hague, The Netherlands, 2011.

[105] Kim, S. W., Less, J. F., Wang, L., Yan, T., Kiron, V., Kaushik, S. J. and Lei, X. G. 2019. Meeting Global Feed Protein Demand: Challenge, Opportunity, and Strategy. Annual Review of Animal Biosciences, Vol. 7 (1), 221-243. doi: 10.1146/annurev-animal-030117-014838

[106] Henchion, M., Hayes, M., Mullen, A. M., Fenelon, M. and Tiwari, B. 2017. Future Protein Supply and Demand: Strategies and Factors Influencing a Sustainable Equilibrium. Foods, Vol. 6 (7), doi: 10.3390/foods6070053

emissions, water demand and land use compared to conventional animal-based protein with disadvantages in high energy demand[107].

In the "technology" due to technological maturity and a good acceptance of those sources. In the "sufficiency" scenario, alternative protein sources provide a relatively high share of dietary protein due to technological maturity and a good acceptance of those sources. In the "sufficiency" scenario, scepticism towards novel protein sources prevents a broader market penetration of alternative protein sources.

Vegetarian / vegan diets

Today, the share of Europeans describing themselves as vegetarians / vegans is between 2 and 10%.[108]

Livestock farming requires significant inputs of feed, energy and water. At the same time, it generates emissions like methane, ammonia and other pollutants, resulting in various environmental problems. Crops use 23% of the world's agricultural land but provide 82% of the calories and 63% of the proteins and are therefore much more area efficient than livestock.[109]

In the "technology" scenario, vegetarian / vegan diets have a moderate increase due to technological improvements in plant-based food production and broad acceptance of those technologies. In the "sufficiency" scenario, increasing awareness of environmental impacts of excessive agricultural production contributes to a shift towards a more, or even exclusively plant-based diets.

Consumption of meat and dairy products

This parameter is closely related to the parameters "vegetarian / vegan diets". An increased share of plant-based diets reduces the demand for meat and dairy products.

Organic food production

Organic food production describes a farming system which aims at sustaining healthy soils and ecosystems by using various agricultural principles like crop protection, green manure and biological pest control, by prohibiting the use of synthetic fertilisers and pesticides as well as by emphasising animal welfare in livestock production.

It is a common misconception that organic food production has less or even generally beneficial environmental impacts compared to conventional farming systems. Organic livestock production tends to have higher GHG emissions, acidification potential as well as land- and energy use per kg produced than the conventional production[110]. The transformation to exclusively organic could harm biodiversity and raise emissions due to lower yields in organic farming which cause emissions from land use changes.

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[107] zur Strassen, T., Scharf, A., Carus, G., Carus, M.. (2020). nova-Paper #14: Are new food and biomass technologies more sustainable?. nova-Institut (Ed.). Hürth, Germany, see http://bio-based.eu/nova-papers/#novapaper14

[108] Chemnitz, C. and Becheva, S. 2014. Meat atlas: Facts and figures about the animals we eat.

[109] Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. Science, 360(6392), 987-992.

[110] zur Strassen, T., Scharf, A., Carus, G., Carus, M.. (2020). nova-Paper #14: Are new food and biomass technologies more sustainable?. nova-Institut (Ed.). Hürth, Germany, see http://bio-based.eu/nova-papers/#novapaper14

Nevertheless, a smart combination of conventional and organic food production promises environmental benefits.[111]

In the "sufficiency" scenario, the demand for organic food increases due to the good reputation of organic food production and concerns about animal welfare. In the "technology" scenario, the demand for organic food increases moderately. Organic food is produced with the help of improved agricultural technologies (e.g. precision farming) and closely combined with conventional food production to foster environmental benefits.

Losses in the food production chain

Food losses refer to the decrease in edible food mass and food quality throughout the food supply chain before reaching the final stage (end consumer). The loss of food takes place at production, post-harvest and processing stages in the food supply chain. According to the EU, production and processing sectors contribute about 30% of food losses in the EU.[112]

The environmental impacts of food losses are diverse. FAO states that food losses' carbon footprint is estimated at 3.3 billion tonnes of CO_2eq. The total volume of water used each year to produce lost food is equal to the annual water flow of Russians Volga river (250 km^3). Further 28% of the world's agricultural area is used to produce food that is lost eventually. It also should be noted that agriculture is responsible for a majority of threats to serval plant and animal species[113]. Overall, reducing food loss would provide less GHG emissions, less pressure on the environment as well as increased productivity and economic growth. This would also lead to a decreased demand for carbon in the food sector.

In both scenarios, a reduction in food losses of 50% is assumed. Efficient new harvesting technology, refrigerated storage and improved transport allow for a reduction of food losses. Those logistic technologies rely on strong improvements in digitalisation and the use of Big Data. In the "technology" scenario, those technological opportunities lead to an intensive reduction of food losses while in the "sufficiency" scenario, not all technological options are utilised but the reduction is supported by raised awareness on the consumer side.

Utilisation of food waste

Worldwide, around 30% of the food production is wasted.[114]

The biomass flow from food waste could be used for recycling to create new raw materials or recover energy if treated properly. However, there are conflicting targets, a reduction of food waste and losses reduces the available biomass for recycling. Therefore, the Waste Framework Directive prefers prevention over recycling and recovering.

In both scenarios there's an increase of the utilisation rate for food waste with a higher utilisation rate in the "technology" scenario due to further improved bio-waste utilisation

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[111] Smith, L.G., Kirk, G.J.D., Jones, P.J. et al. The greenhouse gas impacts of converting food production in England and Wales to organic methods. Nat Commun 10, 4641 (2019). https://doi.org/10.1038/s41467-019-12622-7

[112] Stenmarck, Â., Jensen, C., Quested, T., Moates, G., Buksti, M., Cseh, B., ... & Östergren, K. (2016). Estimates of European food waste levels. IVL Swedish Environmental Research Institute, see http://www.eu-fusions.org/phocadownload/Publications/Estimates%20of%20European%20food%20waste%20levels.pdf

[113] Food and Agriculture Organisation of the United Nations. (2013). Food wastage footprint: Impacts on natural resources, see http://www.fao.org/news/story/pt/item/196402/icode

27 Piotrowski, S., Essel, R., Carus, M., Dammer, L. and Engel, L. 2015. Nachhaltig nutzbare Potenziale für Biokraftstoffe in Nutzungskonkurrenz zur Lebens- und Futtermittelproduktion, Bioenergie sowie zur stofflichen Nutzung in Deutschland, Europa und der Welt. nova-Institut (Ed.), Hürth, Germany, 2015-08. See http://bio-based.eu/markets/#Biomassepotenziale

technologies and higher public acceptance of biotechnological solutions (e.g. based on GMO).

Table 14 summarises the parameters explained above. With regard to the individual parameters, the overall carbon demand of the food and feed sector is estimated. Furthermore, the shares of food and feed on the carbon demand is determined. In the "sufficiency" scenario the carbon demand for food and feed declines by –20%, mostly determined by the strong increasement of plant-based diets. Therefore, the distribution of carbon demand for food and feed drops from 24%/76% today to 50%/50% in 2050. In the "technology" scenario the carbon demand for food and feed decreases even further by –30% compared to today. The main drivers for this development are the moderate increase of plant-based diets together with strong efficiency gains in yields, harvesting and logistics and the reduction of losses in the food production chain. Due to the moderate increase the distribution of carbon between food and feed is 30%/70%

Table 14. Parameters influencing the carbon demand in the food and feed sector for the scenarios Sufficiency and Technology, 2050, compared to 2018 values

Parameter	"Sufficiency" 2050	"Technology" 2050	Background information
Yield improvements in agricultural systems	+10%*	+30%*	Increased yields expected as a result of technology progress[115]
Protein feed from alternative sources (CO_2 / insects)	10%†	20%†	Growth rates in accordance with scenarios by IPIFF (2019)[116]
Vegetarian / vegan diets	+300%*	+150%*	2014: 2-10% in the EU[117]
Consumption of meat and dairy products	-30%*	-20%*	prognosis for 2030: -2%[118]; Impacts of stronger reduction depicted by Santini et al. (2017)[119]
Organic food production	30%†	20%†	Area share in the EU-27 2018: 8,0%[120]; Green Deal target: 25%
Losses in the food production chain	-50%*	-50%*	2011, 18% of EU-27 food & feed production was wasted, 50% reduction examined by Piotrowski et al. (2015)[121]; Drivers in "Sufficiency": Awareness raise, Sharing culture; Drivers in "Technology": Precision agriculture, meal-kit shipping
Utilisation of food waste	50%†	80%†	Current utilisation rate underlies a high uncertainty due to conflicting definition approaches[122]

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[115] FAO 2018. The future of food and agriculture - Alternative pathways to 2050. Food and Agriculture Organisation of the United Nations Rome (Ed.), see http://www.fao.org/3/CA1553EN/ca1553en.pdf

[116] International Platform of Insects for Food and Feed (IPIFF) 2019. The European insect sector today: Challenges, opportunities and regulatory landscape -

IPIFF vision paper on the future of the insect sector towards 2030. (Ed.), see https://ipiff.org/wp-content/uploads/2019/12/2019IPIFF_VisionPaper_updated.pdf

[117] Chemnitz, C. and Becheva, S. 2014. Meat atlas: Facts and figures about the animals we eat.

European Commission 2019a. EU Agricultural Outlook for markets and income 2019 - 2030. (Ed.), see https://ec.europa.eu/info/food-farming-fisheries/farming/facts-and-figures/markets/outlook/medium-term_en

[119] Santini, F., Ronzon, T., Perez Dominguez, I., Araujo Enciso, S. R. and Proietti, I. 2017. What if meat consumption would decrease more than expected in the high-income countries? Bio-based and Applied Economics Journal, Vol. 6 (1050-2018-3684), 37-56. doi: 10.22004/ag.econ.276285

[120] European Commission 2020b. Dashboard: Organic Production. (Ed.), see https://agridata.ec.europa.eu/Qlik_Downloads/Organic-Production-sources.htm

[121] Piotrowski, S., Essel, R., Carus, M., Dammer, L. and Engel, L. 2015. Nachhaltig nutzbare Potenziale für Biokraftstoffe in Nutzungskonkurrenz zur Lebens- und Futtermittelproduktion, Bioenergie sowie zur stofflichen Nutzung in Deutschland, Europa und der Welt. nova-Institut (Ed.), Hürth, Germany, 2015-08. See http://bio-based.eu/markets/#Biomassepotenziale

[122] Corrado, S. and Sala, S. 2018. Food waste accounting along global and European food supply chains: State of the art and outlook. Waste Management, Vol. 79 120-131. doi: 10.1016/j.wasman.2018.07.032

C Demand for Food & Feed	**-20%***	**-30%***	Estimation based on the parameters stated above
Share of C used for food / feed	50% food, 50% feed[†]	30% food, 70% feed[†]	Today: 24% food, 76% feed (see EU-27 carbon flows in work package 1). The extent of the increase of the share of C used for food instead of feed is mainly determined by the share of plant-based diets
* growth / reduction compared to 2020 † absolute share in 2050			

2.3.4 *Parameters influencing the carbon demand for material use*

Analogously as for food and feed, the parameters influencing the carbon demand for the material sector with special focus to the plastic and chemical sector are explained.

Chemicals and plastics based on biomass, CO_2, recycling

Currently, the predominant share of carbon used in the industry comes has a fossil origin. More than 90% of the carbon demand of the EU-27 industry sector (chemicals and plastics) is covered by fossil resources[123]. Direct emissions and the incineration of used products contribute to global warming, if carbon is sourced from the geosphere.

To mitigate climate change, the energy sector is being decarbonised with the use of renewable energy sources. For the chemical and material use, decarbonisation is not an option because organic chemistry fundamentally depends on carbon. Therefore, alternative sources of carbon are needed. The concept of renewable carbon includes carbon from biomass, from recycling and from CO_2 (carbon capture and utilisation (CCU) or direct air capture). Those carbon sources form a circular carbon flow and therefore don't contribute to global warming. A variety of parameters influence each of the sources of renewable carbon with different technological readiness, profitability and acceptance levels.

Current studies expect strong growth of bio-based polymers (CAGR of 3.5% worldwide until 2050124,125,126). In the "sufficiency" scenario bio-based as well as (conventionally) recycled products benefit from a good reputation due to their green image. The use of carbon from CO_2 as well as the use of chemical recycling technology is minor due to lacking public acceptance. In the "technology" scenario technological improvements and broad public acceptance lead to high shares of renewable carbon sources.

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[123] Porc, O., Hark, N., Carus, M., Dammer, L., Dr. Carrez, D. and BIC 2020: European Bioeconomy in Figures 2008–2017. nova-Institute (Ed.), September 2020, see https://biconsortium.eu/sites/biconsortium.eu/files/downloads/BIC%20%26%20nova-Institute%20-%20Bioeconomy%20in%20figures%202008-2017.pdf

[124] Chinthapalli, R., Skoczinski, P., Carus, M., Baltus, W., de Guzman, D., Käb, H., Raschka, A. and Ravenstijn, J. 2019: Bio-based Building Blocks and Polymers – Global Capacities, Production and Trends 2018–2023. nova-Institut (Ed.), Huerth, Germany, 2019-02, see http://bio-based.eu/reports

[125] European Bioplastics 2020: Bioplastics market data 2019 – Global production capacities 2019–2024. European Bioplastics (Ed.), 2020-02, see https://docs.european-bioplastics.org/publications/market_data/Report_Bioplastics_Market_Data_2019.pd

[126] Skoczinski, P., Chinthapalli, R., Carus, M., Baltus, W., de Guzman, D., Käb, H., Raschka, A. and Ravenstijn, J. 2020: Bio-based Building Blocks and Polymers – Global Capacities, Production and Trends 2019–2024. nova-Institut (Ed.), Hürth, Germany, 2020-01, see http://bio-based.eu/markets/#TRPolymerdata2020

Substitution of plastics with other materials

Plastics are synthetic materials with a wide range of properties. Therefore, they replaced other materials in a broad field of technical and everyday applications. The highest demand for plastics in the EU occurs for packaging (40%), building & construction (20%), and automotive (10%). Hence, substitution of plastics with other materials (or vice-versa) is possible, e.g. with glass or paper in the packaging sector or wood and mineral wool or wood fibres in the construction sector.

The broad range of properties make plastic beneficial for certain applications (e.g. their light weight and robustness is beneficial for packaging) while disadvantageous for others (e.g. littering from non-biodegradable plastics when disposed in nature). Therefore, the substitution of plastics with other materials is currently discussed in the public. Also, legislative measures are being implemented like the EU's single-use plastic ban. Environmental effects of the substitution of plastics with other materials strongly depend on the use case and on the properties and origins of the exchanged materials.

In the "sufficiency" scenario the public debate on the use of plastics continues and in some sectors plastics are replaced with other materials (single-use plastic articles in favour of paper bags or bamboo cutlery or fossil-based insulation material in favour of mineral wool or wood fibres). In the "technology" scenario, the benefits of plastics in certain use cases are appreciated publicly, resulting in even broader applications of plastics. The substitution only influences the overall carbon demand if the substituted materials have different carbon contents (e.g. paper bags contain carbon as well as plastic bags).

CAGR in the chemicals and plastics sector

The compound annual growth rate (CAGR) of the chemicals and plastics sector is foreseen to be around 1.5 to 2%[127] with even higher annual growth rates for the worldwide chemicals and plastics sector[128] and for certain sub-sectors of the European chemical and plastic sector.[129]

Developments in the European chemical and plastic sector have important implications for the sustainable sourcing and use of carbon, both regarding the type of carbon resources (fossil, bio-based, recycling or CO_2-based) and the overall demand.

In the "technology" scenario, the CAGR from past years remains stable leading to a prospering European chemicals and plastics sector. In the "sufficiency" scenario, public opinion leads and generally reduced consumption patterns (see below) lead to a decline of the CAGR which culminates in no growth for the chemicals and plastics sector in 2050.

Recycling and circularity rate

The circularity rate is an indicator for the share of material recovered and reused in an economy's overall material use. The current circular material use rate EU-27 is 11.9% (2019). The recycling rate is the share of waste that is recycled. The recycling rate 2018

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[127] Piotrowski et al., S. E., Roland; Carus, Michael; Dammer, Lara; Engel, Linda 2015: Nachhaltig nutzbare Potenziale für Biokraftstoffe in Nutzungskonkurrenz zur Lebens- und Futtermittelproduktion, Bioenergie sowie zur stofflichen Nutzung in Deutschland, Europa und der Welt". nova-Institut (Ed.), Hürth, 19.08.2015, see http://bio-based.eu/downloads/nachhaltig-nutzbare-potenziale-fuer-biokraftstoffe-in-nutzungskonkurrenz-zur-lebens-und-futtermittelproduktion-bioenergie-sowie-zur-stofflichen-nutzung-in-deutschland-europa-und-der-welt/

[128] Roland Berger 2015. Chemicals 2035 – Gearing up for Growth - How Europe's chemical industry can gain traction in a tougher world. Roland Berger Strategy Consultants GmbH (Ed.), Munich, Germany, see https://www.rolandberger.com/publications/publication_pdf/roland_berger_tab_chemicals_2035_20150521.pdf

[129] Rothermel, J. r. and Peters, D. 2019. Zwei Jahrzehnte stoffliche Nutzung nachwachsender Rohstoffe. Fraunhofer UMSICHT (Ed.), Oberhausen, Germany.

in the EU-27 is 56%.[130] The circularity rate is always lower than the recycling rate because not all materials end up as waste at the end of their lifecycle and are therefore counted as recyclable (e.g. fossil fuels burned or biomass for food and feed).

The circularity rate has an important impact on the resource supply of the economy and therefore on the sustainability. An extensive use of recycled materials reduces the need for the extraction of raw materials. In the case of carbon-based materials, it's especially important because the use of fossil-based resources results in an increase of atmospheric CO_2 concentration. Carbon from renewable sources can lead to greenhouse gas emissions but due to the circularity of renewable carbon flows doesn't contribute to climate change.[131]

Due to ambitious policy goals set in the European Green Deal and future legislation, the circularity rate increases strongly in both scenarios. In the "sufficiency" scenario this development is supported by a high demand of recycled products in the market. In the "technology" scenario, the increase of the circularity rate is driven by improvements in recycling technology (e.g. chemical recycling).

Demand for Packaging

Packaging is important for the transportation of goods for the protection, the conservation and labelling of products. Packaging waste is continuously growing and adds up to 174 kg per EU-citizen in 2018 mostly composed by paper & cardboard (41%), plastics (19%) and glass (19%).

The sourcing of the feedstock for packaging is a sustainability issue; single-use packaging has a short lifespan and produces waste and reusable packaging needs to be transported.

In both scenarios the overall demand for packaging decreases even though there are trends that foster the packaging demand like the increase of e-commerce. In the "sufficiency" scenario, the increase is driven by generally reduced consumption patterns (see below). In the "technology" scenario, the reduction of packaging demand is a result of efficiency gains along the value chain caused by digitalisation (improved logistics) and packaging technology (reusable packaging systems, material improvements).

Influence of consumer behaviour; change on consumption rates

Spending from consumers are the backbone of an economy beneath exports. Consumption patterns change only slowly and are depend on a large number of drivers. Economic growth was a main driver for improved human wellbeing in the OECD countries and still is in developing countries.

However, due, to the resource use entailed by economic growth those two need to be decoupled. For OECD countries this could mean refocussing from economic growth to quality of growth or de-growth.

In the "technology" scenario, consumption patterns are unchanged. In the "sufficiency" scenario, awareness changes lead to changes in general consumption patterns. Those patterns reduce spending of private households and reduce the overall growth rates of the economy.

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[130] Eurostat (2020): Material flows in the circular economy, see https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Material_flows_in_the_circular_economy#Sankey_diagram_of_material_flows

[131] Carus, M., Dammer, L., Raschka, A., Skoczinski, P., vom Berg, C.. (2020). nova-Paper #12: „Renewable Carbon – Key to a Sustainable and Future-Oriented Chemical and Plastic Industry". nova-Institut (Ed.). Hürth, Germany, see http://bio-based.eu/nova-papers/#novapaper12

Table 15 summarises the parameters explained above. With regard to the individual parameters, the overall carbon demand of the material use sector is estimated. In the "sufficiency" scenario the carbon demand for the material sector remains the same as today. The generally reduced consumption patterns terminate the growth in this sector. In the "technology" scenario, the growth rates remain stable at +2% per year leading to an overall growth of carbon demand of +80% in 2050 compared to 2018.

Table 15. Parameters influencing the carbon demand in the material use sector for the scenarios Sufficiency and Technology, 2050, compared to 2018 values.

Parameter	**"Sufficiency" 2050**	**"Technology" 2050**	**Background information**
chemicals and plastics based on biomass, CO_2, recycling	50%†	70%†	"Sufficiency": good reputation of biogenic materials "Technology": Improvement in production technologies; High CAGR expected for the near future (11.6 - 35%)[132,133]; Scenarios for bio-based share 2050 between 20% and 95%[134]
Substitution of plastics with other materials	+10%* (substitution of plastics with other materials)	-5%* (substitution of other materials with plastics)	"Sufficiency": negative image of plastics in the public "Technology": extended use of plastics; substitution of plastics with other carbon-based materials does not alter carbon demand. Scenario for European plastic production: CAGR 1.75%[135]
CAGR in the chemicals and plastics sector	±0%	+2% / yr	All scenarios from Mathijs et al. (2015)[136] assume a CAGR for European plastics & polymer sector of 1.5-2%; expected CAGR for some sub-sectors: +1.8%[137]; worldwide CAGR in the chemical sector 2011 – 2035: 3.6-4.2%[138]

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[132] Aeschelmann, F. and Carus, M. 2015. Bio-based building blocks and polymers in the world.

[133] Nexant, I. 2014. Renewable Chemicals & Materials Opportunity Assessment: Major Job Creation and Agricultural Sector Engine.

[134] Piotrowski, S., Essel, R., Carus, M., Dammer, L. and Engel, L. 2015. Nachhaltig nutzbare Potenziale für Biokraftstoffe in Nutzungskonkurrenz zur Lebens- und Futtermittelproduktion, Bioenergie sowie zur stofflichen Nutzung in Deutschland, Europa und der Welt. nova-Institut (Ed.), Hürth, Germany, 2015-08, see http://bio-based.eu/markets/#Biomassepotenziale

[135] Piotrowski, S., Essel, R., Carus, M., Dammer, L. and Engel, L. 2015. Nachhaltig nutzbare Potenziale für Biokraftstoffe in Nutzungskonkurrenz zur Lebens- und Futtermittelproduktion, Bioenergie sowie zur stofflichen Nutzung in Deutschland, Europa und der Welt. nova-Institut (Ed.), Hürth, Germany, 2015-08, see http://bio-based.eu/markets/#Biomassepotenziale

[136] Mathijs, E., Brunori, G., Carus, M., Griffon, M., Last, L., Gill, M., Koljonen, T., Lehoczky, E., Olesen, I. and Potthast, A. 2015. Sustainable Agriculture. European Commission (Ed.).

[137] Rothermel, J. r. and Peters, D. 2019. Zwei Jahrzehnte stoffliche Nutzung nachwachsender Rohstoffe. Fraunhofer UMSICHT (Ed.), Oberhausen, Germany.

[138] Roland Berger 2015. Chemicals 2035 – Gearing up for Growth - How Europe's chemical industry can gain traction in a tougher world. Roland Berger Strategy Consultants GmbH (Ed.), Munich, Germany, see

Recycling and circularity rate	50%†	50%†	Circular material use rate EU-27 11.9% (2019)[139]; EU Circular Economy Action Plan aims to double the rate[140]. "Sufficiency": driven by consumer demand "Technology": driven by recycling technology
Demand for Packaging	-20%*	-10%*	"Sufficiency": reduced consumption "Technology": efficiency gains
Influence of consumer behaviour change on consumption rates	-20%*	±0%	"Sufficiency": reduced growth rates in consumption of products "Technology": unchanged growth rates in consumption
C Demand for Material Use	±0%	**+2% / yr,** according absolute growth until 2050: **+80%***	Estimation based on the parameters stated above
* growth / reduction compared to 2020 † absolute share in 2050			

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https://www.rolandberger.com/publications/publication_pdf/roland_berger_tab_chemicals_2035_20150521.pdf

[139] Eurostat 2019. Circular material use rate, see https://ec.europa.eu/eurostat/databrowser/bookmark/c70b9a3a-30f1-4c72-b654-76662d32b9fe?lang=en

[140] European Commission 2020a. Questions and Answers: A New Circular Economy Action Plan for a Cleaner and More Competitive Europe. Brussels, Belgium, see https://ec.europa.eu/commission/presscorner/detail/en/QANDA_20_419

2.3.5 *Carbon supply for food, feed and material use*

The scenarios for the energy sector that are based on the European Commission (2018) study[141] already include elements of the required carbon supply. Biogas requires biomass as feedstock, remaining fossil fuels in the transport sector require fossil resources, etc.

For food and feed all carbon is assumed to come from biomass. By contrast, the composition of the carbon supply for the corresponding demand in the material use sector is covered by different sources and varies between the two scenarios depicted. Therefore, the scenarios not only determine the overall carbon demand for the material sector but also the composition of the carbon supply for the chemical and plastic sectors. For the other parts of the material use sector (construction and furniture, pulp and paper, and textiles) the composition remains unchanged due to the fact that the major proportion of organic carbon compounds are biogenic and no changes are expected here.

In the "sufficiency" scenario, the supply for plastics and chemicals is met with a moderately high share of biogenic sources and a large share of fossil sources due to a latent rejection of alternatives like the use of CO_2. In the "technology" scenario, the corresponding supply for plastics and chemicals is met with a moderately high share of biogenic sources and large shares of recycling and CO_2-based materials. Fossil sources play minor role, in cases where no alternatives exist.

The estimated composition of the carbon supply for plastics and chemicals in the two scenarios is presented in Table 16. The absolute carbon supply matches the demand for the material sector previously estimated.

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[141] European Commission 2018. A Clean Planet for all–A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. (Ed.), Download at https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

Table 16. Composition of the carbon supply for the material use sector for the scenarios Sufficiency and Technology, in 2050, compared to 2018 values

Carbon Source	"Sufficiency" 2050	"Technology" 2050
Biomass	10%	12%
Recycling	35%	42%
CO_2	5%	16%
Fossil	50%	30%

2.4 Carbon demand and supply for the energy scenarios

The transformation in the energy sector described in scenarios 1 to 6 and the partial phase-out of fossil fuel influences the carbon demand of the energy sector both in the overall demand as well as in the source of carbon required. Therefore, the consequences of the scenarios for the carbon supply are assessed in the following section.

To calculate the carbon demand, the type and amount of primary energy carriers is needed. As described in work package 1, the data provided in the EC (2018)[141] study is corrected by the UK's energy consumption to correspond to the EU-27 situation. The energy supply is depicted in Figure 32.

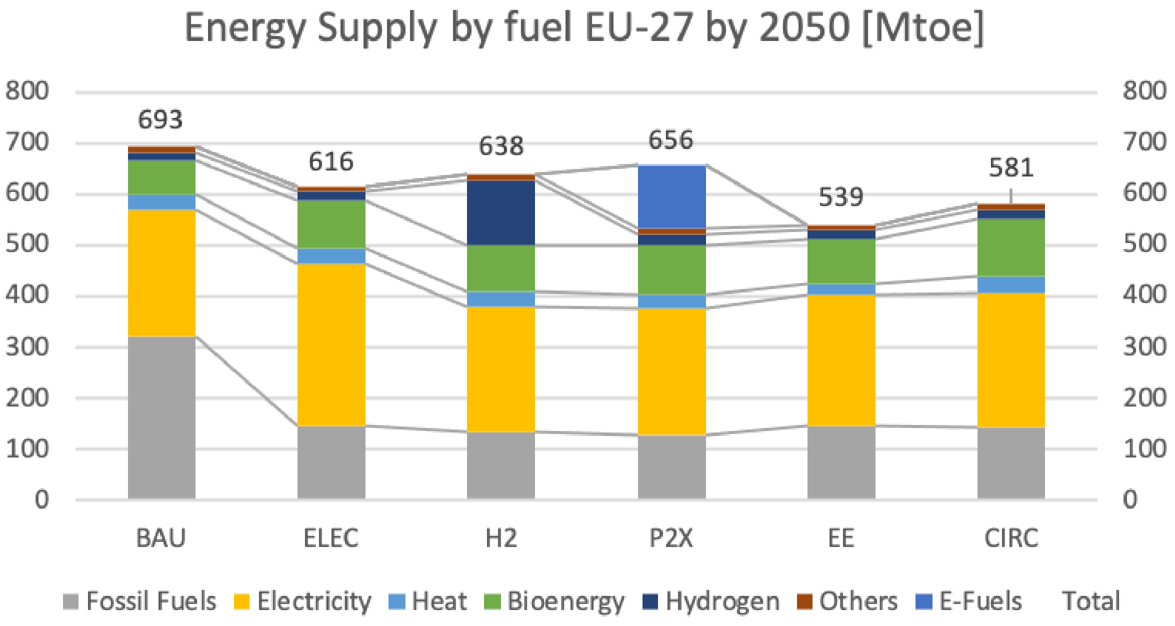

Figure 32. Annual energy supply by fuel by 2050 for scenarios according to European Commission (2018)[141].

To determine the carbon demand for each the scenario, the energy carriers that require carbon are further considered and the respective material demand is calculated. The heating value of fossil fuels are used to calculate the amount of fossil fuels in each scenario (oil, gas and coal considered individually). Electricity from wind, solar or hydro power as well as geothermal or nuclear energy ("others") cause no streams of carbon-based material and is therefore not further considered. The average heating value of bioenergy is used to determine the required biomass flows. The direct use of hydrogen also doesn't cause any carbon streams and is therefore not further considered. In the production process of E-Fuels hydrogen and carbon is required. Therefore, the heating values of E-Fuels (E-Liquids and E-Gas considered individually) is used to calculate the required amount of E-Fuels. The heat used in the scenarios is a side-product of the energy production from fossil fuels or biomass and is therefore not further considered to prevent double-counting.

The amounts of carbon-based resources are multiplied by their carbon content as described in work package 1. The results are shown in Figure 33 together with values for 2018 as derived from work package 1.

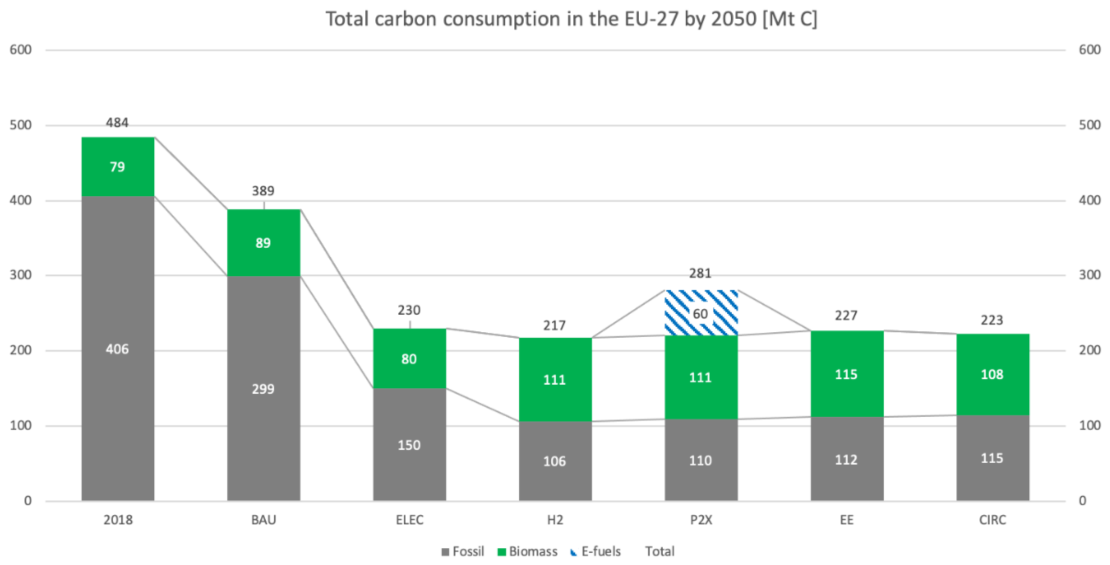

Figure 33. Annual carbon demand in the EU-27 energy sector by 2050 and 2018 for comparison, separated by carbon source. Carbon required to produce E-Fuels separately highlighted. (own calculation based on European Comission, 2018[141])

The carbon demand in the energy sector for all 2050 scenarios is significantly lower compared to the current carbon demand (2018). The BAU scenario has the highest share of fossil carbon and the highest demand for fossil carbon of all scenarios. The lowest total carbon demand shows the H2 scenario with only 45% compared to today. Apart from the BAU the P2X scenario has the highest total carbon demand, when carbon (from CO_2, as depicted in the scenario description) required to synthesize E-Fuels is included. This carbon demand can be sourced by using exhaust fumes from fossil or biomass power plants (CCU) or with carbon from the atmosphere (direct air capture) and therefore doesn’t put additional pressure on fossil or bio-based resources. Apart from the BAU scenario, the highest share of fossil-based carbon is used in the ELEC scenario (65%). The highest share of bio-based carbon is used in the H2 and the EE scenario (51%).

To get further insights, the carbon demand can be divided between the sectors industry, transport and residential. The results are shown in Figure 34.

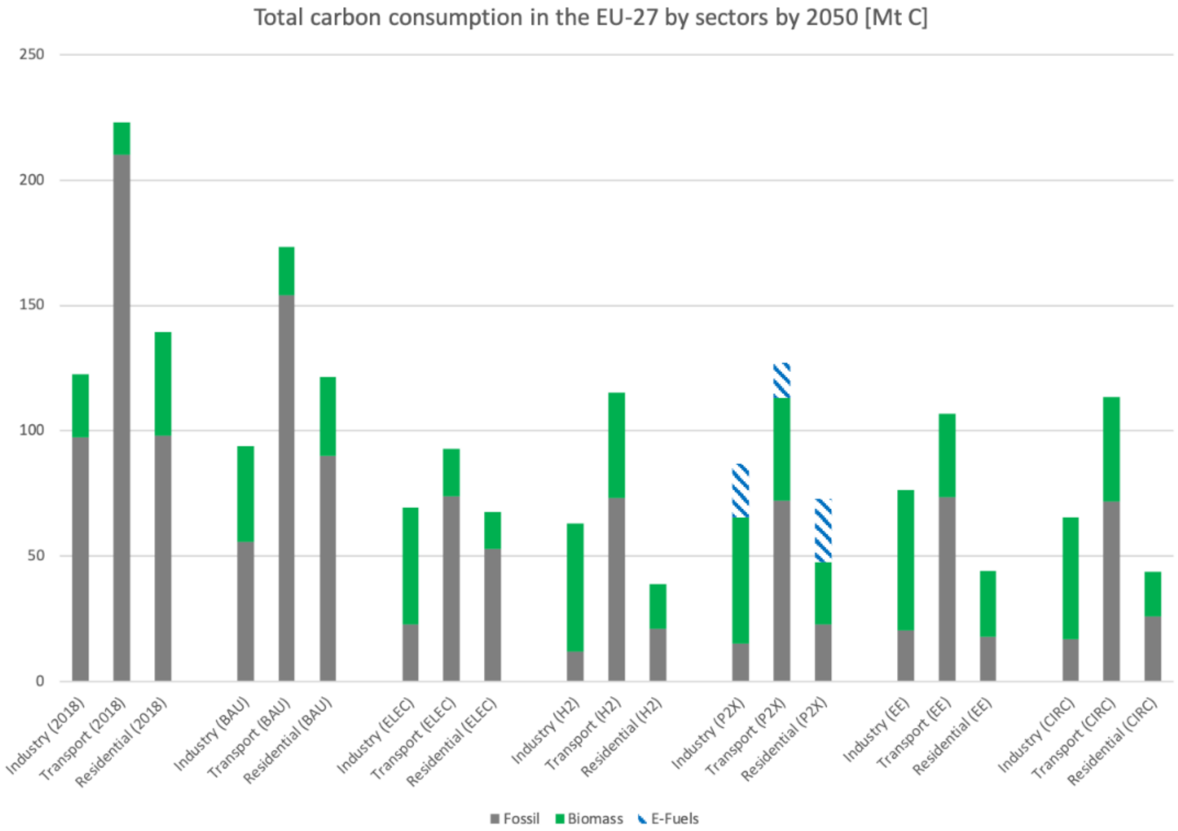

Figure 34. Carbon demand for energetic resources by sector 2018 and by 2050 (own calculations based on European Commission, 2018[141]).

The carbon supply is directly derived by the types of fuel described in the scenarios. The burning of oil, gas and coal and the use of gasoline uses fossil resources, the burning of biomass or the synthesis of biofuels require biomass as resource.

2.5 Carbon demand and supply for the food, feed and material scenarios

To determine the carbon demand for the food and feed sector, the data base created in work package 1 is used as a reference point. From here, the development of the overall carbon demand for both scenarios Sufficiency and Technology as explained above are used to determine the carbon demand for both scenarios in 2050. The results are shown in Figure 35.

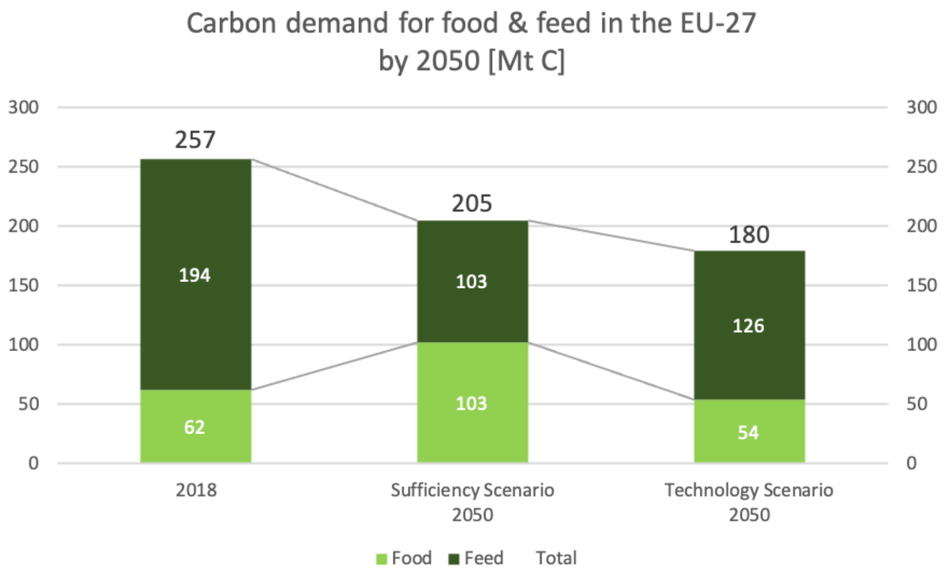

Figure 35. Annual carbon demand for the food and feed sector 2018 and by 2050 (own compilation)

As determined in the scenario descriptions above, the carbon demand decreases in both scenarios with a stronger decrease in the Technology scenario. The distribution of carbon in the food and feed (2018: 24%/76%, see work package 1) changes moderately in the Technology scenario to 30%/70% but drastically in the Sufficiency scenario to 50%/50%.

To determine the carbon demand in the material sector, the chemical and plastic sector are considered separately from the other sectors. For the former, the carbon supply is dominated by fossil carbon sources and is therefore expected to be changed. The composition of carbon supply for these sectors is determined in the scenario description above, see Table 16 The total carbon demand for the chemical and plastic sector follows the general developments described in Table 15. The carbon demand for chemicals and materials is shown in Figure 36.

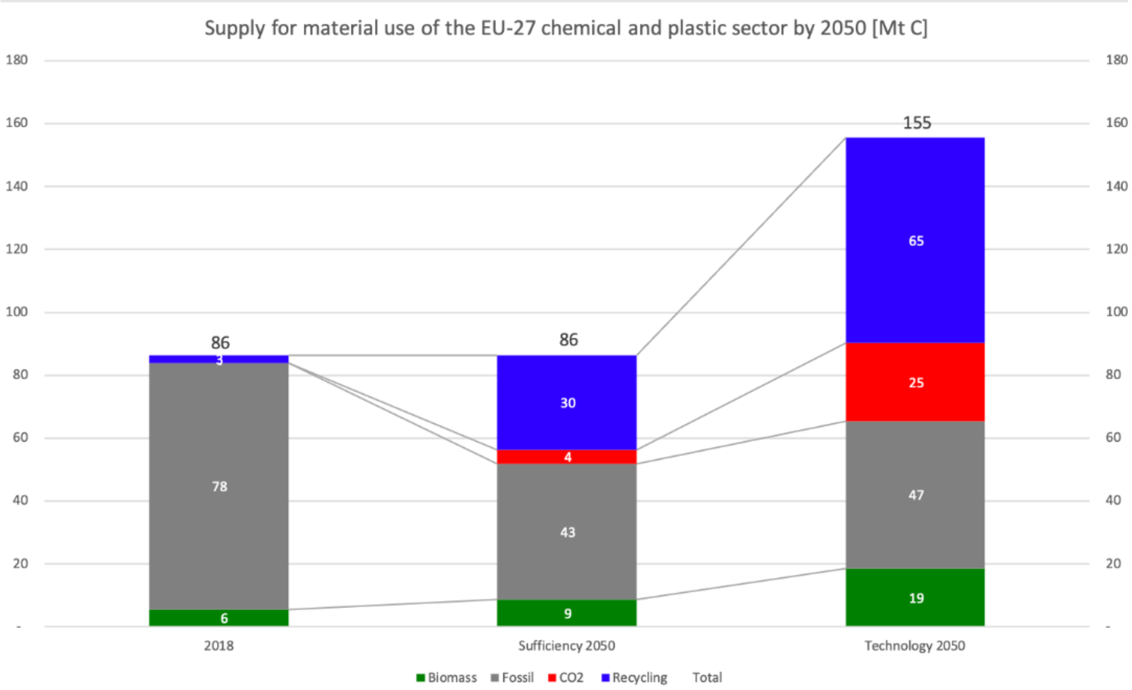

Figure 36. Carbon demand and supply for the EU-27 chemical and plastic sector 2018 and by 2050 (own compilation).

The supply of carbon from fossil resources declines in both scenarios. As depicted in the energy scenarios, fossils fuels still play an important role as feedstock supplying carbon for materials that cannot be produced from alternative sources (50% in the Sufficiency scenario, 30% in the Technology scenario). Instead, the role of recycling gains importance (3% today, see work package 1), supplying 35% of carbon in the Sufficiency scenario and 42% in the Technology scenario. The usage of carbon sourced from CO_2 (CCU or direct air capture) doesn’t play a role today but supplies 5% of the carbon in the Sufficiency scenario and 16% in the Technology scenario. The carbon supply from biomass also grows from 6% today to 10% in the 10% in the Sufficiency scenario and 12% in the Technology scenario.

For other parts of the material sector apart from the chemical and plastic sector (construction and furniture, pulp and paper, and textiles) the source of organic carbon compounds is mostly biogenic. Therefore, no changes in the composition are expected. However, the total carbon demand in these sectors follows the general developments determined within the scenarios. The total carbon demand and its composition is shown in Figure 36 as the sum of the demand for plastics and chemicals with the demand for construction and furniture, pulp and paper, and textiles.

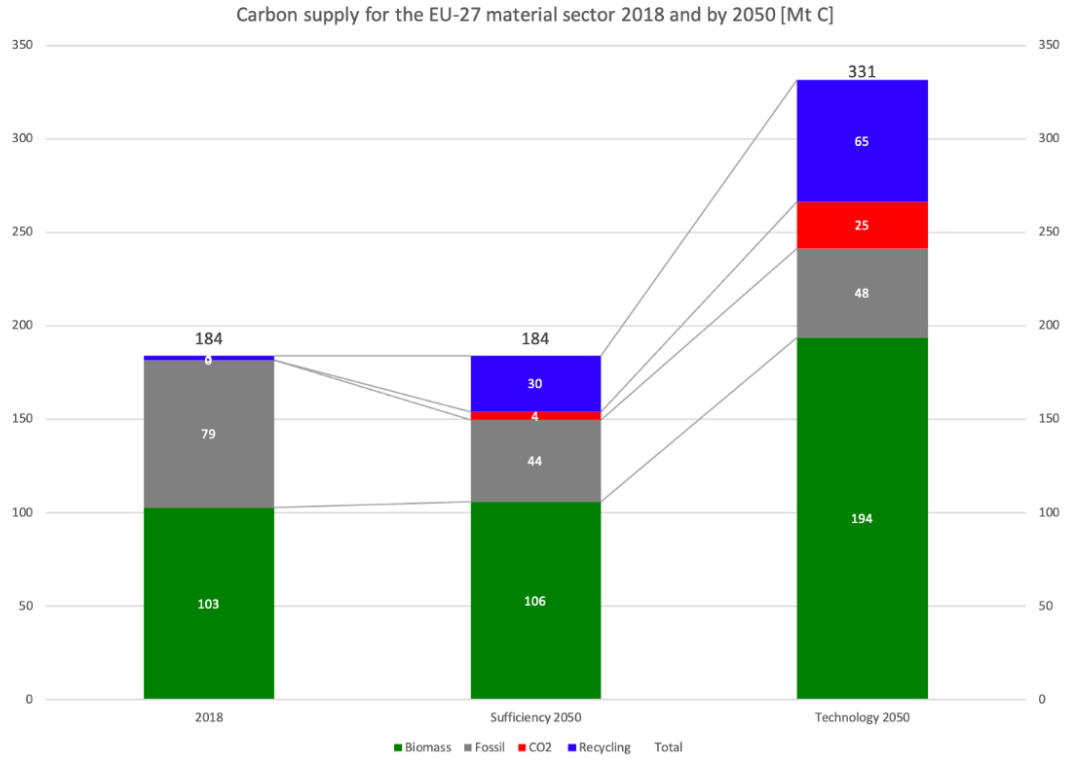

Figure 37. Carbon supply for the EU-27 chemicals and materials in 2018 and by 2050 (own compilation).

The carbon demand and supply for the material sector shows that the majority of carbon today is biogenic (55% today) and will be in both 2050 scenarios (57% in the Sufficiency scenario, 58% in the Technology scenario). The share of fossil carbon supply decreases from 42% today to 24% in the Sufficiency scenario and 14% in the Technology scenario. The main driver for this development is the substitution of fossil resources with alternative sources for carbon in the chemicals and plastics sector.

To determine the total carbon demand for both scenarios the carbon demand for food and feed is added to the one of the material sector, see Figure 38.

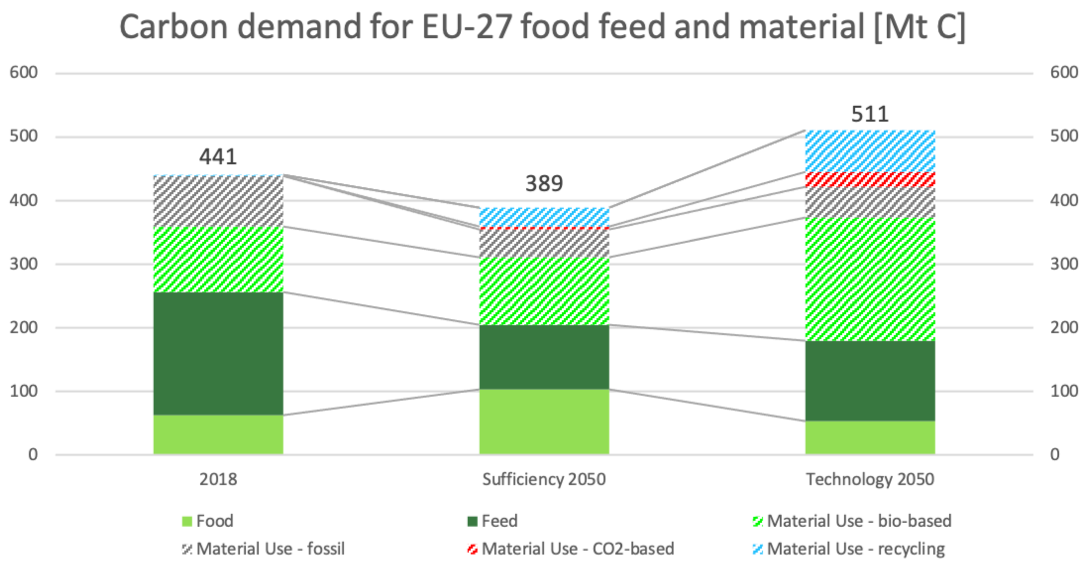

Figure 38. Carbon demand for food, feed and material in EU-27 2018 and by 2050 for both scenarios (own compilation)

In the Sufficiency scenario, the overall carbon demand is reduced by 12% compared to 2018. Since the demand for material use remains unchanged, the decrease is caused by the changes in the food and feed sector. In the Technology scenario, the total carbon demand increases by 16% compared to 2018. Even though the demand of the food and feed sector decreases, the savings are exceeded by the growth of the demand for the material sector.

3 Sustainability considerations of the scenarios

This section presents considerations regarding the sustainability of the analysed scenarios. Due to the different nature of the scenarios, this chapter is organised in two sections. The first section presents sustainability considerations related to the energy scenarios. Given the data availability, this section allows for a quantitative comparison of the scenarios. The second section presents rather qualitative considerations related to the food, feed and material use scenarios. As there is a lack of data on the Sufficiency and Technology scenarios, the following section presents qualitative considerations regarding the sustainability aspects of the scenarios.

3.1 Sustainability considerations of the energy scenarios

The assessment of the energy scenarios is based on the commonly used indicators of the energy sustainability. Specifically, the following indicators are analysed (for the overview of the literature on the commonly used indicators of energy sustainability see Appendix 3):

- share of renewable energy in the final energy consumption (%),
- primary energy consumption (TOE),
- final energy consumption (TOE),
- energy related GHG emissions (index 2000=100),
- energy productivity (EUR/Mtoe),
- land use, and LULUCF ($MtCO_2$).

The energy scenarios that are analysed in the context of this study were developed and defined in the EC report (2018)[141]. The report includes predictions on number of indicators, including energy efficiency indicators (PEC and FEC), share of renewable energy, GHG emissions, energy productivity and LULUCF emissions. This allows for the abovementioned indicators to be quantitatively analysed within this section. Furthermore, the report outlines composition of the LULUCF emissions, including total forest land, forest management, afforestation, deforestation, cropland, grassland, harvested wood products and other. This provided an opportunity for development of a simplified indicator on land use sustainability. The indicator combines indicators on forest sustainability and agricultural sustainability and is based on the LULUCF related emissions.

For the purpose of this analysis, the two indicators are defined as:

1. **Forest sustainability:** An indicator combining LULUCF emissions from forest (+), afforestation (+), harvested wood products (+) and deforestation (-). The scenario with the highest forest sustainability indicator is considered the most sustainable.

2. **Agricultural sustainability:** An indicator combining LULUCF emissions from cropland (+) and LULUCF emissions from grassland (+). The scenario with lowest value of the agricultural sustainability scenario is the most sustainable.

Energy related GHG emissions

Reduction of GHG emissions (excluding LULUCF) is assumed to be 80% by 2050 in each of the energy scenarios. Thus, this indicator will not have impact on the ranking.

Energy efficiency

Energy efficiency has been duly considered in all scenarios. BAU itself assumes significant reductions of energy consumption, including a reduction of 26% by 2030, and a reduction of 35% by 2050. The most ambitious in terms of energy efficiency is energy efficiency scenario, assuming 50% reduction compared to 2005 values of primary energy consumption, and 44% reduction of final energy consumption by 2050. On the other hand, the P2X scenario that is based on extensive use of e-fuels, requires large amounts of electricity. In that case, the reduction in primary energy consumption in 2050 is only -22% compared to 2005, which is worse than the -35% achieved in the BaU scenario. The complete overview is presented in the table and figures below.

Table 17. Changes in primary and final energy consumption 2050 compared to 2005, Source: European Commission (2018)[141]

Scenario	Changes in primary energy consumption in 2050 (%)	Changes in final energy consumption in 2050 (%)
EE	-50%	-44%
CIRC	-45%	-38%
ELEC	-40%	-35%
H2	-36%	-32%
BAU	**-35%**	**-26%**
P2X	-22%	-30%

Figure 39. Changes in primary energy consumption 2050 compared to 2005, Source: European Commission (2018) [141]

Figure 40. Changes in sectoral final energy consumption 2050 compared to 2005, Source: European Commission (2018)[141]

Share of renewable energy in the gross inland energy consumption

The scenarios also predict a strong uptake of renewable energy sources on the market. Overall, the scenarios assume that the share of renewable energy sources will be around 50% by 2050 (see the table below). However, it is worth noting that the percentage change refers to different RES volumes. This is partly explained by different energy efficiency ambition, and hence lower expected consumption volumes. For example, EE scenario, with strong energy efficiency ambition, predicts significantly lower amount of RES as compared to P2X scenario, whose ambition in terms of reduction in energy consumption was significantly lower. The difference in RES share in the energy mix differs only by 1,2%, while corresponding amount is nearly 45% higher. In line with the literature reviewed (see section Table 18, this study considers the share of the renewable energy in the energy mix as an indicator of sustainability.

Table 18. Renewable energy sources in the gross inland final energy consumption in 2050, Source: European Commission (2018)[141]

Scenario	Share of renewable energy sources in the gross inland final energy consumption in 2050 (%)	Renewable energy consumption in 2050 (Mtoe)
H2	54,5%	666
CIRC	53,7%	567,1
ELEC	53%	611,6
P2X	51,7%	762,6
EE	50,5%	496,4
BAU	**36%**	451,8

LULUCF emissions

Substantial use of woody energy crops that is reflected in all the scenarios, is expected to contribute to the maintaining of a net LULUCF sink above 230 $MtCO_2$ across the scenarios. The differences across the scenarios are caused by different economic activities including improved agricultural practices storing soil carbon, afforestation, reduced deforestation and improved forest management[141]. With a decrease of 292 $MtCO_2$, CIRC scenario is expected to have the most significant impact on the LULUCF emissions. This could be partly attributed to the higher rates of recycling, material substitution and circular measures and partly to the improved forest management and afforestation efforts. CIRC scenario is followed by the P2X scenario. The comparatively high impact of the P2X scenario on the LULUCF sink could be possibly explained by high CCS capacity.

On the other hand, the least impact on LULUCF entails ELEC scenario with a decrease of net LULUCF of 238 $MtCO_2$. See the table and figure below.

Table 19. LULUCF emissions 2050, Source: European Commission (2018)[141]

Scenario	LULUCF emissions ($MtCO_2$)
CIRC	-292
P2X	-263
H2	-244
EE	-241
ELEC	-238
BAU	**-236**

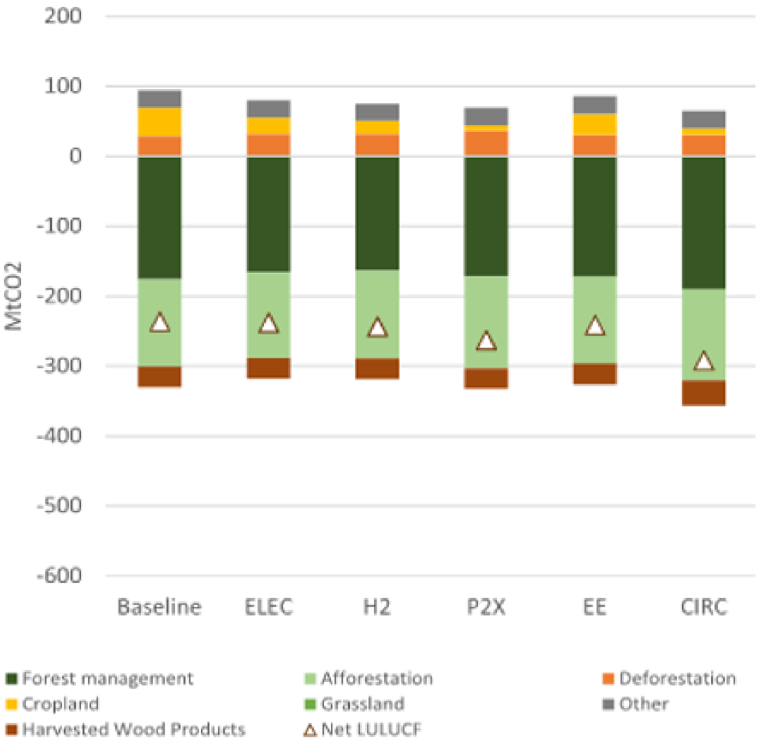

Figure 41. LULUCF emissions across the energy scenarios, 2050, Source: European Commission (2018)[141]

Land use sustainability

The simplified and illustrative land use sustainability indicator, that was developed based on the available data, is composed of forest sustainability indicator and agricultural sustainability indicators. The forest sustainability indicator combines LULUCF emissions from forests, afforestation, harvested wood products and deforestation. The values of the forest sustainability indicator are included in the table below. With the expected reduction of 429 $MtCO_2$, the CIRC scenario is expected to entail the largest reduction of the related LULUCF emissions.

Table 20. Forest sustainability indicator, $MtCO_2$. Own calculations

Scenario	Forest	Afforestation	Harvested wood products	Deforestation	Forest sustainability
P2X	-267	-132	-29	37	-391
H2	-257	-125	-29	32	-379
ELEC	-256	-122	-30	32	-376
EE	-266	-124	-30	30	-390
CIRC	-290	-130	-36	30	-426
BAU	**-271**	**-124**	**-29**	**29**	**-395**

The agricultural sustainability indicator is based on the LULULCF emissions from cropland and grassland. The values of this indicator vary significantly across the scenarios. The P2X scenario together with CIRC scenario are expected to have lower LULUCF emissions related to the agriculture compared to the e.g. EE scenario (for details see the table below).

Table 21. Agricultural sustainability indicator, $MtCO_2$. Own calculations.

Scenario	Cropland	Grassland	Agricultural sustainability
P2X	8	0	8
H2	18	0	18
ELEC	24	-1	23
EE	30	0	30
CIRC	9	0	9
BAU	**40**	**-1**	**39**

Table 22 shows the values of the land use sustainability indicator. Overall, according to this indicator, CIRC scenario is expected to contribute most significantly to the related LULUCF emission reduction. It is followed by P2X, and H2.

Table 22. Land use sustainability indicator. Own calculations.

Scenario	Forest sustainability	Agricultural sustainability	Land use sustainability
P2X	-391	8	**-383**
H2	-379	18	**-361**
ELEC	-376	23	**-353**
EE	-390	30	**-360**
CIRC	-426	9	**-417**
BAU	**-395**	**39**	**-356**

Comparison of the scenarios

This section presents an overview of the ranking of the energy scenarios per indicator. Each scenario is awarded 1-6 points. 6 points signalise the best score, while 1 point is the lowest score. Therefore, the higher the score is, the more sustainable scenario is considered to be according to the given indicator. In addition, the following assumptions were applied:

- The less energy is consumed, the more sustainable. Hence, scenarios with the most significant energy consumption reduction are considered to be the most sustainable.

- On the other hand, higher share of the renewable energy sources replacing fossil fuels in the energy mix, are considered to be more sustainable. Hence, the higher share of renewable energy in the energy mix, the more sustainable.

- The lower the energy import dependency (and therefore higher level of self-sufficiency), the more sustainable.

- The more significant emissions reductions, the more sustainable the related land use is.

- Overall, the more significant LULUCF GHG reduction, the more sustainable.

The following table presents comparison of the scenarios based on the selected indicators. The more points, the higher level of sustainability is considered.

Table 23. Comparison of the energy scenarios, 6=the highest score, 1=the lowest score

Scenario	Changes in primary energy consumption in 2050 (%)		Changes in final energy consumption in 2050 (%)		Share of renewable energy sources in the gross inland energy consumption in 2050 (%)		Land use sustainability		LULUCF emissions ($MtCO_2$)	
P2X	**1**	-22%	**2**	-30%	**3**	52%	**5**	-383	**5**	-263
H2	**3**	-36%	**3**	-32%	**6**	55%	**4**	-361	**4**	-244
ELEC	**4**	-40%	**4**	-35%	**4**	53%	**1**	-353	**2**	-238
EE	**6**	-50%	**6**	-44%	**2**	51%	**3**	-360	**3**	-241
CIRC	**5**	-45%	**5**	-38%	**5**	54%	**6**	-417	**6**	-292
BAU	**2**	**-35%**	**1**	**-26%**	**1**	**36%**	**2**	**-356**	**1**	**-236**

3.2 *Sustainability considerations of the food, feed and material use scenarios*

The two scenarios for food, feed and material use were developed with an aim to explore sustainable oriented futures of the regarding sectors. It is important to note that these two scenarios are not predictions, but rather normative explorations of possible future situations. Thus, data to support detailed quantitative analysis of the sustainability of the two scenarios are not available. Thus, this section presents qualitative considerations related to the possible impacts of the scenarios in the following areas:

- carbon demand,
- land use,
- biodiversity,
- import independency,
- circularity rate,

- Global Warming Potential reduction,
- impact on human health – food and feed,
- material wealth,
- EU competitiveness,
- turnover.

Carbon demand

The determination of carbon demands is a key aspect of this study. However, the amount of carbon alone has no positive or negative sustainability consequences. On the other hand, e.g. biogenic carbon demand influences the area required for sourcing, the use of fossil carbon leads to global warming. Therefore, the carbon demand needs to be complemented with other sustainability indicators.

The carbon demand for food and feed is expected to decrease in both scenarios. Specifically, the Sufficiency scenario assumes 20% reduction of the overall carbon demand, and Technology scenario assumes reduction of 30% respectively. This reduction is mainly driven by the higher share of plant-based diets and efficiency gains along the food production value chain. On the other hand, Technology scenario triggers higher economic growth. This leads to an increase in material use, and therefore the higher demand for carbon. In the Technology scenario, the carbon demand for material use exceeds the savings achieved in the food and feed sector. As a result, the Sufficiency scenario would lead to the reduction of carbon demand. In case of the Technology scenario, the overall carbon demand is likely to increase.

When it comes to fossil carbon demand, reduction compared to 2018 values is likely in both scenarios. This is mainly triggered by higher utilisation of bio-based carbon sources, increased recycling and CO_2 based materials. In both scenarios, chemical and plastic sectors are still expected to depend on the fossil carbon resources for certain applications where alternative sources are technically or economically not feasible in both scenarios.

Reduced land use

According to the OECD (2020)[142], sustainable land use practices include, among others, prevention of the expansion of agricultural land, improvements of the agricultural resource efficiency, reduction of food waste and losses, and intensification of the food production.

In the Sufficiency scenario, the dominant factor is the food and feed sector. Land use is reduced for food and feed due to a strong shift towards more plant-based diets. Compared to the 2018 values, there is also a significant improvement of food losses and utilisation of the food waste. To some extent, the Sufficiency scenario also entails improvements in the food production processes. The land use for material use remains constant due to constant demand for bio-based material (chemicals & plastics, furniture, pulp & paper, textiles). Additional land use to substitute fossil raw materials with bio-based materials exist but is low compared to the savings in the food & feed sector.

In the Technology scenario, there is also reduced land use for food & feed due to improvements in agricultural production systems leading to higher yields per area (e.g. through precision farming, gene editing), and higher utilisation of the alternative protein sources for feed (e.g. insect-based feed). On the other hand, the overall growth in the material use sector in combination with the substitution of fossil based raw materials with bio-based ones for the plastic and chemical sector exceeds the savings in the food and feed sector. Therefore, overall, the Technology scenario would trigger increase in the land use.

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[142] OECD, Towards Sustainable Land Use Aligning Biodiversity, Climate and Food Policies, 2020, see: towards-sustainable-land-use-aligning-biodiversity-climate-and-food-policies.pdf (oecd.org)

Biodiversity

Both scenarios are likely to contribute positively to the biodiversity. One of the main drivers would be higher utilisation of the organic farming in both scenarios. According to Bavec (2015)[143], organic farming can contribute to the higher degree of biodiversity. In addition, the Sufficiency scenario is expected to contribute to the reduction of land use compared to 2018, which is also likely to result in improvements in biodiversity[144]. On the other hand, the Technology scenario combines both, organic farming and technological improvements of the conventional farming (e.g. the use of precision farming). This leads to higher productivity of the utilised land. Thus, higher nutrition value could be produced on the same area than it would be currently feasible.

Import independency

Compared to 2018 values, the two scenarios could contribute significantly to the food and feed import independency. More food and feed would be available locally thanks to eventual significant gains along the value chain (50% less losses), yield improvements in agricultural systems (10% for the Sufficiency scenario and 30% for the Technology scenario), lower feed demand caused by the shift towards more plant-based diets and increased consumption of the alternative protein sources. For example, crickets need six times less feed than cattle, while their protein yield is comparatively high (e.g. 80% of crickets mass is edible, compared to 55% of beef)[145].

For the material use sector, the main determining factor is import share of fossil resources. Today, 93% of the EU-28's oil supply and 79% of gas supply are imported146. The total amount of fossil carbon used in the plastic and chemical sector is foreseen to decline at the same pace in both scenarios.

Circularity rate

Significant improvements in circular economy were attributed to both scenarios based on the related ambition of the recent EU policies (e.g. European Green Deal). This ambition is likely to be reflected also in the future policies. In the Sufficiency scenario, the increase is driven by a higher demand for recycled products in the market and realised e.g. through improvements in waste collection systems. In the Technology scenario, it's driven by improvements in recycling technology (e.g. chemical recycling).

Global Warming Potential reduction

Global warming is caused by the increase of the atmosphere's CO_2 content. CO_2 emissions generally correlate with carbon demand. Apart from the creation of stocks (material, soil) or recycling, processed carbon is emitted to the atmosphere as CO_2 through burning of fuels or incineration of waste. Nonetheless, only carbon from fossil sources leads to an increase of CO_2 in the atmosphere. On the other hand, CO_2 emissions from biogenic carbon don't contribute to global warming because the carbon emitted is bound e.g. by plants in

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[143] M.Bavec and F.Bavec, Impact of Organic Farming on Biodiversity, 2014, see: Impact of Organic Farming on Biodiversity | IntechOpen

[144] Marques, A., Martins, I.S., Kastner, T. et al. Increasing impacts of land use on biodiversity and carbon sequestration driven by population and economic growth. Nat Ecol Evol 3, 628–637 (2019). https://doi.org/10.1038/s41559-019-0824-3

[145] FAO, Edible insects and the environment, see: Insects for food and feed (fao.org)

[146] IRENA "Global Renewables Outlook Energy Transformation European Union" (2020), see https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Apr/IRENA_GRO_R04_European_Union.pdf

the forehand[147]. CO_2 emissions from fossil resources decline in both scenarios leading to a reduced global warming potential.

Impact on human health – food and feed

The aspect that is often discussed in relation to the sustainable food consumption is the impact of a diet on human health. Sufficiency scenario entails significantly higher share of vegetarian/vegan diet and higher organic food production. A higher share of plant-based diets can have positive impacts on human health. G. Segovia-Siapco (2018)[148] argues that a vegetarian diet has beneficial health outcomes compared to the non-vegetarian diets. Specifically, the study estimates that vegetarians have 11-19% lower risk of all cancers compared to non-vegetarians, decreased morbidity risk and lower risk of other chronic diseases. Generally, the positive impact on human health can be also associated with the organic farming, due to the avoidance of chemical fertilisers and pesticides[149]. On the other hand, the Technology scenario is defined by higher yield improvements, increased consumption of protein feed from alternative sources and higher utilisation of food waste. The improvements along the food production value chain can result in an increased nutrition value of the food.

Material wealth

A base assumption for both scenarios is the sufficient food supply and an adequate provision of consumer goods. Nevertheless, the level of material prosperity is very different between the scenarios.

In the Sufficiency scenario, a refocussing on immaterial values is triggered and intensive consumption patterns partly disappear. The demand for materials is constant. Hence, the level of material prosperity stays on today’s level. In the Technology scenario, consumption patterns remain unchanged and growth rates for material use remain constant, leading to a higher material prosperity compared to today and greater material wealth.

EU competitiveness

The competitiveness is at the forefront of the EU strategy, as it is an important factor driving the achievement of the sustainable economy[150]. The Sufficiency scenario entails reduced growth in the material sector, which could hamper the innovations. However, the shift towards more sustainable food and feed production and a related shift in demand presents an opportunity for innovation, as well as for the new market entrants. This could be the case for example in the fields of insect protein, increased production of vegan products, organic food production and related businesses.

To some extent this is also the case for the Technology scenario. In addition, the growing demand for improved food technology and material production allows for strong technological innovations (e.g. in the fields of precision farming, chemical recycling). This

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[147] 39 Carus, M., Dammer, L., Raschka, A., Skoczinski, P., vom Berg, C.. (2020). nova-Paper #12: „Renewable Carbon – Key to a Sustainable and Future-Oriented Chemical and Plastic Industry“. nova-Institut (Ed.). Hürth, Germany, see http://bio-based.eu/nova-papers/#novapaper12

[148] G.Sagovia and J.Sabate, Health and sustainability outcomes of vegetarian dietary patterns: a revisit of the EPIC-Oxford and the Adventist Health Study-2 cohorts, 2019, see: Health and sustainability outcomes of vegetarian dietary patterns: a revisit of the EPIC-Oxford and the Adventist Health Study-2 cohorts | European Journal of Clinical Nutrition (nature.com)

[149] Nicolopoulou-Stamati P, Maipas S, Kotampasi C, Stamatis P, Hens L. Chemical Pesticides and Human Health: The Urgent Need for a New Concept in Agriculture, 2016, see: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4947579/

[150] EC, Glossary of summaries: EU competitiveness, see: https://eur-lex.europa.eu/summary/glossary/competitiveness.html

provides an opportunity for the EU industries to take advantage of the 'first market mover'[151] and profit from the related competitive advantage.

Turnover

Turnover can be used as an indicator for the economic prosperity of a branch. High turnovers (together with profits) allow for the expansion of markets with new groups of products, the introduction of novel technologies and a sufficient monetary base for research and innovation.

In the food and feed sector, an increased demand for organic goods is foreseen. The comparatively higher prices for organic food compared to conventionally produced food could lead a moderate increase in turnovers. This would be slightly more pronounced in the Sufficiency scenario. In the Technology scenario, there is a strong demand for high quality, high-price food products (e.g. meal kit shipping). While the share of plant-based diets is expected to increase, the alternative protein sources are exploited to reduce GHG emissions. The introduction of novel protein sources (e.g. insect protein, CO_2-based protein) together with longer and more complex value chains in the food industry could lead a significant increase of turnovers.

In the material use sector, different consumption patterns are foreseen in each of the scenarios. The Sufficiency scenario foresees reduced growth rate of material demand, and inter alia constant demand for the material goods. Even though the demand for alternative carbon sources (in particular for bio-based and recycled materials) is expected to increase and allow for the premium prices for chemicals and plastics, the turnovers are likely to remain nearly constant compared to today, due to the constant demand. In the Technology scenario, the growth rates remain unchanged compared to today possibly leading to significantly higher overall demand in 2050 compared to today. Additionally, the market demand for renewable carbon sources increases and the exploitation and marketing of novel technologies (e.g. CO2-based chemicals) would allow for premium prices. Therefore, the turnovers in the Technology scenario are likely to exceed today’s figures significantly.

Table 24. Comparison of the possible impacts of the Sufficiency and Technology scenarios, 2050, compared to the 2018 values

Impact	“Sufficiency” 2050	“Technology” 2050	Short description
Low carbon demand	+ (carbon demand decreases)	- (carbon demand increases)	The carbon demand for food & feed decreases in both scenarios due to an increase of plant-based diets, efficiency gains in the food production value chain and a better use of food losses. In the Technology scenario, the overall carbon demand for material use increases due to the general growth and exceeds the savings in the food and feed sector.
Low fossil carbon demand	+ (fossil carbon demand decreases)	+ (fossil carbon demand decreases)	In both scenarios, the reduction of fossil carbon demand is expected due to the utilisation of bio-based carbon resources, recycling and CO2-based materials.

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[151] Investopedia, First mover definition, see: First Mover Definition (investopedia.com)

Reduced land use	+	0	In food and feed sector, the land use is expected to decrease in both scenarios, either due to the strong shift towards more plant-based diets (Sufficiency scenario) or due to the efficiency gains (Technology scenario). In the sufficiency scenario, the land use for material use remains constant due to the constant demand for bio-based material. On the other hand, in the Technology scenario, the overall growth in the material use sector in combination with the substitution of fossil based raw materials with bio-based ones for the plastic and chemical sector exceeds the savings achieved by the food and feed sector.
Biodiversity	+	+	Improved biodiversity is likely in both scenarios. In the Sufficiency scenario, it would be due to the increased organic farming in combination with reduced land use leads to improvements for biodiversity. In the Technology scenario, the improvements would be triggered by a combination of improved efficiency of the conventional farming and organic farming.
Import independency food and feed	++	++	Both scenarios are expected to trigger significant efficiency gains along the food production chain (stronger for the Technology scenario). For both scenarios, plant-based diets could lead to less feed demand and therefore less imports of feed (much stronger for the Sufficiency scenario).
Import independency material use	+	+	As the main determining factor could be considered import share of fossil resources. The total amount of fossil carbon used in the plastic and chemical sector would decline almost identically for both scenarios.
Circularity rate	++	++	High circularity rate is expected as a result of the EU policy ambition. In the Sufficiency scenario, the increase would be driven by a higher demand for recycled products in the market. In the Technology scenario it would be driven by improvements in recycling technology.
Global Warming Potential reduction	+	+	Reduced Global warming potential would be caused by decline in CO_2 emissions from fossil resources decline in both scenarios.
Impact on human health – food and feed	+	++	In the Sufficiency scenario, consumers lean towards more plant-based diet and organic farming. In the Technology scenario, improvements in food processing are expected nutrition value of food.
Material wealth	0	++	In the Sufficiency scenario, a refocussing on immaterial values compensates intensive consumption patterns partly. In the Technology scenario, consumption patterns remain unchanged and growth rates for material use continue, leading to material prosperity and greater material wealth.

EU competitiveness	+	++	In the Sufficiency scenario, the reduced growth in the material sector could hamper innovations. New innovations are triggered by the demand for plant-based food. In the Technology scenario, the growing demand for improved food technology and material production allows for strong technological innovations.
Turnover - food and feed	+	++	High turnover from organic food (stronger in Sufficiency scenario). In the Technology scenario, longer and more complex value chains lead to higher turnovers. In the food and feed sector, biomass flows like waste streams are transformed to valuable food and feed. CO_2- and bio-based materials require the application of complex technologies.
Turnover - material use	0	++	In the Sufficiency scenario, the demand for alternative carbon sources allows for slightly higher turnovers but the changes in consumer behaviour keeps the turnover nearly constant. In the Technology scenario, the overall growth and increasing demand for renewable carbon sources allow for premium prices.
-: moderate deterioration compared to 2018 0: no significant improvement compared to 2018 +: moderate improvement compared to 2018 ++: strong improvement compared to 2018			

WORK PACKAGE 3 - REGULATORY ANALYSIS AND ASSESSMENT OF INNOVATIVE TECHNOLOGIES

1 Introduction

The transformation of an economy with high dependency on fossil carbon and high greenhouse gas (GHG) emissions to a circular-based economy with low GHG emissions is necessary to mitigate climate change. A deep analyse is provided by this study regarding the current state of the European carbon economy (work package 1), the exploration of possible future pathways (work package 2) as well as concrete assessment of current practices and obstacles for the use of carbon sources from urban waste streams (work package 4). To make progress in the transformation of the economy towards more sustainability both, policical measures as well as technologic innovation is necessary. Hence, the first part of this work package is dedicated to identify regulatory drivers and obstacles for the production of bio-based products from urban bio-based carbon sources. In the second part of this work package innovations and technologies are assessed regarding their utility for a resource-efficient sourcing and use of carbon in a future carbon economy.

2 Regulatory analysis

The scope of the regulatory analysis carried out in this report are biogenic carbon sources that occur in cities. Urban bio-waste and wastewater sludge are valuable feedstocks that can be used to produce a wide range of bio-based products. Therefore, the previous study "Survey report on regulatory obstacles and drivers for boosting a sustainable and circular urban bio-based economy" analysed the results of a survey carried out 2017 and 2018.[152] The aim of the previous survey report was to provide feedback on EU regulatory drivers and obstacles for the production of bio-based products from bio-waste and wastewater sludge. The aim of this study is to improve the analysis by updating the findings with regard of any amendments that have been made to the regulations since the publication of the previous report.

2.1 Methodology

The goal of this activity has been closely coordinated between the partners and adjusted from the original goals. The scope follows the agreement of the inception report and the progress report. To update and improve the previous analysis the structure of the old report is repeated by analysing regulatory obstacles and barriers (i) per legislation and (ii) per bio-based value chain/product.

For this study, all amendments to the regluations analysed in the previous report have been considered that have been introduced beteween 1st of January 2018 and the 10 July 2020. If the amendmends include substantial changes to the regulation or if they influence any of the drivers or bottlenecks for bio-based products identified in the old report, the regulation is analysed regarding the influence of the amendmends on the drivers and bottlenecks. The analysis answers the question if a driver or bottleneck still exists, if it is amplified or if it isn't affected by the amendmend in question. All regulations analysed in the old report are listed in Table 25. All regulations with relevant amendmends are printed bold. The others aren't of further interest for this study and are excluded from further investigation.

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[152] Urban Agenda for the EU. (2018). Survey report on regulatory obstacles and drivers for boosting a sustainable and circular urban bio-based. economy https://ec.europa.eu/futurium/en/system/files/ged/analysis_of_regulatory_obstacles_and_drivers_urban_circular_bioeconomy_report_final_version_29.10.19_rv_27.04.2020.pdf

Table 25. Regulations analysed in the old survey report with amendmends since 1st January 2018. Updated regulations with relevance to identified Drivers and Bottlenecks are analysed for this report and printed in bold type.[153]

No.	EU Regulation Name	Amendments since 1st January 2018
I	**Landfill Directive**	**Amended in June 2019**
II	Animal by-products Regulation	No definitions or relevant changes
III	**Nitrates Directive**	**Derogations only by annex amendments**
IV	**Fertilisers Regulation**	**Repealed by 2019/1009**
V	Proposal for a Regulation laying down rules on the making available on the market of CE marked fertilising products	Amended by 2019/1009 (outlined in Fertilisers Regulation update)
VI	**REACH Regulation**	**Amendment to Annex V plus others**
VII	**Waste Framework Directive**	**Substantial changes**
VIII	**Sewage Sludge Directive**	**Amendments to multiple articles and replacing article 14**
IX	Urban Waste Water Treatment Directive	No updates past 2015
X	**Renewable Energy Directive**	**RED II in force**
XI	EU ETS-Innovation Fund	Combined with proposal emission reduction fund, no new updates as of April 2018
XII	Effort Sharing Decision & Regulation	Proposal for effort sharing regulation (2016/0231/COD) updated
XIII	A Bio-economy for Europe	2018 updates already included in old report
XIV	Council Regulation on Organic Farming	Some additions for 2021 to Annex II but do not apply to the bottlenecks as they concern aquaculture and bee colonies

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[153] Urban Agenda for the EU. (2018). Survey report on regulatory obstacles and drivers for boosting a sustainable and circular urban bio-based. economy https://ec.europa.eu/futurium/en/system/files/ged/analysis_of_regulatory_obstacles_and_drivers_urban_circular_bioeconomy_report_final_version_29.10.19_rv_27.04.2020.pdf

XV	Directive to reduce indirect land use change for biofuels and bioloquids	No updates past 2015
XVI	Fuel Quality Directive	No updates past 2009
XVII	**The Gas Directive**	**Updates to articles in 2018 and 2019**
XIX	Regulation on Detergents	No updates
XX	Packaging Waste Directive	Updated as of April 2018 already included in the old report
XXI	Cosmetic Regulation	Updates to annexes (II,III,IV,V,VI and article 2), no relation to the bottlenecks
XXII	CMO Regulation	Updates to articles in 2019 and 2020 but all irrelevant
XXIII	Regulation on the placing on the market and use of feed	Updates in Annexes IV,V,VI,VII,II in December 2018
XXIV	**Plastics Regulation**	**Updates to annex I,II,III,IV,V and article 6**
XXV	Regulation on recycled plastics in food	No new updates
XXVI	Water Framework Directive	No new updates
XXVII	**A European Strategy for Plastics in a Circular Economy**	**New document**
XXVIII	**Closing the loop - An EU acton plan for the Circular Economy**	**New document**
XXIX	Towards a circular economy - a zero waste programme for Europe	No new updates

Following the structure of the old report, the responder's feedback to the regulations is subdivided into different product categories, see Table 26.

Table 26. Product Categories for the subdivision of the survey results

1.	Fertilisers (organic/inorganic)
2.	Biogas and biomethane
3.	Bioethanol and biomethanol
4.	Bio-based chemicals
5.	Bio-based plastics
6.	Bio-based food & feed ingredients
7.	Recovered cellulose

The Classification system of bottlenecks and drivers is adopted from the old report as follows:

I. All EU legislations/policy documents are numbered with roman numbers.

I.**1**. Product categories are numbered secondly. It is possible that a certain bottleneck/driver is mentioned in different product categories, then multiple numbers are mentioned here divided by a / (e.g. I.1/3).

I.1.**1** The final number indicates the chronological order of the bottlenecks/drivers belonging to the specific legislation.

2.2 Analysis of amended regulations

In the following section all regulations with amendmends with implications for any of the drivers or bottlenecks identified in the old report are listed.

For each of the analysis updates the legislative acts that is referred to are stated (for the old report and the amended regulations for this study). Then, an updated conclusion is drawn for each regulation, followed by a table with the analysis of the old report (including the respective bio-based product, bottlenecks and regulatory drivers, and the old analysis) and the updated analyses (update 2020), grouped by product categories.

I. EU Landfill Directive

The old report refers to both the 'old' EU Landfill Directive 1999/31/EC and to the proposal to change the Landfill Directive (2015/0274/COD). As the proposal has resulted in a newly adopted Directive 2018/850/EU amending the Landfill Directive, this Directive was used to analyse the feedback provided. The then consolidated Landfill directive can be found here. For the 2020 Updates, Directive (EU) 2018/850 of 30 May 2018 has been analysed, that amends the Landfill Directive.

2020 Updated Conclusion:

- In the old report the then existing regulation as well as the proposal to amend the Landfill Directive have been considered. The conclusion emphasises the positive trend for stricter maximum percentage of municipal waste that is allowed to be landfilled. Furthermore, the respondents call for stricter measures against the landfilling of biodegradable waste. They also criticise that the underlying definition of "biodegradable waste" is not clear enough.

- Many of the positively evaluated changes that were only anticipated for the amended regulation in the old report are now realised and part of the current Landfill Directive like a call to the Member States to endeavour to restrict the landfill of recyclable waste (e.g. Bottleneck I.1.1).

- On the other hand, some of the anticipated changes have not been realised in the current Landfill Directive like a ban for landfill of biodegradable waste (Driver I.3.5, Driver I.4/5/6.9, etc.) making the old conclusions partly invalid.

- The need for clarification for regulation of sludge remains relevant since sludge is still excluded from the scope of the regulation (Bottleneck I.4/5/6.8 (old legislation)).

1. Fertiliser (organic/inorganic)				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Organic fertiliser (compost or digestate)	**Bottleneck I.1.1 (new legislation)** One of the respondents (4) representing waste management companies argued for an addition of the term 'non-recyclable' in article 5(5) of the new Landfill Directive: · Member States shall take the necessary measures to ensure that by 2030 the amount of non-recyclable municipal waste landfilled is reduced to 10% of the total amount of municipal waste generated. To make sure that only non-recyclable residual waste is sent to a landfill.	**Driver I.1.1 (old legislation)** A regulatory driver in the old Landfill Directive in relation to organic fertilisers mentioned by one of the respondents (6) was that article 5 (that sets up a national strategy for the implementation of the reduction of biodegradable waste going to landfills), also encourages the separate collection of biodegradable waste, sorting in general, recovery and recycling. **Driver I.1.2 (old legislation)** This government authority (6) also found it useful that (sewage) sludges used for soil fertilisation or improvement are excluded from the scope of this directive.	**Bottleneck I.1.1 (new legislation) and I.1.2 (new legislation)**: Both these bottlenecks refer to article 5(5) in the newly adopted Landfill Directive and are directed at reducing the amount of (recyclable) municipal waste that is being landfilled, especially when there are more desirable alternatives (see the waste hierarchy in article 4 of the Waste Framework Directive). In relation to bottleneck I.1.1, the new Directive has a new paragraph added into article 5: - 5.3a: Member States shall endeavour to ensure that as of 2030, all waste suitable for recycling or other recovery, in particular in municipal waste, shall not be accepted in a landfill with the exception of waste for which landfilling delivers the best environmental outcome in accordance with Article 4 of Directive 2008/98/EC. This paragraph seems to have the same goal as what the respondent suggested. However, "shall endeavour" is less strict then for example, "shall take measures" (used in article 5(3)(f)). This implies an intention to achieve and not an obligation.	Update on Bottleneck I.1.1 is already included in the analysis from 2018; the amended article 5 now puts Member States to action that they shall endeavour to prevent that any recyclable waste is accepted in landfills. Update on Bottleneck I.1.2 is already included in the analysis from 2018; the quota was not reduced to 5% as suggested, but remained at 10%. Driver I.1.1 (old legislation) & Driver I.1.3 (new legislation) The analysis from 2018 is not correct, since the finally adopted new article 5.3(f) does not prevent the landfilling of biodegradable waste; it reads: Member States shall take measures in order that the following wastes are not accepted in a landfill: (f) waste that has been separately collected for preparing for re-use and recycling pursuant to Article 11(1) of Directive 2008/98/EC and Article 22 of that Directive, with the exception of waste resulting from subsequent treatment operations of the separately collected waste for which landfilling delivers the best environmental

		Driver I.1.3 (new legislation) Furthermore this respondent (6) stated that stricter measures shall be taken in order to achieve the landfill targets, according to the amended Article 5, aiming at the further reduction of biodegradable waste going to landfills.	For specific forms of waste (see article 11(1) and article 22(1) of the Waste Framework Directive) there are obligations for separate collection. E.g. paper, metal, plastic, glass, textiles and bio-waste. These separately collected waste streams cannot be landfilled after the implementation of the new landfill directive (see article 5(3)(f)). However, this does not exclude the possible landfilling of other recyclable wastes. With regard to Bottleneck I.1.2 it is clear that the suggested 10% maximum target of landfilled municipal waste is maintained in the new directive (article 5(5)). The 5 year derogation period for Member States that landfill a large percentage of their waste (article 5(6)) is also present. It is logical that a lower maximum would positively affect the valorisation of OFMSW. However, one can wonder whether this is achievable politically. **Driver I.1.1 (old legislation) & Driver I.1.3 (new legislation)** The regulatory driver I.1.1 is related to the old directive and encourages the implementation of a national strategy that also encourages the separate collection of biodegradable waste (article 5(1)). This article is still present in the new Landfill Directive, however, as suggested in driver I.1.3, the new Directive has taken further steps against the landfilling of	outcome in accordance with Article 4 of that Directive.'; This does not contain a special mention of biodegradable waste; if separate collection of biodegradable waste is not implemented in a country, article 5.3(f) will for example not apply. **Driver I.1.2 (old legislation) & Driver I.1.4 (old legislation)** With regard to Driver I.1.2, the situation is unchanged, as article 3(2), first indent, has not been amended by the updated landfill directive. Driver I.1.4 is not completely clear, but perhaps the stakeholder originally referred to the exclusion from the scope and not to a ban of landfilling of sludge. There is still no explicit ban in the updated directive.
Hydrochar (HTC biochar)	**Bottleneck I.1.2 (new legislation)** A respondent (15) belonging to a research institute argues that the defined maximum percentage of landfilled municipal waste in the proposal (10%) should be lower. They suggest a target of 5% with a possible five year derogation for some countries (Estonia, Greece, Croatia, Latvia, Malta, Romania and Slovakia). This could function as a strong driver in the development of a new OFMSW valorisation strategy. Reducing the amount of landfilled material has a direct impact on the			

	development of new EoW products.		biodegradable waste (article 5(3)(f)). See the analysis of bottleneck I.3.3 below. **Driver I.1.2 (old legislation) & Driver I.1.4 (old legislation)** Both these drivers relate to sludge. According to driver I.1.2 the fact that sludges used for soil fertilisation or improvement are excluded from the scope of the directive (article 3(2) first indent), is positive. This means that when sludges are used for these goals, this will not be treated as landfilling. However, Driver I.1.4 is less clear. In the new or revised directive there is no mention of a ban on landfilling sludge or organic waste. The new directive does however provide a prohibition of landfilling bio-waste. See the analysis of bottleneck I.3.3 below.	
Mixed concentrated liquid fertiliser		**Driver I.1.4 (old legislation)** A responder (10) from an EU funded project also considered the fact that landfilling is not allowed for sludge and organic waste a driver for the use of organic fertiliser. They mention the forbidding of landfilling for sludge and organic waste.		
3. Bioethanol and biomethanol				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Biomethanol/ (Bio)ethanol	**Bottleneck I.3.3 (new & old legislation)** A respondent (13) from an EU funded project considered that both the new and the old directive lack prohibitions in relation to landfilling biodegradable waste. It only sets targets for reduction.	**Driver I.3.5 (old legislation)** The responder (13) found it positive that the directive (article 5(2)c) obliges Member States to reduce the amount of biodegradable municipal waste that they landfill to 35% of 1995 levels by 2016 (for some countries by 2020).	**Bottleneck I.3.3 (new & old legislation)** In the new directive a couple of new subparagraphs are included in article 5: - 5.3. Member States shall take measures in order that the following wastes are not accepted in a landfill: (f) waste that has been separately collected for preparing for re-use and recycling pursuant to Article 11(1) of Directive 2008/98/EC and Article 22 of that Directive, with the exception of waste resulting from subsequent treatment	As mentioned in the update for the fertilisers with regard to drivers I.1.1 and I.1.3, the analysis of the previous survey is not correct, since the mentioned new sub-paragraph 5(3)f was not finally adopted. The same applies to the analysis of driver I.3.5 – the driver is still the same, meaning that the reduction goals of bio-waste still apply and there was

	They suggest further restrictions on the landfilling of biodegradable waste by prohibiting the landfilling of biodegradable waste that has been separately collected	As producing bioethanol from OFMSW helps to reduce the amount of bio-waste sent t	operations of the separately collected waste for which landfilling delivers the best environmental outcome in accordance with Article 4 of that Directive. Following article 22 (1) on bio-waste of the recently altered Waste Framework Directive (Directive 2008/98/EC), bio-waste must be collected separately or separated and recycled at source before 2024. Resultantly in combination with article 5(3)(f) of the new Landfill Directive, it is prohibited to landfill bio-waste after 2024. Thereby seemingly resolving the bottleneck with regard to biodegradable waste. However, the definitions of bio-waste and biodegradable waste do not completely match. It seems that waste can be biodegradable waste but not fall within the category bio-waste. Article 3(4) of the WFD: 'bio-waste' means biodegradable garden and park waste, food and kitchen waste from households, offices, restaurants, wholesale, canteens, caterers and retail premises and comparable waste from food processing plants' Article 2(m) of the Landfill Directive: 'biodegradable waste' means any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste, and paper and paperboard; Driver I.3.5 (old legislation) This driver is no longer relevant as the new limits on the landfilling of biodegradable waste	no complete ban of landfilling bio-waste.

			are more strict (see text above). However, these newly formed prohibitions/limits should/could stimulate the production of bioethanol even further.	
4. Bio-based chemicals				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Adipic acid, Muconic acid / 1,5-pentanediamine	**Bottleneck I.4/5.4 (old & new legislation)** A respondent (8) representing EU funded projects stated that waste prevention policy could reduce available feedstocks for the creation of these products. **Bottleneck I.4/5.5 (old & new legislation)** Furthermore, they (8) suggest to carry out a global assessment of the initial waste reduction versus the efficiency of the product obtained.	**Driver I.4/5.6 (old & new legislation)** The interviewee (8) also states that the Landfill Directive should promote the use of waste as raw material for the production of by-products or other products and should include rewards for these good practices.	**Bottleneck I.4/5.4 (old & new legislation)** Respondents seem to suggest that when waste prevention policy is functioning effectively that this could reduce available feedstocks for the creation of mentioned products. **Bottleneck I.4/5.5 (old & new legislation)** Not really a regulatory bottleneck, they seem to want to carry out an global enquiry to assess how effective the production of these products is (waste reduction vs. the efficiency of the product). Better knowledge action. **Bottleneck I.4/5.6 (old legislation)** Article 5(5) of the new directive clearly states a new maximum percentage (10%) of municipal waste that is allowed to be landfilled. So the amount of waste devoted to landfills is going to be reduced substantially. **Bottleneck I.4/5/6.7 (old legislation) & Driver I.4/5/6.9 (new legislation)** The definition of biodegradable waste in the Landfill Directive has not changed in the revised directive. Article 2(m): Biodegradable	
Biosurfactant	**Bottleneck I.4/5.6 (old legislation)** One of the EU funded projects that responded (13) stated that the amount of waste devoted to landfills should be reduced.	***Driver I.4/5.6 (old & new legislation)*** *This driver was also mentioned by another EU funded project (13) in relation to this product.*		

(Poly)lactic acid	***Bottleneck I.4/5.4 (old & new legislation)*** *This bottleneck was also mentioned by another EU funded project (13) in relation to this product.* ***Bottleneck I.4/5.5 (old & new)*** *This bottleneck was also mentioned by the respondent (13).*	***Driver I.4/5.6 (old & new legislation)*** *This driver was also mentioned by another EU funded project (13) in relation to this product.*	waste means any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste, and paper and paperboard. The European Parliament did suggest a different definition. See amendment 25: (m) ‘biodegradable waste’ means food and garden waste, paper, paperboard, wood and any other waste that can undergo anaerobic or aerobic decomposition. The OECD definition is: Biological waste is waste containing mostly natural organic materials (remains of plants, animal excrement, biological sludge from waste-water treatment plants and so forth). **Bottleneck I.4/5/6.8 (old legislation)** The definition of biodegradable waste does indeed not explicitly include sludges, neither in the old or the revised Directive. See the definition above and also notice that the OECD definition does include sludges (bottleneck I.4.7). **Bottleneck I.4/5/6.9 (new legislation)** In the old directive no definition of recycling is given. In the revised Directive reference is made to the definition described in article 2 of the Waste Framework Directive: 17. ‘recycling’ means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for	
Single Cell Oil for oleochemical industry produced by yeasts	**Bottleneck I.4/5/6.7 (old legislation)** A respondent belonging to an EU research funded project (14) argued that the OECD definition of biological waste should be taken into account to fully cover the input scope of the VFAP (Volatile Fatty Acid Platform) value chain. **Bottleneck I.4/5/6.8 (old legislation)** The definition of biodegradable waste does not explicitly mention sludges (respondent 14). **Bottleneck I.4/5/6.9 (new legislation)**	**Driver I.4/5.7 (old legislation)** The responder (8) found it positive that the (old) directive (article 5(2)) sets mandatory targets for the reduction of biodegradable waste and organic components that is allowed to be landfilled. Another respondent (9) belonging to an EU project also considered these binding targets a good driver. Especially in relation to AHP (Absorbent Hygiene Products) waste. **Driver I.4/5/6.8 (new legislation)**		

	The respondent (14) further suggested that to promote the value chain of bio-based products, a more detailed description of recycling by means of VFAP (volatile fatty acid platform) in anaerobic digestion would be helpful. Currently the revised WFD defines recycling but the Art. 11a(4) text "… or other output with a similar quantity of recycled content in relation to input…" restricts the validity for VFAP and the evidenced fact that this method leads to high-level added-value output in comparison with traditional output compost and digestate.	Another interviewee (14) belonging to an EU funded project states that the further restrictions on the landfilling of waste is positive for this value chain. Especially, the prohibition of separately collected biodegradable waste in landfills. **Driver I.4./5/6.9 (new legislation)** The respondent (14) stated that the European Parliament have suggested amendments of the Commission proposal (COM/2015/594) that would alter the proposal towards the objectives of the VFAP value chain (amendments 1, 2, 8, 9, 25, 27, 29 and 51).	the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations; Furthermore, in paragraph 4 of article 11a of the WFD further clarification is given when biodegradable waste that enters anaerobic treatment counts as being recycled. It does not specifically mention VFAP or fatty acids or bioplastics, while compost and digestate are mentioned. The respondent (14) further states that as from 01-01-2027 municipal bio-waste treated in AD is considered as recycled only if separately collected or separated at source (WFD, Art. 11a (4)). That means, considered as recycled only if separately collected or separated at source (WFD, Art. 11a (4)). That means, VFA generated from the biological fraction of MSW is not considered a recycling product. **Driver I.4/5.6 (old & new legislation)** The use of waste as raw material for the production of by-products or other products and rewards for good practices are not mentioned in either the old or new Landfill Directive. The Directive does mention: "waste suitable for recycling or other recovery", it seems that according to the definitions given	

			by article 3 of the Waste Framework Directive, the use of waste for the production of by-products is covered by this definition. There are no rewards available for the usage of waste for the production of by-products. However, a new paragraph is added in article 15, namely **Driver I.4/5.7 (old & new legislation)** This driver is similar to driver I.3.5. The limits/targets set by the newly adopted Landfill Directive are even stricter. So this should have an even greater effect. **Driver I.4/5/6.8 (new legislation)** This driver is certainly valid. See analysis bottleneck I.3.3.	
5. Bio-based plastics				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Bio-based plastics	**Bottleneck I.4/5.4 (old & new legislation)** *Same feedback as bio-based chemicals.*	**Driver I.4/5.6 (old & new legislation)** *Same feedback as bio-based chemicals.*		**Bottleneck I.4/5 & 5.6 (old & new legislation)** **Bottleneck I.4/5/6.7 & 6.9 (old legislation)** **Driver I.4/5.6 (old & new legislation)** Remains unchanged. **Bottleneck I.4/5/6.8 (old legislation)** Since sludges are excluded from the scope of the Directive (article 3(2), first
Bio-Polyamide 56 / Long chain Bio-Polyamides / Polyhydroxyalkanoate (PHA)	**Bottleneck I.4/5.5 (old & new legislation)** *Same feedback as bio-based chemicals.*	**Driver I.4/5.7 (old legislation)** *Same feedback as bio-based chemicals.*		

				indent), this seems hardly relevant. Situation is unchanged. **Driver I.4/5.7 (old & new legislation)** **Driver I.4/5/6.8 (new legislation)** Analysis of the previous report is contradictory. In its analysis of bottleneck I.3.3 is mentioned that the reduction goals for landfilling of biodegradable waste (article 5(2)) are no longer valid, since the landfilling of biodegradable waste is banned, here it now says that the goals for reducing landfilling of biodegradable waste have been made stricter. Both is not correct, article 5(2) has not been amended with regard to the sub-paragraph on biodegradable waste. So the driver and the bottleneck both remain. **Driver I.5.10 (new legislation)** The analysis of the previous report remains unchanged
6. Bio-based food and food ingredients				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Omega 3-fatty acids	**Bottleneck I.4/5/6.7 (old legislation)** *Same feedback as bio-based chemicals.*	**Driver I.4/5/6.8 (new legislation)** *Same feedback as bio-based chemicals.*	*Same analysis as bio-based chemicals.*	*Same updated analysis as for bio-based chemicals.*

	Bottleneck I.4/5/6.8 (old legislation) *Same feedback as bio-based chemicals.*			
	Bottleneck I.4/5/6.9 (new legislation) *Same feedback as bio-based chemicals.*			

III. EU Nitrates Directive

The old report refers to feedback given on the EU Nitrates Directive (Directive 91/676/EEC). The consolidated version can be found here. For the 2020 Updates, a number of derogations have been granted, that can be found here.

2020 Updated Conclusion:

- The majority of the identified bottlenecks state inconsistencies across the Member States as well as between national and regional regulations on the nitrogen limits in manure (kg). There are multiple derogations that have been granted between 2018-2020, which in theory adds to these bottlenecks as more and more countries are asking for derogations.

- All updates were to Annex III in the form of derogations from United Kingdom (2019/1325), Belgium (2019/1205), Denmark (2018/1928), Netherlands (2020/1073).

1. Fertiliser (organic/inorganic)				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Organic fertiliser (compost or digestate)	**Bottleneck III.1.1** One of the respondents (4) belonging to waste management industry argued that differences in implementation exist on the national/regional level, with regard to the limit on nitrogen in manure applied to the land each year. The limit of the amount of nitrogen in manure is set at 170 kg N. **Bottleneck III.1.2** According to a respondent belonging to a research institute (17) the many derogations of MS with regard to the conditions of the Directive lead to many differences between MS. This bottleneck is closely related to bottleneck III.1.1 mentioned above. **Bottleneck III.1.3** According to two respondents representing different categories (4 & 17), there is a problem in relation to the low availability (or effectivity) of nitrogen of digestate/compost when compared to inorganic fertilisers. The limits set in the Nitrates Directive with regard to nitrogen content of fertilisers do not take this into consideration.		**Bottleneck III.1.1 & III.1.2** The problem identified here is a lack of harmonisation. According to the respondents the ways in which nitrogen is taken into account varies in the MS, moreover the many derogations leads to even greater differences between and within MS. **Bottleneck III.1.3 & III.1.4** These bottleneck relates to the effectivity/availability of the nitrogen in compost/digestate and other characteristics of bio-based fertilisers. The availability of nitrogen for crops in compost is low as most of the nitrogen (95%) is fixed in organic matter and thus not available. The limits in the Nitrates Directive do not take this into consideration. Moreover, the specific characteristics of bio-based fertilisers are not taken aboard. The different solutions provided: - To exempt compost from the Nitrates Directive based on the fact that it is an organic soil improver could be a solution. - The inclusion of the effectivity of nitrogen in compost/digestate in the mandatory Action Plans (article 5(4)(a) in conjunction with Annex III). The respondents comment is based on the national (Dutch) context in which the effective amount of nitrogen is calculated using the "fertiliser	Derogations granted to the United Kingdom (2019/1325), Belgium (2019/1205), Denmark (2018/1928), Netherlands (2020/1073) all regarding changes to Annex III paragraph 2 on the 170 kg limit. **Bottleneck III.1.1** All derogations request exemptions to the Annex III paragraph 2 regarding the limit of 170 kg. E.g. granted the UK increase to 250 kg N per hectare a year on farms in Northern Ireland with at least 80% grassland. Farmers must apply for approval. **Bottleneck III.1.2** No changes as there are still differences across the Member States and differing conditions. **Bottleneck III.1.3** No specific changes in terms of derogations. These again would not change the overall directive, simply grant exemptions.

	Both respondents have a different solution for this problem however:- The first respondent (4) argued that compost as an organic soil improver should be exempted from the Nitrates Directive. **Bottleneck III.1.1 & III.1.2** The problem identified here is a lack of harmonisation. According to the respondents the ways in which nitrogen is taken into account varies in the MS, moreover the many derogations leads to even greater differences between and within MS. **Bottleneck III.1.3 & III.1.4** These bottleneck relates to the effectivity/availability of the nitrogen in compost/digestate and other characteristics of bio-based fertilisers. The availability of nitrogen for crops in compost is low as most of the nitrogen (95%) is fixed in organic matter and thus not available. The limits in the Nitrates Directive do not take this into consideration. Moreover, the specific characteristics of bio-based fertilisers are not taken aboard. The different solutions provided: - To exempt compost from the Nitrates Directive based on the fact that it is an organic soil improver could be a		equivalent” or “fertiliser replacement value”. It seems that the nitrogen fertiliser equivalent is used to calculate the right amount of organic fertilisers needed for a particular crop. However, this systematic does not seem to change the calculation of the total use of nitrogen. This would imply that more organic fertiliser is needed with a higher count of nitrogen because of the lower effectiveness in comparison to mineral fertilisers. Resulting in an advantage for mineral fertilisers. - The revision of the Nitrates Directive specifically directed at bio-based fertilisers with low solubility or improved time release profile of N and P. The goal is to promote the use of new advanced bio-based fertilisers. **Bottleneck III.1.5** The respondent provided the example of compost from sewage sludge. In this case the rules on quality and use of sewage sludge are in force. These regulations are based on the Sewage Sludge Directive 86/278/EEC. This problem of the feedstock determining the regulatory position of products is also mentioned in relation to other products (phosphates and ammonium sulphate). For ammonium sulphate the research institute considers the problem to originate from the definition of ‘livestock manure’ in the Nitrates Directive (article 2(g)). (**see also bottleneck IV.1.**3). The respondent stated that JRC’s project SAFEMANURE will propose criterions to solve this issue.	**Bottleneck III.1.4** As the time release profile has not been outlined, the derogations do not mention to include this as it would most likely complicate their monitoring processes. Remains a bottleneck. **Bottleneck III.1.4** As the time release profile has not been outlined, the derogations do not mention to include this as it would most likely complicate their monitoring processes. Remains a bottleneck.

	solution. - The inclusion of the effectivity of nitrogen in compost/digestate in the mandatory Action Plans (article 5(4)(a) in conjunction with Annex III). The respondents comment is based on the national (Dutch) context in which the effective amount of nitrogen is calculated using the "fertiliser equivalent" or "fertiliser replacement value". It seems that the nitrogen fertiliser equivalent is used to calculate the right amount of organic fertilisers needed for a particular crop. However, this systematic does not seem to change the calculation of the total use of nitrogen. This would imply that more organic fertiliser is needed with a higher count of nitrogen because of the lower effectiveness in comparison to mineral 23 - The second respondent (17) argued that the effectivity of nitrogen in compost/digestate has to be included in the obligatory fertilising plan. They suggest to distinguish availability of nitrogen (mineralisation) from solubility of phosphorus (chemical equilibria). Focus on nitrogen fertilising products from animal manure. If these products have a similar action as chemical nitrogen fertilisers, they can be set free of use requirement of animal manure.		These bottlenecks result partly from an interconnection issue, which entails that the bottleneck arises from the counterproductive interplay of EU legislation.	

	JRCis working on criterions (SAFEMANURE). **Bottleneck III.1.4** A respondent belonging to an EU funded project (13) explicitly highlighted the problem that the Directive does not differentiate the time release profile and other characteristics or properties of organic and/or bio-based fertilisers. They argue for revisions of the Nitrates Directive with regard to OFMSW and new bio-based fertilisers with low solubility or improved time release profile of N and P. **Bottleneck III.1.5** The origin (feedstock) of the product (compost) determines its regulatory position, this was mentioned by a research institute (17).			
Recovered phosphates	**Bottleneck III.1.2** The respondent (17) belonging to a research institute provided the same bottlenecks for this product. **Bottleneck III.1.3** The respondent (17) belonging to a research institute provided the same bottlenecks for this product. **Bottleneck III.1.5**			

	The respondent (17) belonging to a research institute provided the same bottlenecks for this product.			
Ammonium Sulphate	**Bottleneck III.1.2** The respondent (17) belonging to a research institute provided the same bottlenecks for this product. **Bottleneck III.1.3** The respondent (17) belonging to a research institute provided the same bottlenecks for this product. **Bottleneck III.1.5 (see also bottleneck IV.1.3)** The respondent (17) belonging to a research institute provide the same bottlenecks for this product. With regard to ammonium sulphate, the respondent gave a specific example of the bottleneck: Ammonium Sulphate has a dual status depending on its feedstock. When animal manure is not the feedstock, it is adesignated chemical fertilising product. If animal manure is the feedstock it is designated as animal manure and thus the rules on the use of animal manure apply.			
4. Bio based chemicals				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020

Single Cell OIl & Omega-3 Fatty acids	**Bottleneck III.4/5/6.6** This bottleneck was provided by a respondent belonging to a EU funded project (14). The action programmes to be established following the Nitrates Directive includes an annual application limit for nitrogen from manure (170 Kg/ha N). It does not consider fertilisers other than manure. Rules for other fertilisers (e.g. sewage sludge, digestate of non-animal origin, compost) would need to be included. The Directive sets a fixed limit of 170kg p.a. for application of nitrogen, one of the most important plant nutrients, but mentions only one example for a nutrient source, the organic fertiliser manure. Currently, there are individual national solutions on this issue. Hence, the list of organic nitrogen sources would need to be expanded by inclusions or exclusions (e.g. for digestate from VFA), with view on applications for VFAP process residues.		**Bottleneck III.4/5/6.6** This bottleneck seems to be closely related to bottlenecks III.1.3 & III.1.4. Their solution is the introduction of specific rules directed at fertilisers other than manure in the Nitrates Directive.	**Bottleneck III.4/5/6.6** The derogations submitted again only refer to the application limits outlined in Annex III Paragraph 2, not the types of organic fertiliser. All derogations refer simply to livestock manure and do not refer to an expansion of the list.
5. Bio-based plastics				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Bio-based plastics	**Bottleneck III.4/5/6.6** The respondent (14) provided the same bottleneck for this product.			Bottleneck remains unchanged due to derogations request to exemptions in the Annex III paragraph 2. No update to the entirety of the directive.
6. Bio-based food & food ingredients				

Omega-3 fatty acids	**Bottleneck III.4/5/6.6** The respondent (14) provided the same bottleneck for this product.			Bottleneck remains unchanged due to derogations requires to exemptions in the Annex III paragraph 2. No update to the entirety of the directive.

IV. EU Fertilisers Regulation

The old report refers to the EU Fertilisers Regulation (Regulation 2003/2003/EC). The then consolidated version of the Regulation can be found here. For the 2020 Updates, Regulation (EU) 2019/1009 has been analysed. The regulation is laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003. The new regulation is repealing No 2003/2003 by July 16, 2022.

2020 Updated Conclusion:

- The Proposal has been approved and resulted in a new EU regulation laying down rules on the making available on the market of EU fertilising products ((EU) 2019/1009). As these both have been updated, there has been a significant update specifically as many of the bottlenecks say that the main issue with the Fertilisers Regulation is its inattention to organic fertilisers. The new regulation states, *'The scope of the harmonisation should therefore be extended in order to include recycled and organic materials.'*

- The issue of disposal and recycling is still outstanding as it is not covered in the new regulation only mentioned briefly

1. Fertiliser (organic/inorganic)				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Organic fertiliser (compost or digestate)	**Bottleneck IV.1/4/5/6.1** Three respondents (4, 13 & 14) representing different types of organisations, namely relevant industry and an EU funded projects consider the fact that organic fertilisers and organic soil improvers are not covered in the scope of this regulation the main issue in relation to this product category. Because this leads to the exclusion of recycled bio-waste materials from being placed as EU fertilising products on the EU market. They suggest a revision of the Regulation to cover these products as well. **Bottleneck IV.1.2** A respondent (6) belonging to a government authority considered the lack of standards for digestate an issue. These standards could function as an important driver for this product.		**Bottleneck IV.1/4/5/6.1** The Fertilisers Regulation in its current form only applies to inorganic mineral fertilisers. This is considered to be the main issue with this regulation in relation to bringing to the market the bio-based products in this framework (compost/digestate/ammonium sulphate/hydrochar/phosphates/omega-3 fatty acids/bio-based plastics). The respondents belong to different categories, namely relevant industry, EU funded project, government authorities, and research institutes. Therefore it seems that this is a widely shared problem. The European Commission has taken action on this issue with the introduction of a new proposal to extend rules to non-harmonised fertiliser products and to improve the workings of the EU fertilisers market (2016/084/COD). The respondents were also asked to provide feedback on this proposal. Consult framework V on the proposal for more information. **Bottleneck IV.1.2** This bottleneck is closely related to bottleneck VI.1.1 because it argues for standards for digestate within the Fertilisers Regulation. This would be a logical consequence of the inclusion of bio-based fertilisers to the scope regulation. **Bottleneck IV.1.3**	The bottlenecks for the fertilisers regulation mainly concern the fact that the regulation only applies to inorganic fertiliser rather than organic. In addition, the old regulation does not offer a clear framework to environmental and material safety in inorganic fertilisers (Bottleneck IV.1/4/5/6.1). The new regulation says 'The scope of the harmonisation should therefore be extended in order to include recycled and organic materials.' It includes criteria for end-of-waste for compost and digestate that can be used in organic fertilisers. The regulation does not apply to animal by-products or derived products which are subject to 1069/2009 so Bottleneck IV.1.3 remains as an issue. Animal manure is treated within the Nitrates Directive so ammonium sulphate is as well. Further ammonium sulphate has not been updated within the new regulation neither is animal manure mentioned at all. According to the new regulation, within six months after 15 July 2019 the Commission would initiate an assessment of the products in Article 32 that are already used in the Union as

Ammonium Sulphate	**Bottleneck IV.1.3** A respondent (17) from a research institute states that the issue with ammonium sulphate is that if the feedstock is animal manure, it is defined as animal manure. Therefore the rules in on the use of animal manure apply. They argue that the origin of this problem stems from the definition of animal manure in the Nitrates Directive.		This is partly an interconnection issue, which entails that the bottleneck arises from the counterproductive interplay of EU legislation. The respondent argues that due to the definition of animal manure in the Nitrates Directive, ammonium sulphate does not fall within the scope of the Fertilisers Regulation (see bottleneck III.1.5). Furthermore, the respondent indicated that the Joint Research Centre is commissioned by DG ENVI to formulate criterions for reaching an end of-manure status of these type of fertiliser products (the JRC project SAFEMURE for adaption of the Nitrates Directive). Furthermore, the JRC installed a working group STRUBIAS (JRC project for the new EU regulation on fertilisers).	fertiliser (this includes manure). This assessment is not listed among the updates or amendments to the new regulation. Status is unclear. The new Annex I for the regulation expands the categories for fertilisers to include both organic (solid and liquid) and organo-mineral fertiliser (both not included within the original regulation). In addition, Annex II designates Component Material Categories (CMC) of which fertilising products must comply with the requirements. According to the Annex, EU fertilising product of virgin material and mixtures cannot contain digestate. On the other hand, Fresh crop digestate through anaerobic digestion of certain material is allowed. More standards are also outlined for different digestate types within CMC categories. In short, the new regulation is very specific regarding digestate (Bottleneck IV.1.2 is essentially eliminated).
Hydrochar (HTC biochar)	***Bottleneck IV.1/4/5/6.1*** *An interviewee (15) belonging to a research institute provided the same bottleneck for this product.*			
Recovered phosphate	***Bottleneck IV.1/4/5/6.1*** *A respondent (17) belonging to a research institute provided the same bottleneck for this product.* *If the feedstock for phosphate is animal manure or other organic material, there is still organic carbon present which is not allowed.*			
4. Bio-based chemicals				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020

Single Cell Oil for oleochemical industry produced by yeasts	***Bottleneck IV.1/4/5/6.1*** *An interviewee (14) belonging to an EU funded project provided the same bottleneck for this product.*			Update to the regulation concerns organic fertiliser now, but does not necessarily have any updates regarding bio-based chemicals.
5. Bio-based plastics				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Bio-based plastics (PHA)	***Bottleneck IV.1/4/5/6.1*** *An interviewee (14) belonging to an EU funded project provided the same bottleneck for this product.*	**Driver IV.5.1** A respondent (11) belonging to an EU funded project considers the fact that the Fertilisers Regulation clearly states EoW criteria from products derived from sewage sludge to be used as fertilisers. So this would apply for chemicals/materials derived from processing of sewage sludge when they are used as fertilisers. Possible applications for PHA in this sense are slow release fertiliser matrixes. The respondent further states that PHA can be used as a coating to obtain controlled	**Driver IV.5.1** It seems that the respondent refers to the possibility to add fertilising products to the list of EC fertilisers (annex I) if it fulfils the requirements of article 14. Following the procedure of article 31. However, there is no mention of PHA as a fertilising product	In the new regulation (2019/1009), there is a brief outline regarding sewage sludge and the new technologies for recycling of it. It states that there is a need for a regulation that provides a green light to products that currently have barriers to their material end-use, for example. **Driver IV.5.1** concerns the fact that there is no mention of PHA as a fertilising product in the original regulation and the same goes for the new regulation. The mention of recycling is within part (58) of the pretext of the regulation. Point (60) says '*An EU fertilising product can contain polymers other than nutrient polymers. However, this should be limited to cases where the purpose of the polymer is that of controlling the release of nutrients or increasing the water retention capacity or wettability of the EU fertilising product. It should be possible for innovative products containing such polymers to access the internal market.*'

		release fertilisers. They could replace polyurethane coatings that under the new Fertiliser ordinance will need to be replaced by biodegradable polymers. It should be possible to use PHA derived from sewage sludge for this application.		
6. Bio-based food & food ingredients				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Omega-3 fatty acids	***Bottleneck IV.1/4/5/6.1*** *An interviewee (14) belonging to an EU funded project provided the same bottleneck for this product*			Same applies under the new regulations such that fatty acids are not mentioned, but organic fertiliser is now included.

VI. EU REACH Regulation

The old report refers to feedback on the REACH Regulation (1907/2006/EC). Since then a number of amendments have been made. The current version can be found here.

2020 Updated Conclusion:

- Amendment to Annex V adds digestate to the exemptions. This is specifically related to Bottleneck VI.4 o it is effectively eliminated. No other significant updates.

1. Fertiliser (organic/inorganic)				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Organic fertiliser (compost or digestate)	**Bottleneck VI.1.1** One of the respondents belonging to industry (4) stated that it is not clear which information has to be provided to fulfill the requirements of Article 2(7)(b) of the REACH regulation. **Bottleneck VI.1.2** One of the respondents belonging to EU projects (11) argued that registration of new products to the market, such as UVCB (Substance of Unknown of Variable Composition) including biological materials, entails so high costs that it is impossible for SME's to register its bio-based products. According to this respondent all materials recovered from waste which will not be in direct contact with persons during their use should be exempted from REACH registration. **Bottleneck VI.1.3** One of the respondents belonging to EU projects (13) argued that the required REACH registration could be a barrier for new bio-based products as they will need to be registered for the first time. This is a barrier to develop new bio-based products. This	**Driver VI.1.1** According to one of the respondents belonging to industry (4) one of the drivers of REACH is that compost is exempted from REACH registration.	**Bottleneck VI.1.1. & VI.1.4** Article 2(7)(b) of the REACH-regulations sets out criteria for exempting substances covered by Annex V from the registration, downstream user and evaluation requirements. The problem identified here is that the criteria for exempting substances covered by Annex V of the REACH-regulations are formulated in a general way. Entry 12 of the document Guidance for Annex V prescribes that the exemption for compost covers compost when it is no longer waste according to Directive 2008/98/CE, and is understood as being applicable to substances consisting of solid particulate material that has been sanitised and stabilised through the action of micro-organisms and that result for the composting treatment. However, Entry 12 of the document Guidance for Annex V states that the explanation about biogas is without prejudice to discussions under Community waste legislation on the status, nature, characteristics and potential definition of compost, and may be updated in the future. **Bottleneck VI.1.2 & VI.1.3 & VI.1.5**	**Bottleneck VI.1.1** Regarding update to Bottleneck VI.1.1 there are no amendments that have updated Annex V which outlines the requirements for Article 2(7)(b) of the regulation. The only change was a word replacement as mentioned below. **Bottlenecks VI.1.2, VI.1.3 & VI.1.4** Those bottlenecks concern updates to the exemptions which are outlined in Annex IV and V. Specifically, Annex V was amended on 30 Oct 2019 and replaced the exemption 'compost and biogas' to include digestate. Thus, Bottleneck VI.1.4 is no longer a bottleneck. **Bottleneck VI.1.2, VI.1.3 & VI.1.5** Those bottlenecks concern high costs of registration. This has not been addressed in the amendments. Amendments to Article 41 raised the percentage of dossiers to receive compliance from 5% to 20%. This is in effect until December 31 2023 for tonnage bands of 100 tonnes or more and December 31 2027 for tonnage

	bottleneck is closely related to bottleneck VI.1.2. **Bottleneck VI.1.4** One respondent belonging to industry (4) and one respondent belonging to a research institute (17) stated that digestate is not exempted from REACH and should be exempted from this regulation as is the case for compost an biogas.		These bottlenecks relate to the registration costs of (new) bio-based products. This is an administrative burden, especially to bring new bio-based products on the market. The cost to register a product are a barrier for SME's.	bands of less than 100 tonnes per year.
Hydrochar (HTC biochar)	**Bottleneck VI.1.5** One of the respondents belonging to research institutes (15) argued that the registration costs for new products under REACH are (too) high. This bottleneck is closely related to bottleneck VI.1.2 and bottleneck VI.1.3. The respondent argues that the cost influencing costs should be taken into account, for example the registered product potential contribution to EU climate targets.			
4. Bio-based chemicals				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Biosurfactant	**Bottleneck VI.4.6** One of the respondents belonging to an EU project (13) argued that biosurfactant should be characterised as a chemical reagent.	.	**Bottleneck VI.4.6** The respondent seems to suggest that biosurfactants are treated differently than (chemical) surfactants. Article 2(7)(b) of the REACH-regulations sets out criteria for exempting substances covered by Annex V from the	The only updates to Annex V after Q1 2018 concern adding digestate. Therefore, surfactants are not covered. There are no updates to Article 2 and so this does not alter any exemptions with regard to surfactants (**Bottleneck VI.4.6**) or
(Poly) lactic acid	**Bottleneck VI.4.7** One of the respondents belonging to			

	an EU project (13) stated that it is hard to fulfill all the requirements of Article 2.7. (d) of the REACH-regulation.		registration, downstream user and evaluation requirements. The document Guidance for Annex V describes the exemptions from the obligations to register in accordance with Article 2(7)(b) of the REACH Regulation. Surfactants are exempted from registration in so far a chemical reaction takes place with a substance in the context of its use as surfactant. Thus, only the products derived from the surfactant as a result of its reaction with another substance are exempted from the registration provision. The manufacture or import of a surfactant itself is subject to the registration provisions. (see entry 4 of the Guidance for Annex V). **Bottleneck VI.4.7 & VI.4.8** The respondents seem to suggest that the requirements to apply Article 2.7.(d) are too strict. The exemption from registration for recovered substances in Article 2.7.(d) of REACH relies on the condition that the same substance has been registered before. The recovered substance must be the same as the substance already registered. Although the registration provision under REACH does not apply to	adipic acid and 1,5-pentanediamine (**Bottleneck VI.4.8**). No article 2 amendments are in place otherwise.
Adipic acid Muconic acid / 1,5-pentanedia mine	**Bottleneck VI.4.8** One of the respondents belonging to an EU project (8) argued that the monomers (Adipic acid and 1,5-pentanediamine) only are exempted from REACH registration if Article 2.7 (d) can be fulfilled.			

			polymers, an importer of polymer is required to register the monomers and other substances used to manufacture the polymer. For recovered polymers, the monomers and other substances have to be registered in order to be able to rely on the exemption of Article 2.7(d). The impurities in the monomer need to be identified and to establish the hazard profile as well as the classification and labelling of the recovered monomer.	
5. Bio-based plastics				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Bio-based plastics (PHA)	**Bottleneck VI.5.9** One of the respondents belonging to EU project (8) argued that in some cases bio-based polymers need to be registered, although polymers are in principle exempted from registration. **Bottleneck VI.5.10** One of the respondents belonging to industry (7) stated that the rules for non-pure bio-based products, such as PHA polymers with low purity, are not clear and the respondent argues that a better definition for bio-based products that are not totally pure should be included. **Bottleneck VI.5.11** Poly-hydroxy-alkanoates are falling under the category of polymers	**Driver VI.5.2** A respondent belonging to an EU project (11) PHA (and PHA precursors) fall within the definition of polymer and are exempted from REACH registration.	**Bottleneck VI.5.9 & VI.5.10 & VI.5.11 and Driver VI.5.2** Respondents seem to argue that although polymers are exempted from registration, this is not the case for bio-based polymers as the monomers are subject to registration or because of the impurity of these polymers. Polymers are exempted from registration under REACH. According to Article 6(3), the manufacturer of a polymer must however submit a registration for the monomer substance(s) that have been not already been registered, if: (a) the polymer consists of 2% weight by weight (w/w) or more of such monomer substance(s) or other substance(s) in the form of monomeric units and chemically bound substance(s);	Regarding **Bottleneck VI.5.10** the amendments throughout the consolidated version up to 24 August 2020 do not contain any additional classification regarding UVCB. There have not been any clarifications to the definition of monomer in further amendments.

	according to REACH and thus exempted from registration. However, if the PHA has a level of impurities of 2% and whose composition is not known, it would be identified as an UVCB and not be exempted from registration, stated one of the respondents belonging to an EU project (11).		(b) the total quantity of such monomer substance(s) or other substance(s) makes up 1 tonne or more per year (the total quantity in this context is the total quantity of monomer or other substance ending up chemically bound to the polymer). Whenever it is not scientifically possible to establish 1) whether the substance falls under the definition of a polymer or 2) the chemical structure of the monomer unit(s), the substance can be regarded as a UVCB substance. In this case the registration for the substance itself can be submitted. A respondent further states that in the case of PHA production from fermented waste the monomers are the volatile fatty acids (VFA's) in the fermented waste. There can be many different types of VFA's that are used by the bacteria to product the PHA. The PHA product can be made such that it has more than 98% purity. In this case it is not clear whether they are exempted or the monomer has to be registered. In that case: the PHA polymer and the repeating chains in the polymer can be well defined, but the feed composition is much more difficult to define and may vary, while the bacteria still make a similar polymer. Here bio-based production differs from classical polymer production. Therefore, the REACH	

			regulation should provide clarity on how to interpret “monomer” in this case. We propose that the regulation should look at the repeating chains in the PHA and define this as the “monomer”.	

VII. EU Waste Framework Directive

The old report refers to feedback on both the 'old' EU Waste Framework Directive 2008/98/EC and the feedback on the proposal to change the WFD (2015/0274/COD). As the proposal has resulted in the newly adopted Directive 2018/851/EU amending the WFD, the analysis in the old report also refers to this Directive which can be found here. For the 2020 update, Directive (EU) 2018/851 amending Directive 2008/98/EC has been analysed.

2020 Updated Conclusion:

- Measures on bio-waste related to separate collection and recycling targets in the revised WFD (new legislation) remain a strength also in the updated regulations

- While the old report emphasises municipal waste recycling targets and the elaboration on the incentives for the application of the waste hierarchy as positive developments, legislation in other sectors is criticised for the non-level playing field between energy and material (see conclusions for REDII).

- One of the main obstacles is the lack of separate bio-waste collection in many Member States and regions. This was mentioned three times and repeated for several product categories (*see e.g. Bottleneck VII.1/4/6.2 (old legislation)*).

- The change in the revised waste legislation to set up a separate bio-waste collection correspondingly is one of the most often mentioned drivers. However, the goal is set for 2024, so the results will not be immediately tangible.

- The lack of End-of-Waste criteria criticised by a number of respondents is solved by the amendment of general EoW criteria. This should also simplify the process of reaching EoW status, a problem also mentioned by respondents.

- Another criticism from the old report was a lack of a clear reference to treatment of bio-waste outside of composting and digestion. Other treatment like chemical recycling is not included in the updated legislation. Therefore, this criticism remains relevant.

1. Fertiliser (organic/inorganic)				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Compost or digestate	**Bottleneck VII.1.1 (old legislation)** A respondent representing a waste management company (1) stated that the distinction between source separated and not source separated OFMSW should be clear (in relation to the old WFD). E.g. compost from mixed MSW and sewage sludge cannot be used in agriculture (risks are too high). They recommend a definition of bio-waste that is source separated. **Bottleneck VII.1/4/6.2 (old legislation)** A respondent (4) belonging to relevant industry argued that the old WFD does not stimulate the implementation of the separate collection of bio-waste. The separate collection of bio-waste should become mandatory without exemptions. **Bottleneck VII.1.3 (old & new legislation)** The respondent (4) considered	**Driver VII.1/4/5.3 (old & new legislation)** A respondent (6) representing a government authority stated that the separate collection of bio-waste with a view to the digestion and composting of bio-waste according to article 22, contributes to the production of high quality organic fertilisers. **Driver VII.1.4 (new legislation)** A representative from an EU project (13) argues that the combination of the conditions for OFMSW of the new WFD (separate collection), and the possible EoW criteria for bio-based fertilisers according to the new proposed Regulation (2016/084/COD) form an important driver for bio-based fertiliser products.	**Bottlenecks VII.1.1 (old legislation) ,VII.1/4/6.2 (old legislation) and Driver VII.1.1 (new legislation)** These bottlenecks and driver are based on the unrevised WFD. In the new WFD, the definition of bio-waste does not include reference to separate collection in either the old or new WFD (article 3 paragraph 4). However, article 22 on the treatment of bio-waste has changed substantially. From January 2024 onwards bio-waste has to be either separated and recycled at source, or be collected separately and not be mixed with other types of waste. It seems that the new WFD resolves the bottlenecks identified here. There is a clear focus and mandatory commitment on source separated bio-waste in the new article 22. There are however possible exemptions on the separate collection of bio-waste. E.g. waste with similar biodegradability and compostable properties as bio-waste may be collected together with bio-waste. Furthermore, according to the newly added article 11a paragraph 4 municipal bio-waste entering aerobic or anaerobic treatment may only count as recycled if it is separately collected or separated at source. **Bottleneck VII.1.3 (old & new legislation)**	**Bottlenecks VII.1.1 (old legislation) ,VII.1/4/6.2 (old legislation) and Driver VII.1.1 (new legislation)** The analysis of the previous report remains unchanged. **Bottleneck VII.1/3 (old & new legislation)** Article 10 (2) states, that where necessary, waste shall be subject to separate collection and shall not be mixed with other waste or other materials with different properties. **Bottleneck VII.1.4 (old legislation)** and **Driver VII.1/5.2 (new legislation)** The analysis of the previous report remains unchanged. **Bottleneck VII.1.5 (old & new legislation)** In the revised legislation article 6 is amended as follows: Member States shall take appropriate measures to ensure that waste which has undergone a recycling or other recovery operation is considered to

	that there is a lack of specific recycling targets for separately collected bio-waste. Including targets for industrial bio-waste. **Bottleneck VII.1.4 (old legislation)** A respondent (4) representing relevant industry argued that there was/is a lack of incentives to: - support the implementation of separate collection and management of bio-waste. - Encourage the use of recycled organic materials **Bottleneck VII.1.5 (old & new legislation)** Two interviewees belonging to relevant industry (4) and government authority (6) argued that both the old and the new WFD lack End-of-Waste criteria for biodegradable waste at EU level. **Bottleneck VII.1.6 (new legislation)** An interviewee (4) belonging to relevant industry further		The new WFD does mention that the Commission shall consider setting reuse and recycling targets for municipal bio-waste by 31 December 2024. This means that additional legislation is needed to set these targets. Furthermore, industrial bio-waste is not mentioned. There are however other indirect ways in which recycling and preparation for recovery for separately collected bio-waste is ensured (by excluding less desirable options with reference to the waste hierarchy): - Article 10(4) WFD does state that MS shall take measures to ensure that waste that has been separately collected for reuse and recycling pursuant of article 22 (on bio-waste) is not incinerated. - Article 5(3)(f) of the new Landfill Directive ensures that it is not allowed to landfill bio-waste. **Bottleneck VII.1.4 (old legislation) and Driver VII.1/5.2 (new legislation)** In the revised WFD a new paragraph is added to article 4 in which is stated that MS shall make use of economic instruments and other measures to provide incentives for the application of the waste hierarchy. Reference is made to Annex IVa which include measures to support separate collection of waste and encourage the use of recycled materials. E.g. Annex	have ceased to be waste if it complies with the following conditions: - the substance or object is to be used for specific purposes **Bottleneck VII.1.6 (new legislation)** The analysis of the previous report remains unchanged. **Bottleneck VII.1.7 (new legislation)** The analysed novel regulations do not indicate changes." **Driver VII.1/4/5.3 (old & new legislation)** The analysis of the previous report remains unchanged. " **Driver VII.1.4 (new legislation)** EoW criteria added for waste, that is used for a specific purpose after undergoing a recycling process. This applies to bio-degradable waste recycled to become bio-based fertiliser" **"Bottleneck VII.1.8 (old legislation)** The analysis of the previous report remains unchanged. "

	argued that no specific waste codes for municipal and industrial bio-waste are included. **Bottleneck VII.1.7 (new legislation)** The respondent (4) also found the inclusion of the TEEP clause in the new proposal to be counterproductive.		IVa paragraph 7: sustainable public procurement to encourage better waste management and the use of recycled products and materials. With this addition it seems that MS are activated to provide more incentives towards the goals mentioned in the bottleneck. **Bottleneck VII.1.5 (old & new legislation)** There has been no mention in the new Article 6 or the new WFD in general with regard to EoW criteria for bio-waste. However, following Recital 19 (2018/851/EU) that states that EoW rules can be established in product-specific legislation, the new Proposal for a Regulation laying down rules on the making available on the market of CE marked fertilising products 2016/084 (COD) does provide for EoW criteria for bio-waste for fertilising products (article 18). Thereby, providing possible EoW criteria for compost and digestate. **Bottleneck VII.1.6 (new legislation)** Recital 10 of Directive 2018/851/EU does mention codes for municipal waste based on Commission Decision 2014/955/EU. Chapter 20 of this Decision deals with municipal wastes, here are several codes deal with different forms of bio-waste. E.g. 200108: biodegradable kitchen and	**"Bottleneck VII.1.9 (old legislation)** The analysis of the previous report remains unchanged. " **"Bottleneck VII.1.10 (old legislation)** The analysis of the previous report remains unchanged."
Hydrochar (HTC biochar	**Bottleneck VII.1.8 (old legislation)** A representative (15) of a research institute argued that there are differences in Member State treatment of End-of-Waste criteria because of a lack of harmonisation. As MS are responsible and have the final decision for the End-of-Waste certification of products, this creates different approaches in different countries. **Bottleneck VII.1.9 (old legislation)** The respondent (15) also found the non-mentioning of HTC as relevant alternative technology (next to composting and digestion) for			

	treatment of bio waste an omission in Article 22 of the old WFD. **Bottleneck VII.1.10 (old legislation)** The respondent (15) also argued that the concept of "urban mining" should be included in EoW product certification criteria. "		canteen waste and 200201 biodegradable waste). **Bottleneck VII.1.7 (new legislation)** The TEEP clause is: Technically, Environmentally and Economically practicable. This clause relates to separate collection of waste and can be found in article 10 and 11 of both the old and the revised WFD and could result in exemptions on the separate collection of waste. In the proposal to amend the WFD this clause was also added to article 22 on bio-waste (2015/0275(COD)). **Driver VII.1/4/5.3 (old & new legislation)** The text mentioned as a driver is restructured in the revised WFD however, its content remains the same. (article 22(2)(a)) **Driver VII.1.4 (new legislation)** Combination of: - conditions for separately collected OFMSW (see analysis bottlenecks VII.1.1 (old), VII.1.2 (old) and VII.1.3 (old & new)) - EoW criteria of bio-based fertilisers under the new proposal for CE marked fertilising products (see analysis Bottleneck VII.1.5 (old & new)) Could indeed function as a driver for bio-based fertiliser products.	

			Bottleneck VII.1.8 (old legislation) According to article 6(3) of the new WFD MS can still set EoW criteria if they are not set at the Union level. Furthermore, when the Commission deems it necessary they can set EU-wide criteria (art. 6(2)). This was also possible under the old article 6(2). Recital 19 of the directive amending the WFD (2018/851/EU), also states that EoW rules can be established in product-specific legislation. With regard to fertiliser products these EoW rules are proposed in the new Proposal for a Regulation laying down rules on the making available on the market of CE marked fertilising products (2016/084/COD article 18) see bottleneck VII.1.5 (old & new). However, hydrochar is not mentioned in this proposal (see framework V for further information). **Bottleneck VII.1.9 (old legislation)** Article 22 paragraph 3 of the revised WFD also only mentions the creation of European standards for bio-waste intended for composting and digestion. Other products are not mentioned. However, article 22 paragraph 2(a) does mention: “recycling of bio-waste, including composting and digestion”. Thereby not limiting it to composting and digestion alone.	

			"Bottleneck VII.1.10 (old legislation) No mention of urban mining as a form of recovery operation (neither in the new or old WFD Annex II). It is however, a non-exhaustive list. Therefore the question remains how to incorporate this in legislation (e.g. as recovery or recycling technique).	
2. Biogas and biomethane				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Biomethane	**Bottleneck VII.2.11 (old legislation)** A representative (6) of a government authority stated that permitting difficulties arise when a biomethane plant is characterised as waste treatment facility.		**Bottleneck VII.2.11 (old legislation)** It does not seem that any changes have been made in the WFD with regard to the permitting process described in this bottleneck. According to article 23 of the WFD, MS have to require any establishment or undertaking who carries out waste treatment to obtain a permit from the competent authority with specific requirements. The issuing of a permit is also connected to article 13 on the protection of human health and the environment. If the treatment is not in line with this article, a permit will not be issued.	**Bottleneck VII.2.11 (old legislation)** Article 13 & 23 of the WFD have not been subject to amendments. Therefore, the analysis of the previous report remains unchanged.
3. Bioethanol and biomethanol				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 202
Bio-methanol/Bio-ethanol	**Bottleneck VII.3.12 (old & new legislation)** A respondent belonging to relevant industry (5) argued		**Bottleneck VII.3.12 (old & new legislation)** In the new WFD the waste hierarchy (article 4) stays the same and annex II	**Bottleneck VII.3.13 (new legislation)** The measures already mentioned in Annex IV of the original WFD has been expanded in the

	that the waste conversion for advanced biofuels should be higher in the waste hierarchy. As biofuel production is currently at the same level in the hierarchy as incineration with energy recovery. While there is a higher economic value in reprocessing waste for the biofuel sectors than simply incinerating the waste for stationary energy production according to the respondent. The respondent states that the Commission services should fine-tune the waste hierarchy by making a distinction between the use of waste for energy (incineration) purpose ONLY and the use of the waste for chemicals, biofuel and/or bioplastics. This sort of processing should be equal to recycling. **Bottleneck VII.3.13 (new legislation**) The respondent (5) also stated that the WFD lack mechanisms to encourage price premiums for chemicals produced from wastes. Chemicals from waste receive the same price as		does not change in relation to this bottleneck. According to Annex II (R1) the use of waste for fuel is indeed regarded as equal to waste used for incineration with high levels of energy recovery. See also: the role of waste-to-energy (European Commission).	revised WFD (Annex IVa). It could be possible for MS to provide incentives based on Annex IV (for example based on paragraph 11). However, there is no specific mention of waste-to-chemicals in the WFD or EU-wide harmonisation of incentives for waste-to-chemicals. **Bottleneck VII.3.14 (new legislation)** Paragraph 1 of the annex IVa of the new WFD states that charges and restrictions for the landfilling and incineration of waste are examples of economic measures to provide incentives for the implementation of the waste hierarchy. No further guidance is given. The Commission could be advised to provide guidance documents on how to implement landfill and incineration charges while ensuring that recovery of wastes for conversion to fuels and chemicals is not subjected to these charges. **Bottleneck VII.3/5.15 (old legislation)** As stated in Bottleneck VII.1.5 (old & new), the Commission could introduce EU-wide EoW criteria for bio-products based on the WFD. In relation to organic fertiliser products

	chemicals from virgin material. The production of products from wastes requires the use innovative technologies and costs are typically higher than production of virgin fossil sources **Bottleneck VII.3.14 (new legislation)** The respondent (5) further argued that more guidance on landfill and incineration charges should be offered, ensuring that recovery of wastes for conversion to fuels and chemicals is not subjected to these charges. **Bottleneck VII.3/5.15 (old & new legislation)** A representative (13) of an EU project argued that end-of-waste status needs to be developed for bio-products and by-products on an EU level. Thereby promoting the production of bio-products from bio-waste beyond only compost and digestate. **Bottleneck VII.3.16 (old legislation)**			these EoW criteria are included in product specific legislation (2016/084/COD). It seems that this is not the case for the product discussed here (bio-ethanol) or bio-plastics (this bottleneck is also mentioned in relation to this product). According to a respondent this leads to lack of clarity and homogeneity among MS. Greater harmonisation and simplification of the legal framework on by-products and end-of-waste status could help. Introduction of an obligation for the Commission to act where divergent EoW/by-product criteria exist among member states (as suggested by a respondent (9)) could be an interesting approach. **Bottleneck VII.3.16 (old legislation)** The respondent argues for the inclusion of bio-products production in the WFD. E.g. by changing article 22(2)(a) of the revised WFD, the paragraph now states that MS shall take measures to encourage the recycling of bio-waste, including composting and digestion. The inclusion of bio-product production to composting and digestion would stimulate bio-product production in

	The representative (13) also argued that the WFD lacks a suggestion to production of bio-products from waste or an obligation to produce a percentage of bio-products from OFMSW. There should be a broader focus then only compost and digestate. "			their view. It is important to note that the article does not exclude other forms of recycling than composting and digestion. Furthermore, paragraph 2(c) of article 22 is specifically directed at promoting the use of materials produced from bio-waste. **Bottleneck VII.3.12 (old & new legislation)** In the new WFD, the following paragraph is added to Article 4: Member States shall make use of economic instruments and other measures to provide incentives for the application of the waste hierarchy, such as those indicated in Annex IVa or other appropriate instruments and measures. Annex IVa, paragraph 12 includes economic incentives for regional and local authorities, in particular to promote waste prevention and intensify separate collection schemes, while avoiding support to landfilling and incineration. The waste hierarchy and Annex II remain unchanged. **Bottleneck VII.3.13 (new legislation)**

				The analysis of the previous report remains unchanged. " **Bottleneck VII.3.14 (new legislation)** The analysis of the previous report remains unchanged. **Bottleneck VII.3/5.15 (old legislation)** As stated in Bottleneck VII.1.5 (old & new): In the revised legislation article 6 is amended as follows: Member States shall take appropriate measures to ensure that waste which has undergone a recycling or other recovery operation is considered to have ceased to be waste if it complies with the following conditions: - the substance or object is to be used for specific purposes **Bottleneck VII.3.16 (old legislation)** The analysis of the previous report remains unchanged"
4. Bio-based chemicals				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Single Cell Oil	**Bottleneck VII.4/5/6.18 (new legislation)**	***Driver VII.1/4/5.3 (old & new legislation)*** *This driver was also*	**Bottleneck VII.4/5/6.17 (old & new legislation)**	**Bottleneck VII.4/5/6.17 (old & new legislation)**

	The representative (14) further argued that specific rules for remaining bio-fractions of MSW should be included in the WFD. **Bottleneck VII.4/5/6.19 (old & new legislation)** The respondent (14) further argued for the inclusion of biodegradable plastics in the WFD. Moreover, the respondent wants to include priority options for extracting substances from the bio-waste."	*mentioned by a representative of an EU project (14).* **Driver VII.4/5.5 (new & old legislation)** According to two respondents (8 and 13) belonging to EU projects, the waste hierarchy benefits the innovative product generation from waste.	The definition of bio-waste in the revised WFD has been expanded to include some forms of biodegradable waste (article 3(4)). However, UWWS is excluded. The definition provided by the OECD does include sludge and while the directive 2018/851/EU does emphasise the importance of the definition of municipal waste to be in line with the OECD (recital 10), this is not stated for bio-waste. For undertakings that use both UWWS and OFMSW feedstock it is difficult if these waste streams are treated/defined differently in the relevant EU legislation. See also the framework on Sewage Sludge directive (VIII). The respondent states that if the same OECD definition on biological waste would apply in the WFD, the Landfill directive and the Sewage sludge directive, a more coherent waste legislation could be achieved and waste stream management with VFAP could be facilitated. **Bottleneck VII.4/5/6.18 (old & new legislation)** The respondent argues that further rules are needed for the bio-fractions of the MSW that remain after compliance with the mandatory separate collection and treatment of bio-	UWWS has not been added to the definition of bio-waste in the WFD. Therefore, the analysis of the previous report remains unchanged. **Bottleneck VII.4/5/6.18 (old & new legislation)** The analysis of the previous report remains unchanged. **Bottleneck VII.4/5/6.19 (old & new legislation)** As stated in Bottleneck VII.1.5 (old & new) and Bottleneck VII.3.15: In the revised legislation article 6 is amended as follows: Member States shall take appropriate measures to ensure that waste which has undergone a recycling or other recovery operation is considered to have ceased to be waste if it complies with the following conditions: - the substance or object is to be used for specific purposes This may also include bio-plastics and VFAP in the scope of EoW criteria"
Medium chain fatty acids and Volatile fatty acids (VFA)	**Bottleneck VII.4.20 (old & new legislation)** A respondent (7) belonging to relevant industry stated that the EoW process for by-products Is unclear and complex. Hereby limiting the development of promising recovery technologies.			
(Poly) lactic acid and Adipic acid/Muconic acid	**Bottleneck VII.4/5.21 (old & new legislation)** Two respondents (8 and 13) belonging to EU projects argue that the transport and treatment of waste in this value chain (polylactic/ adipic/muconic acid) itself is			

	more impressive than the result and therefore it is not a recovery (this is related to the efficiency of the process and the logistics). They suggest improving the logistics of the system and efficiency of the processes. Furthermore, they suggest to carry out a global assessment of the initial waste reduction versus the efficiency of the product obtained.		waste from municipal waste. Hereafter, there might still be remaining bio-fractions in MSW due to e.g. waste misthrow and mixed bio-waste (with meat). These remaining bio-fractions could be considered for volatile fatty acids platform treatment (VFAP). In the revised WFD, OFMSW treatment in AD is no more considered as recycling from 2027, due to separate collection requirements in article 11a (4) WFD. **Bottleneck VII.4/5/6.19 (old & new legislation)** This bottleneck is related to Bottleneck VII.3.15 (old), the respondent also wants to include more products and techniques to the WFD to stimulate the value chain of the discussed products. E.g. volatile fatty acids platform (VFAP) and bio-plastics. **Bottleneck VII.4/5.20 (old & new legislation)** In the revised WFD the EoW requirements for by-products have not changed (article 5(1)(a-d). However, similar as with EoW requirements in article 6, the MS have a more direct responsibility to take appropriate measures (article 5(1) and (3)). Moreover, the rules for EU-wide requirements for by-products are also	**Bottleneck VII.4/5.20 (old & new legislation)** The analysis of the previous report remains unchanged. **Bottleneck VII.4/5.21 (old & new legislation)** Bottleneck does not describe improvements for the regulation. Therefore, the analysis of the previous report remains unchanged. **Driver VII.4/5.5 (old & new legislation)** The waste hierarchy was not part of the update. Therefore, the analysis of the previous report remains unchanged.

			explained in more detail (article 5(2)). This does however, not result in compulsory harmonisation. **Bottleneck VII.4/5.21 (old & new legislation)** This is not a better regulation action but rather better knowledge. Global assessment is required and further development of the process and logistics. **Driver VII.4/5.5 (old & new legislation)** The correct application of the waste hierarchy stimulates the reuse and recycling of waste above other alternatives such as incineration and dumping. As the conversion of waste into chemicals can be seen as recycling this helps the value chain of the product discussed here. "	
5. Bio-based chemicals				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Bio-based plastics (PHA)	***Bottleneck VII.3/5.15 (old & new legislation)*** *This bottleneck is also mentioned by a representative of an EU project (9) in relation to bio-based plastics.*	**Driver VII.1/5.2 (new legislation)** This driver was also mentioned by a representative of an EU project (9). **Driver VII.1/4/5.3 (old & new legislation)**	**Bottleneck VII.5.22 (old & new legislation)** Article 13 of the old WFD states that waste management must be carried out without endangering human health and the environment. This article and its application has not change in the revised WFD. The specific product and hygiene conditions for the use of waste streams as a feedstock for	**Bottleneck VII.5.22 (old & new legislation)** The analysis of the previous report remains unchanged. **Bottleneck VII.5.23 (old legislation)** The revised directive updated the EoW criteria as follows:

	Bottleneck VII.4/5/6.17 (old & new legislation) *This bottleneck was also mentioned in relation to bio-based plastics by the same respondent belonging to an EU project (14) and by another (11).* ***Bottleneck VII.4/5/6.18 (old & new legislation)*** *This bottleneck was also mentioned in relation to bio-based plastics by the same respondent belonging to an EU project (14).* ***Bottleneck VII.4/5/6.19 (old & new legislation)*** *This bottleneck was also mentioned in relation to bio-based plastics by the same respondent belonging to an EU project (14).* ***Bottleneck VII.4/5.20 (old & new legislation)*** *This bottleneck was also mentioned in relation to PHA by*	This driver was also mentioned by a representative of an EU project (11).	products can be found in product specific or hygiene legislation and therefore that specific legislation would have to be revised to solve this bottleneck. **Bottleneck VII.5.23 (old legislation)** The bottleneck was made in regard to the old WFD, however, it is also relevant with regard to the revised WFD. The example given by the respondent illustrates their point clearly: the EoW criteria, formulated by the Joint Research Centre, for biodegradable waste subject to biological treatment to produce compost and/or digestate, excludes digestate and compost materials derived from the organic fraction of mixed municipal waste and sewage sludge because of their impurities. This while the techniques used in the creation of e.g. bi-polymers consists of a much more extensive biological and chemical treatment of the waste feedstock resulting in higher removal of impurities and contaminants. However, as another respondent (14) stated, the proposal for CE marked fertilisers (2016/084/COD: annex II part II CMC 3&5) mentions OFMSW and UWWS as ingredients for CE marked fertilisers if treated by AD and not exceeding a certain limit of contaminants (pp.27-29). **Driver VII.5.6 (new legislation)**	1. Member States shall take appropriate measures to ensure that waste which has undergone a recycling or other recovery operation is considered to have ceased to be waste if it complies with the following conditions:

	the same respondent belonging to relevant industry (7). ***Bottleneck VII.5.22 (old legislation)*** *A representative from an EU project (13) mentioned that there is a lack of consistency in product and hygiene legislation in relation to waste as a feedstock. Many uses of PHAs produced from waste feedstocks are suspect or prohibited.* ***Bottleneck VII.5.23 (old legislation)*** *A respondent belonging to an EU project (11) argued that new technologies and new bio-products require a reframing/re-construction of the principles of the present regulations for waste valorisation. Especially as these new technologies can offer much higher protection against contamination but do not fit the current legislative frame*.		The revised article 11(2) WFD sets binding targets for the preparing for re-use and recycling of municipal waste.	

6. Bio-based food and food ingredients				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Omega-3 fatty acids	***Bottleneck VII.1/4/6.2 (old legislation)*** *A representative of an EU project (14) also mentioned this bottleneck in relation to this product.* **Bottleneck VII.4/5/6.17 (old & new legislation)** This bottleneck was also mentioned in relation to this product by the same respondent belonging to an EU project (14) **Bottleneck VII.4/5/6.18 (old & new legislation)** This bottleneck was also mentioned in relation to this product by the same respondent belonging to an EU project (14). **Bottleneck VII.4/5/6.19 (old & new legislation)**			

	This bottleneck was also mentioned in relation to this product by the same respondent belonging to an EU project (14).			
7. Recovered cellulose				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Cellulose	**Bottleneck VII.8.24 (old legislation)** A respondent from an EU project (11) found that the procedures to let a product derived from waste loose its waste status (EoW criteria) are complex in the old WFD.		**Bottleneck VII.8.24 (old legislation)** As can be read above, there have been several changes with regard to EoW criteria in the revised WFD (see Bottleneck VII.1.7 (old). However, it does not seem that the process has become simpler for the product discussed here (cellulose).	**Bottleneck VII.8.24 (old legislation)** The EoW criteria have been revised and state as follows: 1. Member States shall take appropriate measures to ensure that waste which has undergone a recycling or other recovery operation is considered to have ceased to be waste if it complies with the following conditions: (a) the substance or object is to be used for specific purposes;' This should simplify the process of losing the waste status after recycling.

VIII. EU Sewage Sludge Directive

The feedback in the old report refers to feedback on the Sewage Sludge Directive (Directive 86/278/EEC). For the 2020 update, the Sewage Sludge Directive that has been consolidated in June 2018 has been analysed. It can be found here. Additional updates for 2021 do not cover the bottlenecks outlined for each of the categories.

2020 Updated Conclusion:

- The main conclusion with the sewage sludge directive is the current evaluation under way of the directive from which there may be an entirely updated directive.

1. Fertilisser (organic/inorganic)				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Hydrochar (HTC biochar)	**Bottleneck VIII.1.1** A research institute indicated (15) that there is a lack of common interpretation between member states of sewage sludge derived products applicability in agriculture. Therefore it is recommended to include advanced sewage sludge upgrading technologies, such as HTC or pyrolysis, among the treatment technologies considered viable solution for the production of sewage sludge end of waste product in all member states.	**Driver VIII.1.1** A research institute (15) indicated that the limits to heavy metal concentration in the sewage sludge directive is an important driver for the application of hydrochar derived from sludge in agriculture. This is due to the fact that the HTC process, in comparison to raw dried sludge, concentrates carbon nutrients but also some other heavy metals.	**Bottleneck VIII.1.1** indicates a regulatory divergence between member states regarding allowed sewage sludge upgrading technologies and limit values of heavy metals. Regulatory divergence in general regarding the sewage sludge directive was also mentioned in the 2014 '’ex-post evaluation of Five Waste Stream Directives’’ by the European Commission. This divergence is due the fact that the directive has not been updated for many years and therefore most member states have implemented stricter limits to heavy metals the application of sewage sludge for agricultural purposes in national regulations. **Driver VIII.1.1.** however indicated that the sewage sludge directive in general can be a driver for the Hydrochar production since the heavy metal limits set by the directive stimulates	**Bottleneck VIII.1.1** recommends to include advanced treatment as viable solutions for the production of sewage sludge. Of note, though, is a plan to update the Directive as outlined in the New Circular Economy Action Plan from March 2020 (see: https://ec.europa.eu/environment/circular-economy/). The Landfill as well as the Waste Water Directives also relate to sewage sludge and the treatment of it and have been updated for 2020 separately. The Directive 2018/851 amending 2008/98 on waste has also been updated and applies to application of sewage sludge on agriculture. More specifically, biological sewages sludge can be treated in order to produce biosolids. This in part relates to **Bottleneck VIII.1.1** as it refer to the treatment of sewage sludge for application in agriculture. There is an evaluation of the directive under way (2020) exploring, efficiency, effectiveness, coherence, relevance and European added value. The questions and inquiries that will be explored in the evaluation can be located here (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=PI_COM%3AAres%282020%293116544).
4. Bio-based chemicals				

Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Single cell oil for oleochemical industry produced by yeasts	**Bottleneck VIII.4/5/6.2** A respondent belonging to a EU project (14) indicated that to stimulate the use of Volatile Fatty Acids platform within Anaerobe Digestion to bio-based products would need to be regulated or documented as a preferable application of sewage sludge instead of other methods, such as direct application in agriculture (which is mentioned in the sewage sludge directive).		**Bottleneck VIII.4/5/6.2** indicated that the EU regulatory framework regarding sewage sludge application should promote new treatment technologies, such as Volatile Fatty Acids Platform, by giving preference to these technologies instead of direct application of sewage sludge in agriculture. However, since the sewage sludge directive is intended to promote the use of (treated) sewage sludge in agriculture, it would require changing and extending the current scope and objective of the sewage sludge directive.	Again, **Bottleneck VIII.4/5/6.2** refers to the processing and treatment of sewage sludge. An overhaul of the directive is expected but not yet in effect. The evaluation will take into account the thresholds and look at updates to treatment technologies.
5. Bio-based plastics				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Polyhdroxy alkanoate (PHA)	**Bottleneck VIII.5.3** A respondent belonging to a EU project (11) indicated that the sludge directive is outdated and would need a comprehensive evaluation and reformulation to be aligned with the Circular Economy Package**.**		**Bottleneck VIII.5.3** Indicated a need for the directive to be reformulated and aligned with the Circular Economy package. The directive has been earmarked for revision for several years but so far no new EU action regarding this directive has been announced.	As stated before, there are plans for 2021 to update the sewage sludge directive as an alignment with the circular economy plan.
Bio-based plastics	***Bottleneck VIII.4/5/6.2*** *A respondent belonging to an EU project (14) provided the same bottleneck for this product*			
6. Bio-based food and food ingredients				

Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Omega-3 fatty acids	***Bottleneck VIII.4/5/6.2*** *A respondent belonging to an EU project (14) provided the same bottleneck for this product*			

X. EU Renewable Energy Directive

On the old report, respondents' feedback was directed at the Commission proposal for a revised EU Renewable Energy Directive (RED II, 2016/0382(COD)). As this proposal has been amended by Parliament and Council and later adopted in Parliament after the conclusion of the trilogue negotiations, the compromise text of RED II has been used to analyse the provided feedback in the old report. The version of the RED II analysed in the old report has been published in the Official Journal of the European Union and can be found here. For the 2020 update the consolidated text of the Directive (EU) 2018/2001, which was released on 11 December 2018, can be found here.

- The conclusion drawn in the analysis in the old report[154] is positive, mentioning the ambitious goal of 27% of renewable energy in the final consumption (which has been raised to 32% in later negotiations) as a driver for innovation. Those aspects remain correct and currently even higher targets are discussed under the Green Deal and the Energy Union.
- However, apart from some product- or material-specific barriers (e.g. the lack of support schemes for commercial-scale deployment of advanced biofuels, Bottleneck X.3.9 (new legislation)), it is also recognisable that one of the main barriers is the non-level playing field between energy and material applications when it comes to using bio-waste and wastewater sludge. In the context of the REDII, two recitals and one article call for Member States to respect the waste hierarchy (therefore preferring material recycling as opposed to energy recovery, see e.g. Bottleneck X.4/5/6.11 (old legislation)) when designing their renewable energy policies. However, the much stronger and more concrete Article 25 and Annex IX still awards double counting to biofuels made from bio-waste, therefore setting up strong incentive mechanisms to direct bio-waste to energy applications instead of higher value-added materials.
- This discrimination of bio-based materials is even reinforced by rather beneficial GHG accounting methodology for bioenergy prescribed by REDII compared to rather strict values proposed by JRC (see Bottleneck X.4.13 (new legislation)).
- In contrast, the majority of mentioned drivers fall under the strategic sphere (setting out goals and visions), lacking specific legal implementation (see e.g. Bottleneck X.4/5/6.14 (new legislation) & driver X.4/5/6.8 (new legislation)). This is a weakness.

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[154] Urban Agenda for the EU. (2018). Survey report on regulatory obstacles and drivers for boosting a sustainable and circular urban bio-based. economy https://ec.europa.eu/futurium/en/system/files/ged/analysis_of_regulatory_obstacles_and_drivers_urban_circular_bioeconomy_report_final_version_29.10.19_rv_27.04.2020.pdf

1. Fertiliser (organic/inorganic)				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Compost/Digestate	**Bottleneck X.1.1 (new legislation)** A representative of a group of bio-waste companies (4) said that support schemes for energy from bio-waste are not in line with EU waste hierarchy. This respondent (4) pointed out that public financial support for energy generation that undermines the waste hierarchy should be phased out in order to achieve higher separate collection and recycling rates.	…	**Bottleneck X.1.1 (new legislation)** This bottleneck is based on RED II prior to trilogue negotiations. It appears that the compromise text of RED II addresses this bottleneck by including a new Article 3(1) which urges Member States to design their national policies, based on Article 25, with due regard to the waste hierarchy. Furthermore, the recitals of the compromise text (in particular recitals 20 and 36) emphasise the principles of the waste hierarchy. Support schemes for renewables sources of energy should consider these principles. **Bottleneck X.1.2 (new legislation)** The final compromise text does contain a number of provisions instructing the Member States on how to calculate the share of energy from renewable sources or to ensure that consumers are entitled to become self-consumers. Article 27 and, more specifically, Annex 1a to the Governance Regulation (2016/0375(COD)) does provide guidelines for individual targets for Member States by proposing an	**Bottleneck X.1.1 (new legislation)** While the analysis of the old report remains correct (Article 3(1) was finally adopted as such), the stronger regulatory measures still favour energy generation from bio-waste as compared to bio-based products. This is especially evident in the fact that Annex IX lists bio-waste as a feedstock for advanced biofuels, which may be counted for the quota with twice their energy content. **Bottleneck X.1.2 (new legislation)** The analysis of the previous report remains correct, even though it might be questioned if this is what was meant by the respondent. **Bottleneck X.1.3 (new legislation)** The analysis of the previous report remains correct. **Bottleneck X.1.4 (new legislation)**
Hydrochar (HTC biochar)	**Bottleneck X.1.2 (new legislation)** A representative of a University (15) states that there is no structured pathway for individual Member States towards renewable energy. **Bottleneck X.1.3 (new legislation)** The representative of the University (15) also stated that there is no support for development of new	**Driver X.1.1 (new legislation)** A representative of a University (15) categorised the taking aboard of and use in the new proposal as a driver.		

	industrial projects (production and use of RE). **Bottleneck X.1.4 (new legislation)** The representative from the University (15) stated, furthermore, that targets are needed for biofuels derived from bio-waste (ILUC-free products)		indicative formula. This formula determines the share per Member State by utilising the following four criteria to divide the difference between the Union's targets for 2030 and 2020: 1. a flat rate contribution, the same for each Member State (30%) 2. a GDP per-capita based contribution, capped at 150% of the Union's average (30%) 3. a potential based contribution (30%) 4. a contribution reflecting the interconnection level of the Member State, capped at 150% of the Union's average. (10%) These criteria should be sufficient for individual Member States to determine their individual annual targets until 2030. **Bottleneck X.1.3 (new legislation)** No explicit mention is made of new industrial projects. There is, however, ample mention of support schemes. Article 4, for instance, stipulates that Member States may apply support schemes for electricity from renewable sources in order to reach or exceed the Union's target. This support can take place in the form of direct price support schemes granted in the form of a market premium. Furthermore,	The analysis of the previous report remains correct and bio-waste is listed as a feedstock for advanced biofuels in Annex IX of the REDII. **Driver X.1.1 (new legislation)** Text describing the driver is incomplete. Apparently the comment was about ILUC effects, deducing from the analysis text. The analysis of the previous report seems to remain correct, since the REDII put specific limits on biofuels with higher ILUC risks."

			Member States have more leeway for supporting small-scale installations and demonstration projects. **Bottleneck X.1.4 (new legislation)** Targets for biofuels derived from bio-waste (ILUC-free products) are included in Article 25 of RED II. **Driver X.1.1 (new legislation)** A respondent (15) is of the opinion that the increased focus on ILUC effects of biofuels in RED II compared to RED I is positive. Article 25 of RED II puts emphasis on limiting the use of high indirect land-use change risk food or feed crop-based biofuels, bioliquids and biomass fuels produced from food or feed crops for which a significant expansion of the production area into land with high carbon stock is observed.	
2. Biogas and biomethane				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Biogas		**Driver X.2.2 (old legislation)** A respondent from an EU-funded project (13) categorised the explicit mention of biogas production as a technology which can significantly contribute to	**Driver X.2.2 (old legislation)** The old directive mentioned biogas explicitly as a form of energy from a renewable source. This categorisation is not changed in the new Directive.	**Driver X.2.2 (old legislation)** The analysis of the previous report remains correct.

		sustainable development as positive.		
3. Bioethanol and biomethanol				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Biomethanaol/ (Bio)ethanol	**Bottleneck X.3.5 (old legislation)** A respondent (5) from a bio-waste/bio-fuel company said that the RED has only been marginally successful in expanding use of advanced biofuels due to mandates for technologically advanced biofuels being not specific enough. Double counting under the RED has led to a substantial increase in the production of biodiesel from used cooking oil and animal fats, but has not led to any significant investment in cellulosic biofuels. Furthermore, the addition of an advanced biofuels sub-target in the 2015 revision of RED came much too late to drive investments in advanced biofuels in Europe. Bottleneck X.3.6 (old legislation) A respondent (13) from an EU-funded project states that RED does not differentiate between advanced (based on non-food biomass feedstocks, residues and wastes) and 1st generation (from crops, plants) biofuels."	**Driver X.3.3 (old legislation)** A respondent (5) stated that the RED has driven innovation, but this innovation was hampered by the financial crisis and the resulting decrease in public spending. **Driver X.3.4 (old legislation**) A respondent (13) from an EU funded project categorised the target of 20% of energy consumption from renewable sources as a driver. **Driver X.3.5 (old legislation)** A respondent (13) from an EU funded project stated that the 10% target for the use of renewable energy in transport fuels will contribute to the 20% of renewable energy." "Driver X.3.6 (new legislation) Respondent (5) categorised the strong proposed sub-target for advanced biofuels	**Bottleneck X.3.5 (old legislation)** This bottleneck has largely been solved by REDII as it limits the use of used cooking oil and animal fats. However, the respondent argues that Member States may modify this limit. The cap of 1.7% of part B of Annex IX (used cooking oil and animal fats) feedstock can be increased upon request of Member States provided the Commission agrees to this. In some MS the use of this feedstock now is already twice the cap of 1.7%. Moreover, the fact that it is at the discretion of the Member States to apply double counting (again) on this type of feedstock could lead to unintended effects (fraud by deliberately producing used cooking oils). And finally: the instrument of double counting is used differently depending on the feedstock: the 3.5% advanced biofuel target is in fact only 1.75%. The second part of this bottleneck, the addition of a sub-target for advanced biofuels coming too late for the 2020 targets, is not relevant for the 2030 targets. The higher targets for 2030 should drive	**Bottleneck X.3.5 (old legislation)** The analysis of the previous report remains correct." **Bottleneck X.3.6 (old legislation)** The analysis of the previous report remains correct." **Bottleneck X.3.7 (new legislation)** The analysis of the previous report remains correct. **Bottleneck X.3.8 (new legislation)** The analysis of the previous report remains correct. The recommended change to Annex IX was not implemented by the EC. However, it remains questionable that such regulations promote the material use of bio-ethanol at all, since all of these responses only refer to support schemes for bioethanol as fuel. **Bottleneck X.3.9 (new legislation)**

	"Bottleneck X.3.7 (new legislation) A respondent, representing a bio-waste/biofuel company (5) said that there is no mandate/target set for the use of advanced biofuels" "Bottleneck X.3.8 (new legislation) Respondent (5) points out that due to the new WFD construction and demolition waste (C&D waste) no longer is considered MSW. If the biogenic part of C&D waste is used for the production of biofuels it is not clear under what category of Annex IX part A of the RED this would fall. Possibly industrial waste but it depends on the Member States how to classify this type of waste." "Bottleneck X.3.9 (new legislation) Respondent (5) also highlighted the need for support schemes for commercial-scale deployment of advanced biofuels. **Bottleneck X.3.10 (new legislation)** A respondent from an EU-funded project (13) wrote that the target for renewables for transport fuels is maintained."	that will gradually increase over time as a driver." "Driver X.3.7 (new legislation) Respondent (13), representing an EU-funded project that at least 27% of renewables in the final energy consumption in the EU is met."	investments in advanced biofuels in Europe." "Bottleneck X.3.6 (old legislation) In contrast to REDI, REDII does differentiate between advanced biofuels (based on non-food biomass feedstocks) and 1st generation (from crops, plants) biofuels. Part A of Annex IX to REDII lists the feedstocks for the production of advanced biofuels. This list does not include crops or plants." "Bottleneck X.3.7 (new legislation) Whereas RED I stipulated a single target of 0,5% in 2020 (Article 3(4)(e), RED II stipulates a path to a target for biofuels and biogas of at least 3,5% in 2030 (0,2% in 2022 and 1% in 2025)." "Bottleneck X.3.8 (new legislation) Coherent classification of C&D waste in Annex IX part A lowers the bureaucratic burden for those processors that use C&D waste for biofuel production – no coherency means seeking approval in every MS to process this waste into biofuel – and avoids internal market fragmentation. It is advised that the European Commission through a Delegated Act adds C&D waste to Annex IX part A as a separate category." **Bottleneck X.3.9 (new legislation)**	The analysis of the previous report remains correct. **Bottleneck X.3.10 (new legislation)** While the analysis of the previous report is factually correct (the transport mandate was increased to 14%), it is unclear whether the bottleneck mentioned by the respondent refers to the fact that the target is too low (so a bottleneck for energy applications) – in which case the analysis would be completely correct – or if the respondent referred to the fact that the transport quota is a barrier for material applications. In this case, the bottleneck would even have been made stronger by the revisions of the REDII. **Driver X.3.3 (old legislation)** **Driver X.3.4 (old legislation)** The analysis of the previous report remains correct. The effects of the COVID-19 crisis on innovation and investment could not have been foreseen by any piece of legislation. **Driver X.3.5 (old legislation)**

			RED II does not contain specific provisions regarding support schemes for (commercial-scale deployment of) advanced biofuels. Based on the recitals it can be concluded that the creation and design of support schemes are to be determined by the Member States. **Bottleneck X.3.10 (new legislation)** In the compromise text, the target for renewables for transport fuels has been increased to 14% in 2030(Article 25(1) RED II)) , up from 10% in 2020 (Article 3(4) RED I). Therefore, the bottleneck pointed out by this respondent has been partly solved. However, a respondent (5) further commented that Member States can reduce the 14% by 50% (because of the double count of advanced biofuels and certain other biofuels) and the support of conventional biofuels (capped at 7%) is no longer supported. This means in energy terms a step back compared to the 2020 target of 10% RES-T. **Driver X.3.3 (old legislation)** The increased targets in REDII will further drive innovation. The international commitments to reduce emissions and limit the use of energy	The analysis of the previous report remains correct." **Driver X.3.6 (new legislation)** The analysis of the previous report remains correct. **Driver X.3.7 (new legislation)** While the analysis of the previous report remains correct with regard to the legally binding provisions of the REDII, even higher targets for renewable energy are now being discussed under the Green Deal and the Energy Union.

			from fossil sources should drive public spending in order for it not to be hampered by possible crises. **Driver X.3.4 (old legislation)** The increased target in REDII of 32% shall further drive innovation. **Driver X.3.5 (old legislation)** The target of 10% for the use of renewable energy in transport fuels has been increased to 14% in REDII. This will further contribute to the overall target of 32% in 2030. **Driver X.3.6 (new legislation)** Article 25(1) of the compromise text mandates a minimum share of advanced biofuels in the transport sector (as listed in part A of Annex IX) of at least equal to 0,2% in 2022, 1% in 2025 and, 3,5% by 2030. This will likely drive additional investment and innovation. **Driver X.3.7 (new legislation)** The target of 27% from the proposed RED II has been increased in the compromise text of RED II. Recital 8 of the compromise text, in light of the Paris Agreement, explains that it is appropriate to establish a Union binding target of at least 32%. Article	

			3(1) sets out this target. Furthermore, Article 3(1) of RED II stipulates that the European Commission "shall assess this target, with a view to submit a legislative proposal by 2023 where there are substantial costs reductions in renewable energy production, or where needed to meet the Union's international commitments for decarbonisation or where a significant decrease in energy consumption in the Union justifies this. This means that the set target of 32% is intended as a minimum target and that meeting international commitments is first priority.	
4. Bio-based chemicals				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Single Cell Oil	**Bottleneck X.4/5/6.11 (old legislation)** A respondent (14) from an EU-funded project mentioned the national targets concerning the shares of renewable resources for energy production in general and specifically for the transport sector. To increase the material production from renewable (waste) resources, priority targets for this purpose would need to be defined within this context.		**Bottleneck X.4/5/6.11 (old legislation)** This is considered a bottleneck for the priority of gaining materials from resources as exploitation must be decided between material and energy use. According to the respondent VFAP directly competes with gaining energy from biogas and as such, a priority target for materials is requested against energy uses to boost the circular economy and reduce primary raw material consumption.	**Bottleneck X.4/5/6.11 (old legislation)** The analysis of the previous report remains correct. It is still the case that the support mechanisms of the REDII favour energy applications of bio-based feedstocks as compared to materials. This is especially detrimental to those materials made from feedstocks listed in Annex IX (which are eligible for double counting and therefore justify high investments).

Medium chain fatty acids / Volatille fatty acids (VFA) (acetic, propionic, butyric and valeric acids)	**Bottleneck X.4.12 (old legislation)** A respondent from a waste water management company (7) said that the directive states that significant financial resources should be applied into the development and support of renewable energy (recital 22, REDI). However, for byproducts production from organic waste (such as MCFA), this acts against since more financial support exists for biogas production than for other new by-products which add more value to waste.		**Bottleneck X.4.12 (old legislation)** Providing financial support for the development for renewable energy can have negative effect on the production of non-energy related by-products from organic waste.	**Bottleneck X.4.12 (old legislation)** The analysis of the previous report remains correct. See analysis above, the support schemes of the REDII are a fundamental problem for materials made from biomass.
Biosurfactant	**Bottleneck X.4.13(old & new legislation)** According to a respondent from an EU-funded project (13), REDI and REDII establish sustainability and greenhouse gas emissions saving criteria for biofuels, and bioliquids and biomass fuels. Not for other bio-based products such as biosurfactants.		**Bottleneck X.4.13 (new legislation)** The respondent is correct in pointing out that sustainability and greenhouse gas emissions saving criteria are not included in RED II with respect to biosurfactants.	**Bottleneck X.4.13 (new legislation)** The analysis of the previous report remains correct. It is even worse than that. While the REDII provides rather beneficial default values of GHG emission savings for biofuels, the applied methodologies for calculating exactly such values for bio-based materials are different and much stricter. The JRC values proposed for bio-based plastics are one recent example of that. That leads to a systematic discrimination against bio-based materials when comparing them to energy

				applications made from the same biomass.
Single Cell Oil for oleochemical industry produced by yeasts	**Bottleneck X.4/5/6.14 (new legislation)** A representative from an EU-funded project (14) stated that the [original] Proposal establishes a target of 27% for the share of renewables in the total EU energy consumption of 2030 and limits sources from food and feed production to 3,8% in 2030. It sets minimum targets for the share of various waste feedstocks in advanced biofuels, other biofuels and biogas (Art. 7 and Art. 25; Annexes 9 and 10).To strengthen the benefits of secondary resources from waste as well as energy recovery, the VFAP VC models – as combining material and energy - would need to be considered as a preferable concept in the Proposal. Furthermore, the amendments mentioned in ST53512018 INIT would need to be taken into account within this legal act.	**Driver X.4/5/6.8 (new legislation)** According to a representative from an EU-funded project (14), following the proposal, the waste hierarchy has to be considered (Art.7.1.(c)). The ST5351 2018 INIT amends the Proposal and relates clearly to the circular economy as well as to the waste hierarchy of the WFD 2008/98/EC (e.g. amendments 18, 30, 143, 287, 321, 323) and stresses waste prevention and recycling as being the priority option in case of developing support schemes (18).	**Bottleneck X.4/5/6.14 (new legislation) & driver X.4/5/6.8 (new legislation)** Of the Council amendments referred to by respondent (14) two (18 and 321) have been included in the compromise text agreed by the institutions. Amendment 18 as new recital 20 and amendment 321 as Article 3(3). Member States are thus instructed to design support schemes with due regard to the waste hierarchy. Waste prevention and recycling should be the priority option.	**Bottleneck X.4/5/6.14 (new legislation) & driver X.4/5/6.8 (new legislation)** While the analysis of the previous report remains factually correct, it should be noted that recital 20 and Article 3(3), which stress the importance of the waste hierarchy, are relatively weak measures as compared to concrete support mechanisms and double counting for biofuels from certain feedstocks.
5. Bio-based plastics				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Bio-based plastics	**Bottleneck X.4/5/6.11 (old)** The same bottleneck was mentioned by a respondent from an EU-funded project (14)	**Driver X.4/5/6.8 (new legislation)** A respondent (14) also mentioned this driver in		

	Bottleneck X.4/5/6.14 (new legislation) A respondent from an EU-funded project (14) also mentioned this bottleneck in relation to Single Cell Oil for oleochemical industry produced by yeasts & Omega-3 fatty acids. "	relation to Single Cell Oil for oleochemical industry produced by yeasts & Omega-3 fatty acids.		
Polyhydroxyalkanoates (PHA)	**Bottleneck X.4/5.12 (old legislation)** This respondent (7) also mention this bottleneck in relation to Volatille fatty acids (VFA) (acetic, propionic, butyric and valeric acids).			
6. Bio-based food and food ingredients				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Omega-3 fatty acids	***Bottleneck X.4/5/6.11 (old)*** *The same bottleneck was mentioned by a respondent from an EU-funded project (14)* ***Bottleneck X.4/5/6.14 (new legislation)*** *A respondent from an EU-funded project (14) also mentioned this bottleneck in relation to Single Cell Oil for oleochemical industry produced by yeasts and bioplastics.*	***Driver X.4/5/6.8 (new legislation)*** *A respondent (14) also mentioned this driver in relation to Single Cell Oil for oleochemical industry produced by yeasts & bioplastics.*		

XVII. EU Gas Directive

The analysis of the old report refers to the EU Gas Directive (Directive 2009/73/EC) from 13 July 2009. The 2020 updated includes the Current consolidated version from 23 May 2019, that can be found here.

- The analysis of the old report remains factually correct which has underlined, that The Gas Directive cannot directly influence taxation exemption for green gas since taxation is a domain of the Member States. However, the updated regulation fosters the non-discriminatory access for green gas. Furthermore, updates in other regulations call for certain measures to incentivise the use of biofuels, e.g. the evaluation of the Energy Tax Directive which highlights the need for exemptions for biofuels.

- It can be argued that the Gas Directive in its current form does allow for such exemptions.

2. Biogas and biomethane				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Biomethane	**Bottleneck XVII.2.1** One respondent belonging to a government authority (9) mentioned a need for reduced taxation in order to account the renewable nature of green gas.		**Bottleneck XVII.2.1** It is hard for the Commission to deal with this bottleneck. Taxes are after all the domain of the Member States, as it is stated not to be within the jurisdiction of the European Union in article 3, 4 and 6 of the Treaty on the Functioning of the European Union. However, The compromise text of the new Renewable Energy Directive (REDII) does mention tax exemptions as an instrument that the Member States can apply to promote the use of energy from renewable sources. (article 2(j)). Important to note that these measures do have to be in line with the Waste hierarchy (article 3(3)).	While there is no relevant update regarding reduced taxation as this is the domain of the Member States (see analysis for **Bottleneck XVII.2.1)** there has been a provision regarding exemption such that new infrastructure may be granted exemptions under the condition that *'the exemption must not be detrimental to competition in the relevant markets which are likely to be affected by the investment.'* While this is not directly related to green gas, the exemptions outlined in Article 9, 32, 33, 34 and 41 now must include other markets beyond internal markets (such as growing biogas and biomethane markets). This is also assuming that these internal markets are still primarily traditional natural gas markets. Much of the regulation concerns protection of the transmission lines of gas and the original regulation states that '*Member States should ensure that, taking into account the necessary quality requirements, biogas and gas from biomass or other types of gas are granted non-discriminatory access to the gas system, provided such access is permanently compatible with the relevant technical rules and safety standards.'* The updates are all concerning exemptions which would apply with green gas as well. Exemptions can also be requested under the Energy Tax Directive and The Commission's “Clean Energy for all Europeans” 2016 package 77 aims to remove inefficient fossil fuel subsidies

				in order to pave the way for easier transition to biofuels. Once again, this is not a regulatory update to the Gas Regulation but is in line with it as the ETD directly concerns natural gas and biogas use. The evaluation of the ETD forcefully takes into account the lack of exemptions already existing in the member states such that there is an indication that the tax directive may be altered to make sure there is a reduction in taxes on biofuels.
3. Bioethanol and biomethanol				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Biomethanol/(bio)ethanol		**Driver XVII.3.1** One respondent (13) said that a driver in this Directive was the explicit specification that biogas is granted non-discriminatory access to the gas system	**Driver XVII.3.1** The non-discriminatory access rule for biogas that the respondent mentioned is based on article 1 paragraph 2 of the Directive.	**Driver XVII.3.1** No updates on Article 1 paragraph 2 so the driver remains relevant.

XXIV. EU Plastics Regulation

The analysis of the old report refers to the EU Regulation on plastic materials and articles intended to come into contact with food (Regulation 10/2011/EU). Since Q1 2018, the regulation has been updated several times. For the 2020 update, the current version is analysed that can be found here.

- The one Bottleneck XXIV.5.1 says that there is a limited amount of biodegradable substances registered. The new amendments have added three new biodegradable substances, but this is negligible as the list is very long. It somewhat diminishes the bottleneck still.

3. Bioethanol and biomethanol				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Biomethanol/ (Bio)ethanol	**Bottleneck XXVII.3.1** A representative from a bio-waste/biofuel company (5) said that the Communication does not contain measures to find better waste management solutions for non-recycle wastes, such as conversion into fuels and chemicals. **Bottleneck XXVII .3.2** A representative from a bio-waste/biofuel company (5) said that action is needed at all levels of the waste hierarchy in order to keep more plastic waste out of disposal. **Bottleneck XXVII .3.3** A representative from a bio-waste/biofuel company (5) pointed out that the current policy does not offer a mechanism to encourage a price premium for chemicals	…	**Bottleneck XXVII.3.1** In the Communication (para. 4.1) the Commission refers to proposed rules on waste-management. “ 23 These include clearer obligations for national authorities to step up separate collection, targets to encourage investment in recycling capacity and avoid infrastructural overcapacity for processing mixed waste (e.g. incineration), and more closely harmonised rules on the use of extended producer responsibility.” (COM (2015) 593, COM (2015) 594, COM (2015) 595, COM (2015) 596.) No references to non-recyclable waste are included in the Strategy. **Bottleneck XXVII.3.2** The Communication does provide for action at multiple levels. 1. Improving the economics and quality of plastics recycling, 2. Curbing plastic waste and littering, 3. Driving innovation and investment towards circular solutions and 4. Harnessing global solutions. **Bottleneck XXVII.3.3**	**Bottleneck XXVII.3.1** The analysis of the previous report remains factually correct. However, the comment made by the respondent seems to refer to the so-called ""chemical recycling"" technologies, which are able to process mixed wastes which are not recyclable by current recycling technologies. This is not addressed by the previous analysis. The situation regarding chemical recycling is still unclear. **Bottleneck XXVII.3.2** The analysis of the previous report remains correct. The original statement by the respondent is quite broad and it is not possible to give a more detailed regulatory analysis. **Bottleneck XXVII.3.3** The analysis of the previous report remains correct. Also in following pieces of regulation that are related to the Plastics Strategy, there are no such mechanisms foreseen. As mentioned above, the status of

	produced from wastes (which is recycling in the EU waste hierarchy). Chemicals from waste receive the same price (the commodity price) for the chemical, discouraging investment in this important sector for the circular economy. This is in stark contrast with biofuels which command a higher price due to the compliance value created by regulation. **Bottleneck XXVII .3.4** The representative from a bio-waste/biofuel company (5) mentioned that the production of products from wastes requires the use innovative technologies and costs are typically higher than production of products using conventional virgin fossil sources."		The Communication does indeed not provide for a mechanism that encourages a price premium." **Bottleneck XXVII.3.4** In paragraph 4.3 the Commission mentions that The cost of alternative feedstocks, including bio-based feedstocks and gaseous effluents "can be an obstacle to wider use; in the case of bio-based plastics it is also important to ensure that they result in genuine environmental benefits compared to the non-renewable alternatives. To that effect, the Commission has started work on understanding the lifecycle impacts of alternative feedstock used in plastics production, including biomass. Based on the available scientific information, the Commission will look into the opportunities to support the development of alternative feedstocks in plastic production." Furthermore, to further innovation the Commission pledges to provide direct financial support through the European fund for strategic Investment and other EU funding instruments (e.g. structural funds and smart specialisation strategies, Horizon 2020). The commission is also in the process of developing a Strategic Research	chemical recycling is unclear in terms of desirability and recognition. **Bottleneck XXVII.3.4** The analysis of the previous report remains factually correct."

			Innovation Agenda on plastics to guide future funding decisions. Through this support the costs of production of products from waste can be, in some cases, diminished. However, this does not solve the problem as this funding will only affect certain funded projects (unless innovative cost efficient ways of using waste as a resource are found). The price of conventional virgin materials will have to rise or other ways would have to be found to negate the difference in costs (e.g. taking aboard CO2 costs of virgin materials). "	
4. Bio-based chemicals				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Biosurfactant	**Bottleneck XXVII.4.5** A representative from an EU-funded project (13) said that it was highly recommended for the Communication to become mandatory in all Member States as soon as possible, thus categorising the non-binding nature of the document as a bottleneck. **Bottleneck XXVII.4.6** The representative from the EU-funded project (13)	**Driver XXVII.4.1** The representative from the EU-funded project (13) said that the Strategy would tackle the market bio-products and bioplastics.	**Bottleneck XXVII.4.5** The Strategy from the Commission presents a vision and provides guidelines for stakeholders, and therefore, the possibility for those stakeholders to present their input. Annex I to the Communication contains a list of future EU measures to implement the Strategy. Among these actions are revisions of Directives and Regulations. These actions will be binding upon the Member States." **Bottleneck XXVII.4.6**	**Bottleneck XXVII.4.5** The analysis of the previous report remains correct." **Bottleneck XXVII.4.6** The measures mentioned in the analysis of the previous report do not actually address the criticism of a lack of a roadmap towards bioplastics. Currently, there is no political will to strive for something of a strategic transition towards bioplastics and the measures outlined in the Plastics Strategy highlight this quite nicely. Bio-based and biodegradable plastics

	said that promotion (by an action plan) of the transition from plastics to bioplastics in the EU from production to the market would be beneficial.		In its Strategy, the Commission announced a number of actions on compostable and biodegradable plastics. These include the start of work to develop harmonised rules on defining and labelling compostable and biodegradable plastics and to conduct a lifecycle assessment to identify conditions where their use if beneficial, and criteria for such application. Besides this, the Commission is working on starting the process to restrict the use of oxo-plastics via reach. **Driver XXVII.4.1** The actions announced by the Commission in its Strategy (see Bottleneck XXVII.4.6), combined with an increased focus on decreasing the dependence on fossil-fuel based plastics will lead to a stronger demand for bioplastics.	need to prove their environmental advantages on a case-to-case basis and there is no recognition of a general preferability. **Driver XXVII.4.1** The conclusion of the previous analysis is doubtful. Actually, the Plastics Strategy does not contain any measure to limit the use of fossil-based plastics in favour of bio-based plastics. The mentioned development of LCA for bioplastics is currently leaning more towards a negative result for bioplastics. Also, if fossil-based plastics will be reduced, it will probably be in exchange for more recycled plastics, as outlined by the Communication. As could be seen in the recent COVID-19 crisis, a drop in oil-prices is more powerful than any of the political measures implemented so far. **Driver XXVII.4.2** The analysis of the previous report remains factually correct; however, as explained above, it is doubtful whether these very limited and weak concessions to bio-based plastics will have any impact on the market. **Driver XXVII.4.3**
(Poly) lactic acid		**Driver XXVII.4.2** The representative from an EU-funded project (13) said that the Strategy acknowledges that bio-based feedstock for plastic packaging as well as compostable plastics for separate bio-waste collection contribute to more efficient waste management and help to	**Driver XXVII.4.2** In paragraph 2 it is mentioned that these types of plastics currently represent a small part of the market, in the future they can help reducing dependency on fossil fuels. " **Driver XXVII.4.3** Self-explanatory, no direct link to the Strategy.	

		reduce the impacts of plastic packaging on the environment. **Driver XXVII.4.3** The representative from an EU-funded project (13) said that the revised Waste Framework Directive allows biodegradable and compostable packaging to be collected together with the bio-waste and recycled in industrial composting and anaerobic digestion, which has already successfully been implemented in several Member States. **Driver XXVII.4.4** The representative from an EU-funded project (13) said that by 2023, separate collection of bio-waste is set to be mandatory throughout Europe. Biodegradable plastics verifiably help to collect more bio-waste and ultimately contribute to reaching the new recycling targets. Relevant European standards, such as the harmonised standard EN 13432 for industrially compostable plastic packaging can serve as basis for future standards for composting	**Driver XXVII.4.4** Self-explanatory, no direct link to the Strategy.	The analysis of the previous report remains correct." **Driver XXVII.4.4** The analysis of the previous report remains correct. **Bottleneck XXVII.4/5.7** The analysis of the report fails to address the heart of the respondent's comment. The Plastics Strategy (and the CEAP as a whole) is very focused on recycling and existing technologies, favouring mature processes. Often, innovative processes cannot compete in terms of resource efficiency as of yet – but their future potential is nixed if regulation focuses too heavily on this aspect now."

		outlined in the agreed revision. According to the representative it can be assumed from that perspective that biopolymers (including the partly biotechnological production of the required monomers) will play a major role in order to meet the before mentioned aspects. If we could foresee OFMSW as a possible feedstock for such fermentation processes the further composition and behaviour of MSW (e.g. food waste together with packaging materials) will probably influence the pre-treatment and subsequent processing, respectively."		
Adipic acid & Muconic acid & 1,5-pentanediamine	**Bottleneck XXVII.4/5.7** A respondent from an EU project (H2020) (8) said that the Strategy is aimed at process efficiency, while current biotechnological processes are not yet optimised. This can result in products having a greater impact than that they would have at an industrial-scale production. It can lead to a rejection of the materials/products.		**Bottleneck XXVII.4/5.7** The various actions announced by the Commission in Annex I can help to optimise the current biotechnical processes.	

5. Bio-based plastics				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Bio-based plastics	**Bottleneck XXVII.5.8** A representative from an EU-project (14) said that the Communication requires more plastics recycling in terms of quality and quantity and that the Communication stresses the need of a regulatory framework for biodegradable plastic. Specific references to bio-based plastics and measures thereto could not be found**.**	**Driver XXVII .5.5** Representatives from an EU-funded project (9) mentioned that start of work to develop harmonised rules on defining and labelling compostable and biodegradable plastics." **Driver XXVII.5.6** Respondent (9) mentioned the to be conducted lifecycle assessment to identify conditions where the use of bioplastics is beneficial, and the criteria for such application. **Driver XXVII.5.7** Respondent (9) described the Commission's proposed action to pursue work on life-cycle impacts of alternative feedstocks for plastics production as a driver. **Driver XXVII.5.8** Respondent (9) praised the Commission's proposed action to make better use of economic instruments, especially to raise	**Bottleneck XXVII.5.8** The Commission Strategy does contain a number of actions regarding bioplastics. These actions can be found in Annex I. These actions are mentioned in the analysis for Bottleneck XXVII.4.6. However, according to a respondent it is overlooked that there are various technical applications where biodegradable plastics have a technical function (for instance biodegradable mulch films, fertiliser coatings) and standards and targets for a minimum biodegradability still have to be developed. **Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I. **Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I. **Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I. **"Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I. **Bottleneck XXVII.5.9**	**Bottleneck XXVII.5.8** While the analysis is correct in its statement that the Strategy's Annex contains actions with regard to bio-based and biodegradable plastics, these actions are all exploratory and refer to research, instead of regulatory measures that would boost bio-based plastics. (In some regards they might even hamper the market development, if environmental aspects were set too strictly, for example.) **Driver XXVII.5.5 till XXVVII.5.15** The analysis of the previous report remains correct, even though as explained above it remains to be seen whether these rules will be a driver for bio-based plastics. **Driver XXVII.5.6** The analysis of the previous report remains correct, even though as explained above it remains to be seen whether this framework will be a driver for bio-based plastics. **Driver XXVII.5.7**

		the costs of landfilling and incineration."	Among the actions included in the Strategy are actions to promote investment and innovation in the value chain (see Annex I). These actions include examining the feasibility of a private-led investment fund to finance investments in innovative solutions and new technologies aimed at reducing the environmental impact of primary plastic production, and direct financial support for infrastructure and innovation through the European Fund for Strategic Investment and other EU funding instruments (e.g. structural funds and smart specialisation strategies, Horizon 2020). This funding could lead to a smaller disparity between subsidies for biogas produced with the same feedstocks as PHA and subsidies for PHA production. However, as a respondent states, the analysis above relates to reducing the required funding of investment. However biogas production subsidies are often production/operation related (per m3 of biogas). Such operational subsidies are not available for bio-based products, thus leading to an unlevel playing field.	The analysis of the previous report remains correct, even though as explained above it remains to be seen whether this framework will be a driver for bio-based plastics. **Driver XXVII.5.5 till XXVVII.5.15** The analysis of the previous report remains correct. **Bottleneck XXVII.5.9** The analysis of the previous report remains correct. It should be noted that the Communication – as a strategic document – does not have the power to alter subsidy schemes that are set out by other Directives (REDII in this case). **Driver XXVII.5.5 till XXVVII.5.15** The analysis of the previous report remains correct." **Driver XXVII.5.5 till XXVVII.5.15** The analysis of the previous report remains correct. **Driver XXVII.5.11** The analysis of the previous report remains correct, even though as explained above it remains to be seen whether this framework will be a driver for bio-based plastics.
Polyhydroxyalkanoates (PHA)	**Bottleneck XXVII.5.9** A representative from an EU-funded project (13) pointed out that there is a disparity between subsidies for biogas produced with the same feedstocks as PHA and subsidies for PHA production**.**	**Driver XXVII.5.9** A representative from a waste-water management company (7) mentioned that having a better definition of biodegradable or composting will ensure that truly biodegradable plastics in different conditions, such as PHA, will gain more relevance. **Driver XXVII.5.10** The representative from the waste-water management company (7) furthermore said that the Strategy reinforces the importance of using their own resources (carbon) to produce plastics. **river XXVII.5.11** A representative from an EU-funded project (13) mentioned that establishment of a clear regulatory framework for plastics with biodegradable properties **Driver XXVII.5.12** A representative from an EU-funded project (13) pointed out		

		that the Commission will propose harmonised rules for defining and labelling compostable and biodegradable plastics. **Driver XXVII.5.13** The representative from an EU-funded project (13) said that the Commission will also develop lifecycle assessment to identify the conditions under which the use of biodegradable or compostable plastics is beneficial, and the criteria for such applications.	**"Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I. **"Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I. **"Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I. **Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I. **Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I. **Bottleneck XXVII.5.10** This bottleneck is recognised in paragraph 4.2: "most currently available plastics labelled as biodegradable generally degrade under specific conditions which may not always be easy to find in the natural environment, and can thus still cause harm to ecosystems" To address this the Commission will take the action to start work to develop harmonised rules on defining and labelling compostable and biodegradable plastics, see Annex I. **Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I. **"Driver XXVII.5.5 till XXVVII.5.15**	**Driver XXVII.5.12** The analysis of the previous report remains correct, even though as explained above it remains to be seen whether these rules will be a driver for bio-based plastics." **Driver XXVII.5.13** The analysis of the previous report remains correct, even though as explained above it remains to be seen whether this framework will be a driver for bio-based plastics. **Bottleneck XXVII.5.10** The analysis of the previous report remains correct." **Driver XXVII.5.14** According to the Green Deal, chemical recycling technologies are still being evaluated. Even though they are recognised per se in the European Waste Framework, most national legislations do not allow for them yet. **Driver XXVII.5.5 till XXVVII.5.15** The analysis of the previous report remains correct." **Driver XXVII.5.16** The analysis of the previous report remains correct."
Bio-Polyamide 56 / Long chain Bio-Polyamides / Polyhydroxyalkanoate (PHA)	**Bottleneck XXVII.5.10** A representative from an EU-project (11) said that it is recognised that most currently available plastics labelled as biodegradable generally degrade under specific conditions which may not always be easy to find in the natural environment, and can thus still cause harm to ecosystems. In addition, plastics that are labelled 'compostable' are not necessarily suitable for home composting. If	**Driver XXVII.5.14** A representative from an EU project (H2020) (8) said that biochemical recycling is applied to recover materials and reintroduce them into the production cycle, which significantly reduces resource consumption and waste generation. Waste are thus converted into resources, which is among the main objectives of this circular strategy **Driver XXVII.5.15** A representative from an EU-project (11) said that the		

	compostable and conventional plastics are mixed in the recycling process, it may affect the quality of the resulting recyclates.	Strategy recognises that targeted applications, such as using compostable plastic bags to collect organic waste separately, have shown positive results; and standards exist or are being developed for specific applications. **Driver XXVII.5.16** In addition, the representative from an EU-project (11) said that new feedstocks such as food waste for the production of plastics are a recognised priority to improve the carbon footprint of plastics and to move away from fossil fuels. It is recognised this is still experimental. For consumer applications, the existence of a well-functioning separate collection system for organic waste is essential."	Self-explanatory, see Annex I. **Driver XXVII.5.16** In paragraph 4.3 of the Strategy the Commission highlights that alternative feedstocks can be developed to avoid using fossil resources. Furthermore, the Commission mentions that, so far, Horizon 2020 has provided over EUR 250 million to finance R&D in areas of direct relevance to the strategy. Furthermore, in paragraph 4.3, the Commission calls on public authorities to invest in extended and improved separate collection.	

XXVII. A European Strategy for Plastics in a Circular Economy

The analysis of the old report refers to the European Strategy for Plastics in a Circular Economy (COM/2018/028 final) published on 16 January 2018. For the 2020 update, new developments regarding the plastic strategy have been considered, e.g. the Green Deal, the updated Renewable Energy Directive REDII (see section above) and the New Circular Economy Action Plan (see section below).

- None of the analysed updated regulations fundamentally negate the general positive conclusions of the old report, welcoming many of the proposals by the Commission and the "additional stimulating measures to make bioplastics more attractive in the market compared to traditional plastics". Hence, a quick implementation into binding legislation is desired (Bottleneck XXVII.4.5).

- Nevertheless, some of the pronounced positive conclusions of the old report can be doubted. The concession to the market of bio-based products can be seen as rather weak, recycling products are favoured over bio-based ones by the Commission's regulations and as a result of negative LCA results of bio-based products (Driver XXVII. 4.1/2).

- Examples are the lacking of incentives for recycling-based plastics (Bottleneck XXVII.3.2/4), underlined by the fact, that bio-based and biodegradable products are not generally seen more favourable over their conventional counterparts by the Commission (Bottleneck XXVII. 4.6).

- While R&D projects for new innovations are welcomed (e.g. Driver XXVII.5.16), a demand for fostering more sophisticated technologies remains. Bio-based technologies should be boosted even though, due to their different technologic maturity, they cannot compete (yet) with conventional, well-established technologies in terms of economic and/or environmental benefits (e.g. Bottleneck XXVII.3.1, XXVII.4/5.7).

3. Bioethanol and biomethanol				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Biomethanol/ (Bio)ethanol	**Bottleneck XXVII.3.1** A representative from a bio-waste/biofuel company (5) said that the Communication does not contain measures to find better waste management solutions for non-recycle wastes, such as conversion into fuels and chemicals. **Bottleneck XXVII .3.2** A representative from a bio-waste/biofuel company (5) said that action is needed at all levels of the waste hierarchy in order to keep more plastic waste out of disposal. **Bottleneck XXVII .3.3** A representative from a bio-waste/biofuel company (5) pointed out that the current policy does not offer a mechanism to encourage a price premium for chemicals produced from wastes (which is recycling in the EU waste hierarchy). Chemicals from waste receive the same price	…	**Bottleneck XXVII.3.1** In the Communication (para. 4.1) the Commission refers to proposed rules on waste-management. " 23These include clearer obligations for national authorities to step up separate collection, targets to encourage investment in recycling capacity and avoid infrastructural overcapacity for processing mixed waste (e.g. incineration), and more closely harmonised rules on the use of extended producer responsibility." (COM (2015) 593, COM (2015) 594, COM (2015) 595, COM (2015) 596.) No references to non-recyclable waste are included in the Strategy. **Bottleneck XXVII.3.2** The Communication does provide for action at multiple levels. 1. Improving the economics and quality of plastics recycling, 2. Curbing plastic waste and littering, 3. Driving innovation and investment towards circular solutions and 4. Harnessing global solutions. **Bottleneck XXVII.3.3** The Communication does indeed not provide for a mechanism that encourages a price premium."	**Bottleneck XXVII.3.1** The analysis of the previous report remains factually correct. However, the comment made by the respondent seems to refer to the so-called ""chemical recycling"" technologies, which are able to process mixed wastes which are not recyclable by current recycling technologies. This is not addressed by the previous analysis. The situation regarding chemical recycling is still unclear. **Bottleneck XXVII.3.2** The analysis of the previous report remains correct. The original statement by the respondent is quite broad and it is not possible to give a more detailed regulatory analysis. **Bottleneck XXVII.3.3** The analysis of the previous report remains correct. Also in following pieces of regulation that are related to the Plastics Strategy, there are no such mechanisms foreseen. As mentioned above, the status of chemical recycling is unclear in

	(the commodity price) for the chemical, discouraging investment in this important sector for the circular economy. This is in stark contrast with biofuels which command a higher price due to the compliance value created by regulation." **Bottleneck XXVII .3.4** The representative from a bio-waste/biofuel company (5) mentioned that the production of products from wastes requires the use innovative technologies and costs are typically higher than production of products using conventional virgin fossil sources."		**Bottleneck XXVII.3.4** In paragraph 4.3 the Commission mentions that The cost of alternative feedstocks, including bio-based feedstocks and gaseous effluents "can be an obstacle to wider use; in the case of bio-based plastics it is also important to ensure that they result in genuine environmental benefits compared to the non-renewable alternatives. To that effect, the Commission has started work on understanding the lifecycle impacts of alternative feedstock used in plastics production, including biomass. Based on the available scientific information, the Commission will look into the opportunities to support the development of alternative feedstocks in plastic production." Furthermore, to further innovation the Commission pledges to provide direct financial support through the European fund for strategic Investment and other EU funding instruments (e.g. structural funds and smart specialisation strategies, Horizon 2020). The commission is also in the process of developing a Strategic Research Innovation Agenda on plastics to guide future funding decisions. Through this support the costs of production of products from waste can be, in some cases, diminished. However, this does not solve the problem as this funding will only affect certain funded projects (unless innovative cost efficient ways of using waste as a resource are	terms of desirability and recognition. **Bottleneck XXVII.3.4** The analysis of the previous report remains factually correct.

			found). The price of conventional virgin materials will have to rise or other ways would have to be found to negate the difference in costs (e.g. taking aboard CO2 costs of virgin materials). "	
4. Bio-based chemicals				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Biosurfactant	**Bottleneck XXVII.4.5** A representative from an EU-funded project (13) said that it was highly recommended for the Communication to become mandatory in all Member States as soon as possible, thus categorising the non-binding nature of the document as a bottleneck. "**Bottleneck XXVII.4.6** The representative from the EU-funded project (13) said that promotion (by an action plan) of the transition from plastics to bioplastics in the EU from production to the market would be beneficial.	**Driver XXVII.4.1** The representative from the EU-funded project (13) said that the Strategy would tackle the market bio-products and bioplastics.	**Bottleneck XXVII.4.5** The Strategy from the Commission presents a vision and provides guidelines for stakeholders, and therefore, the possibility for those stakeholders to present their input. Annex I to the Communication contains a list of future EU measures to implement the Strategy. Among these actions are revisions of Directives and Regulations. These actions will be binding upon the Member States. **Bottleneck XXVII.4.6** In its Strategy, the Commission announced a number of actions on compostable and biodegradable plastics. These include the start of work to develop harmonised rules on defining and labelling compostable and biodegradable plastics and to conduct a lifecycle assessment to identify conditions where their use if beneficial, and criteria for such application. Besides this, the Commission is working on starting the process to restrict the use of oxo-plastics via reach.	**Bottleneck XXVII.4.5** The analysis of the previous report remains correct. **Bottleneck XXVII.4.6** The measures mentioned in the analysis of the previous report do not actually address the criticism of a lack of a roadmap towards bioplastics. Currently, there is no political will to strive for something of a strategic transition towards bioplastics and the measures outlined in the Plastics Strategy highlight this quite nicely. Bio-based and biodegradable plastics need to prove their environmental advantages on a case-to-case basis and there is no recognition of a general preferability. **Driver XXVII.4.1** The conclusion of the previous analysis is doubtful. Actually, the Plastics Strategy does not contain
(Poly)lactic acid		**Driver XXVII.4.3** The representative from an EU-funded project (13) said that the revised Waste Framework Directive allows biodegradable and compostable packaging to		

		be collected together with the bio-waste and recycled in industrial composting and anaerobic digestion, which has already successfully been implemented in several Member States." **Driver XXVII.4.4** The representative from an EU-funded project (13) said that by 2023, separate collection of bio-waste is set to be mandatory throughout Europe. Biodegradable plastics verifiably help to collect more bio-waste and ultimately contribute to reaching the new recycling targets. Relevant European standards, such as the harmonised standard EN 13432 for industrially compostable plastic packaging can serve as basis for future standards for composting outlined in the agreed revision. According to the representative it can be assumed from that perspective that biopolymers (including the partly biotechnological production of the required monomers) will play a major role in order to meet the before	**Driver XXVII.4.1** The actions announced by the Commission in its Strategy (see Bottleneck XXVII.4.6), combined with an increased focus on decreasing the dependence on fossil-fuel based plastics will lead to a stronger demand for bioplastics. **Driver XXVII.4.2** In paragraph 2 it is mentioned that these types of plastics currently represent a small part of the market, in the future they can help reducing dependency on fossil fuels. **Driver XXVII.4.3** Self-explanatory, no direct link to the Strategy." **Driver XXVII.4.4** Self-explanatory, no direct link to the Strategy." **Bottleneck XXVII.4/5.7** The various actions announced by the Commission in Annex I can help to optimise the current biotechnical processes."	any measure to limit the use of fossil-based plastics in favour of bio-based plastics. The mentioned development of LCA for bioplastics is currently leaning more towards a negative result for bioplastics. Also, if fossil-based plastics will be reduced, it will probably be in exchange for more recycled plastics, as outlined by the Communication. As could be seen in the recent COVID-19 crisis, a drop in oil-prices is more powerful than any of the political measures implemented so far. **Driver XXVII.4.2** The analysis of the previous report remains factually correct; however, as explained above, it is doubtful whether these very limited and weak concessions to bio-based plastics will have any impact on the market. **Driver XXVII.4.3** The analysis of the previous report remains correct. **Driver XXVII.4.4** The analysis of the previous report remains correct. **Bottleneck XXVII.4/5.7**

		mentioned aspects. If we could foresee OFMSW as a possible feedstock for such fermentation processes the further composition and behaviour of MSW (e.g. food waste together with packaging materials) will probably influence the pre-treatment and subsequent processing, respectively."		The analysis of the report fails to address the heart of the respondent's comment. The Plastics Strategy (and the CEAP as a whole) is very focused on recycling and existing technologies, favouring mature processes. Often, innovative processes cannot compete in terms of resource efficiency as of yet – but their future potential is nixed if regulation focuses too heavily on this aspect now."
Adipic acid & Muconic acid & 1,5-pentanediamine	**Bottleneck XXVII.4/5.7** A respondent from an EU project (H2020) (8) said that the Strategy is aimed at process efficiency, while current biotechnological processes are not yet optimised. This can result in products having a greater impact than that they would have at an industrial-scale production. It can lead to a rejection of the materials/products.			
5. Bio-based plastics				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Bio-based plastics	**Bottleneck XXVII.5.8** A representative from an EU-project (14) said that the Communication requires more plastics recycling in terms of	**Driver XXVII .5.5** Representatives from an EU-funded project (9) mentioned that start of work to develop harmonised rules on defining	**Bottleneck XXVII.5.8** The Commission Strategy does contain a number of actions regarding bioplastics. These actions can be found in Annex I. These actions are mentioned in the analysis for	**Bottleneck XXVII.5.8** While the analysis is correct in its statement that the Strategy's Annex contains actions with regard to bio-based and biodegradable

	quality and quantity and that the Communication stresses the need of a regulatory framework for biodegradable plastic. Specific references to bio-based plastics and measures thereto could not be found.	and labelling compostable and biodegradable plastics." **Driver XXVII.5.6** Respondent (9) mentioned the to be conducted lifecycle assessment to identify conditions where the use of bioplastics is beneficial, and the criteria for such application. **Driver XXVII.5.7** Respondent (9) described the Commission's proposed action to pursue work on life-cycle impacts of alternative feedstocks for plastics production as a driver. **Driver XXVII.5.8** Respondent (9) praised the Commission's proposed action to make better use of economic instruments, especially to raise the costs of landfilling and incineration."	Bottleneck XXVII.4.6. However, according to a respondent it is overlooked that there are various technical applications where biodegradable plastics have a technical function (for instance biodegradable mulch films, fertiliser coatings) and standards and targets for a minimum biodegradability still have to be developed. **Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I." **Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I." **Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I." **Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I. **Bottleneck XXVII.5.9** Among the actions included in the Strategy are actions to promote investment and innovation in the value chain (see Annex I). These actions include examining the feasibility of a private-led investment fund to finance investments in innovative solutions and new technologies aimed at reducing the environmental impact of primary plastic production, and direct financial support for infrastructure and innovation through the European Fund for Strategic Investment and other EU funding instruments (e.g. structural funds and smart specialisation strategies, Horizon 2020).This funding could lead to a	plastics, these actions are all exploratory and refer to research, instead of regulatory measures that would boost bio-based plastics. (In some regards they might even hamper the market development, if environmental aspects were set too strictly, for example.) **Driver XXVII.5.5 till XXVVII.5.15** The analysis of the previous report remains correct, even though as explained above it remains to be seen whether these rules will be a driver for bio-based plastics. **Driver XXVII.5.6** The analysis of the previous report remains correct, even though as explained above it remains to be seen whether this framework will be a driver for bio-based plastics. **Driver XXVII.5.7** The analysis of the previous report remains correct, even though as explained above it remains to be seen whether this framework will be a driver for bio-based plastics. **Driver XXVII.5.5 till XXVVII.5.15**
Polyhydroxyalkanoates (PHA)	**Bottleneck XXVII.5.9** A representative from an EU-funded project (13) pointed out that there is a disparity between subsidies for biogas produced with the same	**Driver XXVII.5.9** A representative from a waste-water management company (7) mentioned that having a better definition of biodegradable or composting will ensure that truly		

	feedstocks as PHA and subsidies for PHA production.	biodegradable plastics in different conditions, such as PHA, will gain more relevance. **Driver XXVII.5.10** The representative from the waste-water management company (7) furthermore said that the Strategy reinforces the importance of using their own resources (carbon) to produce plastics. **Driver XXVII.5.11** A representative from an EU-funded project (13) mentioned that establishment of a clear regulatory framework for plastics with biodegradable properties **Driver XXVII.5.12** A representative from an EU-funded project (13) pointed out that the Commission will propose harmonised rules for defining and labelling compostable and biodegradable plastics. **Driver XXVII.5.13** The representative from an EU-funded project (13) said that	smaller disparity between subsidies for biogas produced with the same feedstocks as PHA and subsidies for PHA production. However, as a respondent states, the analysis above relates to reducing the required funding of investment. However biogas production subsidies are often production/operation related (per m3 of biogas). Such operational subsidies are not available for bio-based products, thus leading to an unlevel playing field. **Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I. **Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I. **Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I. **Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I. **Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I. **Bottleneck XXVII.5.10** This bottleneck is recognised in paragraph 4.2: "most currently available plastics labelled as biodegradable generally degrade under specific conditions which may not always be easy to find in the natural environment, and can thus still cause harm to ecosystems" To address this the Commission will take the action to start work to develop harmonised rules on defining	The analysis of the previous report remains correct. **Bottleneck XXVII.5.9** The analysis of the previous report remains correct. It should be noted that the Communication – as a strategic document – does not have the power to alter subsidy schemes that are set out by other Directives (REDII in this case). **Driver XXVII.5.5 till XXVVII.5.15** The analysis of the previous report remains correct. **Driver XXVII.5.5 till XXVVII.5.15** The analysis of the previous report remains correct. **Driver XXVII.5.11** The analysis of the previous report remains correct, even though as explained above it remains to be seen whether this framework will be a driver for bio-based plastics. **Driver XXVII.5.12** The analysis of the previous report remains correct, even though as explained above it remains to be

		the Commission will also develop lifecycle assessment to identify the conditions under which the use of biodegradable or compostable plastics is beneficial, and the criteria for such applications.	and labelling compostable and biodegradable plastics, see Annex I. **Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I. **Driver XXVII.5.5 till XXVVII.5.15** Self-explanatory, see Annex I. **Driver XXVII.5.16** In paragraph 4.3 of the Strategy the Commission highlights that alternative feedstocks can be developed to avoid using fossil resources. Furthermore, the Commission mentions that, so far, Horizon 2020 has provided over EUR 250 million to finance R&D in areas of direct relevance to the strategy. Furthermore, in paragraph 4.3, the Commission calls on public authorities to invest in extended and improved separate collection.	seen whether these rules will be a driver for bio-based plastics. **Driver XXVII.5.13** The analysis of the previous report remains correct, even though as explained above it remains to be seen whether this framework will be a driver for bio-based plastics. **Bottleneck XXVII.5.10** The analysis of the previous report remains correct. **Driver XXVII.5.14** According to the Green Deal, chemical recycling technologies are still being evaluated. Even though they are recognised per se in the European Waste Framework, most national legislations do not allow for them yet. **Driver XXVII.5.5 till XXVVII.5.15** The analysis of the previous report remains correct. **Driver XXVII.5.16** The analysis of the previous report remains correct.
Bio-Polyamide 56 / Long chain Bio-Polyamides / Polyhydroxyalkanoate (PHA)	**Bottleneck XXVII.5.10** A representative from an EU-project (11) said that it is recognised that most currently available plastics labelled as biodegradable generally degrade under specific conditions which may not always be easy to find in the natural environment, and can thus still cause harm to ecosystems. In addition, plastics that are labelled 'compostable' are not necessarily suitable for home composting. If compostable and conventional plastics are mixed in the recycling process, it may affect the quality of the resulting recyclates**.**	**Driver XXVII.5.14** A representative from an EU project (H2020) (8) said that biochemical recycling is applied to recover materials and reintroduce them into the production cycle, which significantly reduces resource consumption and waste generation. Waste are thus converted into resources, which is among the main objectives of this circular strategy **Driver XXVII.5.15** A representative from an EU-project (11) said that the Strategy recognises that targeted applications, such as using compostable plastic bags to collect organic waste separately, have shown positive results; and standards exist or are being developed for specific applications.		

		Driver XXVII.5.16 In addition, the representative from an EU-project (11) said that new feedstocks such as food waste for the production of plastics are a recognised priority to improve the carbon footprint of plastics and to move away from fossil fuels. It is recognised this is still experimental. For consumer applications, the existence of a well-functioning separate collection system for organic waste is essential.		

XXVIII. Closing the loop - An EU action plan for the Circular Economy

The analysis of the old report refers to the communication of the European Commission: Closing the loop – An EU action plan for the Circular Economy (COM/2015/0614 final). On 11 March 2020 A New Circular Economy Action Plan has been released (COM(2020) 98 final) which is analysed for the 2020 update.

- The small number of bottlenecks mentioned in the old report demands to consider all stages of the lifecycle of the regarded products. Those aspects are generally addressed by the updated regulations even though, the formulation remain quite unspecific (see e.g. Bottleneck XXVIII.4/5/6.2).

4. Bio-based chemicals

Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
PLA for hot melt adhesives.	**Bottleneck XXVIII.4.1** A respondent belonging to an EU project (13) argued that further clarification is needed of aspects of biodegradation of the media for the materials, establishing real conditions and their behaviour.	…	**Bottleneck XXVIII.4.1** Bio-based materials are addressed in the Action Plan (e.g. chapter 5.5). Here the Commission also addresses the need for attention for lifecycle environmental impacts in relation to bio-based materials.	**Bottleneck XXVIII.4.1** The NCEAP states under 6.3: Horizon Europe will support the development of indicators and data, novel materials and products, substitution and elimination of hazardous substances based on "safe by design" approach, circular business models, and new production and recycling technologies, including exploring the potential of chemical recycling. Apart from this statement the analysis of the previous report remains unchanged.
Single Cell Oil for oleochemical industry produced by yeasts	**Bottleneck XXVIII.4/5/6.2** A respondent belonging to an EU project (14) argued for the full integration of product life cycles into waste prevention and management programmes by adaption of the current legislation along all the stages of activities.		**Bottleneck XXVIII.4/5/6.2** The bottleneck stated here, is directed at changing EU legislation along the whole product cycle. The Action Plan does suggest measures along the whole product cycle, from eco-design, production processes to waste management. This seems to support the recommendation by the respondent.	**Bottleneck XXVIII.4/5/6.2** In the NCEAP under point 2 the aim of 'incentivising product-as-a-service or other models where producers keep the ownership of the product or the responsibility for its performance throughout its lifecycle' is stated. Also the implementation of regulatory measures to prevent negative environmental impact at all relevant stages of a products' lifecycle is mentioned in the case of plastics.

5. Bio-based plastics

Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Bio-based plastics	***Bottleneck XXVIII.4/5/6.2*** *This bottleneck was also mentioned by the same respondent (14) in relation to bio-based plastics.*	…	…	…

6. Bio-based food and feed ingredients				
Bio-based product	Bottlenecks (& recommendations)	Regulatory drivers	Analysis	Update 2020
Omega-3 fatty acids	***Bottleneck XXVIII.4/5/6.2*** *This bottleneck was also mentioned by the same respondent (14) in relation to Omega-3 fatty acids.*	…	…	…

2.3 Discussion: The European Green Deal and the Bioeconomy

Following the agreements form the inception phase of the project the regulations and directives in WP3 have been updated using methodology developed in the survey study published in 2018.[155] The report identified EU regulations and directives that were pertinent to the bio-based sector, yet there are several other highly relevant policy changes within the EU have only been mentioned in brief thus far. The most significant is the European Green Deal (EGD), which has become the centrepiece of the EU transition to a circular and green economy and bioeconomy. The EGD presented in December 2019 has implemented stringent targets and proposed billions of euro in funding to help the EU achieve carbon neutrality by 2050. It has the potential to take the pressure off of the regulations and directives presented here that may not have the breadth to fuel the industry as is necessary to see concrete change.

There are several key ways in which the EGD and the bioeconomy go hand-in-hand. The bioeconomy contributes to the EU targets through the promotion of clean energy and transport, investment in innovative green technologies, green industry, lower pollution (decrease in quantity of landfilled waste), growing green jobs, financing green projects, making home heating more efficient, and more. It is clear that these contributions align directly with the EGD's main strategies and actions presented in the figure below. These action points are then spurred by the ways in which the transition will be financed and the Just Transition Mechanism which revolves around support to the regions and sectors that are the most impacted by the transition to a low-carbon economy (e.g. industries dependent on fossil fuels).

Figure 42. Elements of the EGD. Source: The European Green Deal, European Commission

Among the most significant strategies in the EGD relevant to the circular and bioeconomy is the Circular Economy Action Plan of March 2020, EU strategies for energy system integration adopted in July 2020, and the 2030 Climate Target Plan. Generally speaking, all of the policy areas within the EGD are tied in one way or another to the bioeconomy. The bio-based sector is fuelled by the ability and readiness for industries to turn bio-waste or biomass into value through innovative approaches, yet the fact remains that many Member States funds are not available for investment in necessary technologies or

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[155] Urban Agenda for the EU. (2018). Survey report on regulatory obstacles and drivers for boosting a sustainable and circular urban bio-based. economy https://ec.europa.eu/futurium/en/system/files/ged/analysis_of_regulatory_obstacles_and_drivers_urban_circular_bioeconomy_report_final_version_29.10.19_rv_27.04.2020.pdf

industries. The pace of the development of the valorisation of biomass waste at a large scale will determine the success of the whole transformation from a fossil fuel-based economy to the bioeconomy.

The Circular Economy Action Plan will support public-private partnerships for the bio-based industry and boost the implementation of the Bioeconomy Action Plan. Both action plans will support bio-based industries financially and politically, signalling a green light for sectors and countries that have been reluctant to move forward with investing in new technological processes. Alongside the Circular Action Plan is the EU Energy System Integration Plan which incentivises the use of agricultural residues to produce sustainable biogas. Residues are rather abundant in some Central and Eastern European countries, but these countries often don’t have the facilities to process them. Bringing collaboration across MS should be a key focus of the EGD and its attention to bio-based industries.

Within the main agenda of the EGD is of course the 2030 Climate Target Plan with a proposal to cut GHG emissions by at least 55% by 2030. The proposal ties economic growth to environmental objectives, e.g. stimulating jobs in bio-based industries. While these plans are in the works, in some cases the connection to the bio-economy is simply speculative. The Effort Sharing Decision and the Effort Sharing Regulation, for example, do not have new changes and the updated regulation (2018/842/EU) was adopted in time to be included in the previous survey report. Many of the bottlenecks and drivers cited have remained but the constraint on the regulation will be alleviated with the plans set out in the EGD, among others. LULUCF and CAP also play a distinct role in EU policy with regard to factoring in land-use into targets and climate mitigation and adaptation.

One of the key sectors within the EU, which is becoming more and more relevant in climate policy is the land use, land-use change and forestry (LULUCF) sector. LULUCF is a sector that focuses on GHG emissions from all forms of land use as well as the CO_2 absorption from the atmosphere by plants. In European climate legislation, this sector is regulated by Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of GHG emissions and removals from land use, land-use change and forestry in the 2030 climate and energy framework. The regulation sets the rules of reporting and accounting emissions from this sector. The regulation entered in to force in 2018 and includes several indirect linkages with bioeconomy concept. The most prominent one is within Harvested Wood Products. Harvested wood contains carbon in its structures, and the ways of processing and further use of the wood determine the amount of the carbon sequestered and locked in the woody biomass. The LULUCF Regulation promotes the utilisation of wood especially through the construction sector by allowing for delayed reporting of emissions from harvested wood. In other words, delivery, usage of the woody biomass can be rewarded by lowered emissions in the member states emissions accounts.

The EU Common Agricultural Policy (CAP) has also been cited regularly as a means to generate a strong link between the agricultural sector and potential for upscaling innovative bio-processing technologies. In 2018, the CAP introduced a proposal that included, among other things, a refocusing of direct payments for environmental action and an allocation of 10 billion euro to research within Horizon Europe. While both of these proposed actions can fuel the bioeconomy indirectly, there is still a need to further connect CAP objectives to, e.g. the rural bioeconomy. Reform of the CAP is still in the works and has recently been pushed back to 2023, extending the funding allocation from the previous 5 year period. The potential for increasing green ambitions remains and will hopefully create stronger synergies between, e.g. rural farmers and innovation.

2.4 Conclusion

The connection across and between the regulations in this report are important to consider for the future of the circular and bioeconomy. While there are new amendments regarding end-of-waste (EoW) criteria and some other useful amendments that could support the bioeconomy, there is still evidence of heavy discrimination against the bio-based industry. Within the 11 regulations that are analysed, there is not enough financial support or individualisation of bio-products to see real growth in the industry. On the other hand, the EU Action Plan for the Circular Economy and the European Strategy for Plastics in a Circular Economy have now been enveloped within the EGD, giving it and the Bioeconomy Action Plan broad regulatory support.

2.4.1 Barriers

Within the regulations analysed, a common criticism was unclear wording or defining of terms related to the bio-based industry, e.g. definition of 'biodegradable waste' within the Landfill Directive and definition of 'compost' within the REACH Regulation. Driving any EU regulations is the establishment of well-defined terms in order to foster consistency and stringency. In addition, integration between policies is necessary to eliminate roadblocks to achieve policy targets. One of the key bottlenecks cited in the Nitrates Directive (Directive 91/676/EEC) was the inconsistency across MS and the nitrogen limits in manure (kg) and the general lack of harmonisation between how nitrogen is taken into account. This has only been exacerbated by the derogations filed by MS since the survey report was published and simply highlights the need for clear policy wording.

Across the board within this analysis, little or no attention was given to bio-chemicals. The WFD for example does not mention chemical recycling, strictly focusing on the 'main' bio-waste recycling other than composting and digestion. Alternative waste streams are important to consider beyond these existing technologies as the definition of biological waste, for example could be standardised across multiple policies, e.g. WFD, Landfill Directive and Sewage Sludge Directive, to achieve better recycling or waste stream management. Bio-plastics are a one of the leading products within the bioeconomy, yet within the Plastics Regulation and the European Strategy for Plastics in a Circular Economy, not enough attention is given to biodegradable plastics or driving innovation to circular solutions.

Driving home the need for regulatory alignment is conceptualised in the Renewable Energy Directive (REDII) and the preferential treatment given to energy recovery over material recovery, paving the way for energy applications of bio-based feedstocks. Additional pressure from REDII can drive down the potential for other recovery applications of bio-based feedstocks. While REDII paves the way for bio-energy, the Gas Directive also does not directly influence tax exemption for green gas making these two directives contradictory as one promotes production of biogas and the other creates a barrier.

2.4.2 Successes

Since the survey report was published, a number of sweeping changes have occurred, enabling growth in the bio-based sector. A new Fertilisers Regulation (2019/1009), for example has been adopted which now takes into account organic fertilisers. The main bottleneck outlined in the analysis of the old regulation emphasised the fact that only inorganic fertilisers were considered. In this same sphere, the REACH Regulation has since included digestate within the regulation's registration exemptions, removing one of the main bottlenecks.

The Waste Framework Directive, like the Landfill Directive has been criticised for the lack of attention to bio-waste disposal. Since 2018, the proposed changes to the original WFD (2008/98/EC) have been adopted within a new WFD (Directive (EU) 2018/851) and have redefined EoW criteria as well as bio-waste collection, albeit to be fully realised in 2024. Revised targets in the new WFD are also a significant success making diversion of bio-waste more of a focus.

2.4.3 Expected developments

There are a few Directives with proposals underway, which will determine the future of EU policies on the bioeconomy. The Sewage Sludge Directive, for one will be potentially updated in the coming years to include updates to treatment technologies and there, among other things, and will be based on a broad evaluation of the old directive. Aligning all of the directives and regulations with the Circular Economy Action Plan and Bioeconomy Action Plan will be necessary to make sure that the potential for reaching climate targets through the production of bio-based products from bio-waste and wastewater sludge is fully realised.

In general, the main successes within the enabling environment for the bioeconomy is the upscaled targets of the EGD and the new Circular Economy Action Plan. The updated Bioeconomy strategy is another clear pathway to support the regulations and directives analysed thus far

3 Most promising technologies for a resource-efficient sourcing and use of carbon

The mitigation of climate change and the reduction of impacts for nature require wide transformation processes in a number of societal and economic fields. The analysis carried out in work package 1 confirms that fossil-based resources are currently the backbone of today's European carbon supply regarding the energy sector and the material use of carbon-based products. Besides, biogenic carbon also plays an important role for these sectors and is essential for the food & feed supply.

With the need for decarbonisation in the energy sector to meet the greenhouse gas emission goals, a fundamental shift in European carbon supply and demand is expected. The scenarios depicted in work package 2 explore possible pathways to a resource-efficient sourcing and use of carbon. Each of the scenarios is based on the strong exploitation of various technologies (e.g. hydrogen or e-fuels in the energy sector, chemical recycling or gene editing in the food, feed and material use sector). On the other hand, the field studies in work package 4 suggest, that in comparison the technologies currently in use barely match the ones required in the future. One reason is that a number of innovations or advancements is required in various fields to follow one or more of the explored technological pathways.

Therefore, in the following chapters, innovative technologies in different maturity levels are collected and then analysed regarding their benefit for a resource efficient and sustainable carbon economy, their potential to fill technological gaps and techno-economic challenges that need to be met. The most promising technologies for the carbon economy are identified based on five major product groups which are bulk chemicals & fuels, polymers, proteins (feed & food), hydrogen, and fine chemicals. The groups are characterised by a very specific range of different products which are produced from different feedstocks and technologies. In the following chapters a brief overview is given for each product group. A long-list of available technologies is compiled (see chapter 3.2) from which the most promising technologies are selected for the short-list (see chapter 3.3) based on different evaluation criteria (see chapter 3.2) and particularly the need for research and innovation actions. The selected technologies are covering the areas of electrochemistry, photochemistry, chemical conversion, thermochemical conversion, microbial systems, plant systems, insects, stem cells, and extraction. The evaluation criteria are based on technology readiness level (TRL), limitations, potential, research needs and supporting actions, versatility, climate effects, and retrofitting potential (infrastructure/value chain).

3.1 Analysed product groups

3.1.1 Bulk chemicals & fuels

Bulk chemicals (or commodity chemicals) and fuels are representing a product group with large production volumes and a wide field of applications in the sectors of polymers, dyes & coatings, agriculture, pharmaceuticals, cosmetics, cleaning, as well as transportation and energy. Feedstocks for the production of bulk chemicals and fuels can be fossil-based, bio-based, CO_2-based, and recycling-based. Beside large production volumes (> 1,000 tonnes annual), bulk chemicals are characterised by a low price (up to $ 1 per kilogram). The fuels are representing substances (liquid, gaseous, and solid), which are used to generate energy (e.g. in form of heat or electricity via engines) or to execute work (e.g. movement via engines). Fossil fuels are based on fossil feedstocks which include petroleum, coal, and natural gas. Other fuels are grouped into biofuels (e.g. produced through transesterification of biolipids with an alcohol) and synthetic fuels (e.g. produced by indirect synthesis via gasification and Fischer-Tropsch conversion or direct synthesis via pyrolysis).

3.1.2 Polymers

Polymers are characterised by a wide field of applications utilised in different industries for the production of plastics, products for medical applications and therapy, pharmaceuticals (e.g. for drug delivery systems), adhesives, paints and coatings, cosmetics, food, hydrogels, and fuel cells as well as for wastewater treatment. In general, the product group can be subdivided into functional and structural polymers, rubber products, and natural- and man-made fibres. Functional polymers can be synthetic or natural and are used to modify different properties of different products for instance inks, coatings, adhesives, cosmetics, as well as pharmaceuticals. The structural polymers are fossil- or bio-based polymers that form the structural mass of plastics. Rubbers can be natural (e.g. latex from the rubber tree) or synthetic and are used for a wide range of products such as tyres, sealings, insulation material, hoses, flooring or cements. Natural (e.g. bio-based including cotton and wool or mineral based including asbestos) and man-made fibres (semi-synthetic such as cellulose regenerated fibres or synthetic fibres made from petrochemicals) are used for the production of paper, textiles, insulation material, or optical fibres among others. The demand for polymers for the production of plastics is increasing. In the last decades, the world wide plastic production has increased drastically, reaching 400 million tonnes of plastics produced from bio-based, CO_2-based, and fossil-based feedstocks as well as recycling (Carus et al. 2020). Changes in the general trend are not expected for the near future. Until now the bio-based plastics play a niche roll since their worldwide production share is only 1 % of the global and 0.5 % of the European plastic production. In view to a stronger focus on renewable carbon the bio-based plastics will gain more relevance as well as the chemical recycling which keeps produced polymers in the loop or recovers valuable materials that are utilised, inter alia, in textiles.

3.1.3 Proteins (food & feed)

The global protein demand is steadily increasing. Between the year 2000 and 2018 the demand increased by 40 % from 162 million tonnes to 226 million tonnes (Food Innovation Australia (FIAL) 2018). Plant-based proteins are sharing 57 % of the global protein supply followed by animal-based proteins in form of meat (18 %), dairy (10 %), fish and shellfish (6 %), and other products (9 %) (Henchion et al. 2017). Both the global livestock and fish production have a significant impact on the environment being responsible for 12 % of the greenhouse gas emissions and 30 % of the terrestrial biodiversity loss (Westhoek et al. 2011). A reason for the biodiversity loss is the use of land for feed production, two thirds of the agricultural area of the EU is occupied for livestock production while 75 % of protein rich animal feed needs to be imported from South America (Westhoek et al. 2011). Oilseed meals, fish/animal proteins, and biofuel coproducts are currently the main sources for feed proteins but alternative protein supplements in form of insect meal, microbial-derived single-cell protein, microalgae, and protein hydrolysates are coming into focus (Kim et al. 2019). New focus areas can also be identified for food protein sources in the field of plant-derived proteins, insects, algae, and muscle protein sources from stem cell-based *in vitro* fish and meat production (Henchion et al. 2017).

3.1.4 Hydrogen

The hydrogen product group differs greatly from the other selected groups due to the absence of carbon. Nevertheless, it has a very high relevance for a functioning carbon economy since some prerequisites were defined for this listing (see chapter 3.2) such as the expansion of renewable energies or the reduction of feedstocks based on fossil carbon. Zero carbon emissions can be realised for the energy and transportation sector by replacing energy carriers based on fossil carbon with technologies based on renewable energy and hydrogen. This enables the establishment of new technologies that were previously associated with low sustainability. A hydrogen-based energy system e.g. based on energy-to-hydrogen-to-energy would help to decarbonise the whole energy system (Chapman et al. 2019; Dawood et al. 2020; Parra et al. 2019). Furthermore, it helps to overcome obstacles in relation to renewable energies which under certain conditions produce an energy surplus which cannot be stored in satisfactory capacities over a long period of time to bridge periods of energy shortages. Beside that hydrogen can also be used for the synthesis of different chemicals and polymers. Overall there are four technological aspects which are interconnected with an hydrogen-based energy/production systems which are the hydrogen -production, -storage, -safety, and -utilisation (Dawood et al. 2020). This listing is focussed on the technologies for the hydrogen production.

3.1.5 Fine chemicals

The fine chemicals industry is characterised by the production of complex, single, pure chemicals, usually with a low volume (< 1,000 tonnes annually) and a high price (> $ 10 per kilogram) (Panizza 2018). Products made from fine chemicals can be found in a broad range of application areas such as pharmaceuticals, life sciences, agrochemicals, specialty chemicals, and electronics. For the production of fine chemicals different technologies can be utilised including chemical synthesis, biotechnology, extraction, and hydrolysis. Additionally, and in a broader sense CO_2 reduction processes via thermochemical, photochemical, and electrochemical pathways can be utilised for the production of fine chemicals (Modak et al. 2020). Chemical synthesis either utilises petrochemical substances (e.g. petroleum or coal) or natural product extracts (e.g. from plants) as feedstock. Biotechnology utilises biocatalysts, biosynthesis, and cell culture biology to process different feedstocks including CO_2 and biomass. Extraction involves the extraction of fine chemicals from different feedstocks such as plants, animals, and bacteria. Finally, hydrolysis can be utilised to produce amino acids from proteins. The various technologies, feedstocks, and products show that the fine chemical production sector needs to be technology open since there will be no "one-fits-all" technology.

3.2 Short-list evaluation criteria

For the assessment of the identified technologies different evaluation criteria are selected including technology readiness level, limitations and potentials, research needs and supporting actions, versatility, climate effects, and retrofitting potential which are described below in more detail. Several developments such as the expansion of renewable energies, the reduction of feedstocks based on fossil carbon, and an increased utilisation of feedstocks based on renewable carbon are preconditions and therefore prerequisites for the outcome of this study.

3.2.1 Technology readiness level (TRL)

The technology readiness level (TRL) is evaluated for the identified technologies. The categorisation and definition of the different TRLs is conducted according the Horizon 2020 work programme (European Commision 2017). Overall nine categories are defined as follows:

TRL 1: Basic principles observed.

TRL 2: Technology concept formulated.

TRL 3: Experimental proof of concept.

TRL 4: Technology validated in lab.

TRL 5: Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies).

TRL 6: Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies).

TRL 7: System prototype demonstration in operational environment.

TRL 8: System complete and qualified.

TRL 9: Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space).

For the categorisation another aspect needs to be considered which is the differentiation between a single process and the whole production or value chain. For instance, as a single process the well-established Fisher-Tropsch process can be categorised into TRL 9. In contrast to that a lower TRL has to be considered for the Fischer-Trosch process once biomass-based or CO_2-based syngas is considered as feedstock.

3.2.2 Limitations & potentials

Current limitations and potentials are evaluated for the identified technologies. The evaluation considered parameters such as production volume, energy consumption, and process efficiency. Overall three levels for each limitations and potentials is used for the categorisation which are defined as follows:

Non decisive limitations & potentials: Known limitations and potentials have no significant impact on the fulfilment of intended requirements on the technology.

Low limitations: Known limitations are interfering with the fulfilment of intended requirements on the technology. Further research and supporting actions might be necessary to overcome such limitations.

High limitations: Known limitations are considerably interfering with the fulfilment of intended requirements on the technology which might prevent a successful integration and operation. Further research and supporting actions might be necessary to overcome such limitations.

Low potentials: Known potentials are contributing to the fulfilment of intended requirements on the technology. Further research and supporting actions might improve the potentials.

High potentials: Known potentials are contributing or outperforming the fulfilment of intended requirements on the technology which potentially leads to a successful integration and operation. Further research and supporting actions might improve the potentials.

3.2.3 Research needs and supporting actions

The need and feasibility for research and supporting actions was evaluated based on the technology properties including limitations and potentials (see chapter 3.2.2), as well as on the scale of already implemented technologies in the industry. Overall it was differentiated between four recommendations for research needs and supporting actions analogous to the Horizon 2020 work programme (European Commision 2017) as follows:

Research and innovation actions (RIA): Action primarily consisting of activities aiming to establish new knowledge and/or to explore the feasibility of a new or improved technology, product, process, service or solution. For this purpose, they may include basic and applied research, technology development and integration, testing and validation on a small-scale prototype in a laboratory or simulated environment.

Innovation actions (IA): Action primarily consisting of activities directly aiming at producing plans and arrangements or designs for new, altered or improved products, processes or services. For this purpose, they may include prototyping, testing, demonstrating, piloting, large-scale product validation and market replication.

Coordination and support actions (CSA): Actions consisting primarily of accompanying measures such as standardisation, dissemination, awareness-raising and communication, networking, coordination or support services, policy dialogues and mutual learning exercises and studies, including design studies for new infrastructure and may also include complementary activities of strategic planning, networking and coordination between programmes in different countries.

Commercialisation support (CS): Actions consisting of activities aiming at the implementation onto the market.

3.2.4 Versatility

The versatility of the identified technologies was evaluated regarding the spectrum of processable feedstocks and products. Overall three categories were defined as follows:

No versatility: Limited to a single feedstock and/or product.

Versatile: Capability to process a certain range of different feedstocks and/or to produce a range of different products.

High versatility: Capability to process a wide range of different feedstocks and/or to produce a wide range of different products.

3.2.5 Climate effects

Different factors were considered to evaluate the impact of the identified technologies on the climate including life cycle assessment (LCA) indicators and general tendencies in energy consumption, land use, land efficiency, use of by-products, as well as fossil carbon substitution potential and carbon removal potential. Since the available LCAs can hardly be compared, the evaluation can only provide a rough estimate on a more qualitative approach.

Overall three different categories were defined as follows:

1. **Non decisive climate effects:** Effects are unknown, neutral or negative, e.g. leading to similar or more greenhouse gas emissions compared to other processes.

2. **Positive climate effect:** Effects are positive e.g. leading to a reduction of greenhouse gas emissions in comparison to other processes,

3. **High positive climate effect:** Effects are considerable positive e.g. leading to a strong reduction of greenhouse gas emissions or even negative greenhouse gas emissions.

3.2.6 Retrofitting potential

The retrofitting potential was evaluated for the identified technologies based on the potential to directly be integrated into an existing technology/infrastructure and/or value chain. Technologies with retrofitting potential are for instance technologies which produce naphtha or drop-in chemicals. Overall three different categories were defined as follows:

1. **No retrofitting potential:** Cannot be integrated into existing technologies/infrastructures and value chains. New technologies/infrastructures and value chains need to be established.

2. **Medium retrofitting potential:** Can be integrated into existing technologies/infrastructures or value chains.

3. **High retrofitting potential:** Can be integrated into existing technologies/infrastructures and value chains.

3.2.7 Summary of evaluation criteria

Table 27. Summary of evaluation criteria, corresponding chapters, values, and symbols.

Criteria	Chapter [#]	Category	Symbol
Technology readiness level (TRL)	3.2.1	1-9	1-9
Limitations & potentials	3.2.2	Non decisive limitations & potentials	0
		Low limitations	-
		High limitations	--
		Low potentials	+
		High potentials	++
Research needs and supporting actions	3.2.3	Research and innovation actions	RIA
		Innovation actions	IA
		Coordination and support actions	CSA
		Commercialisation support	CS
Versatility	3.2.4	No versatility	0
		Versatile	+
		High versatility	++
Climate effects	3.2.5	Non decisive climate effects	0
		Positive climate effect	+
		High positive climate effect	++
Retrofitting potential	3.2.6	No retrofitting potential	0
		Retrofitting potential	+
		High retrofitting potential	++

3.3 Short-list of technologies for specific product groups

3.3.1 Bulk chemicals & fuels

Table 28. Most promising technologies for bulk chemicals & fuels.

Technology	TRL	Limitations	Potential	Research needs and supporting actions	Versatility	Climate effects	Retrofitting potential (Infrastructure/Value chain)
Electrochemistry	3-5	--	++	RIA	+	++	+
Photochemistry	3	--	++	RIA	+	++	+
Microbial systems for CO_2 utilisation	4-9	-	++	RIA /IA	++	++	+
Microbial systems for biomass utilisation	6-9	-	++	RIA /IA	++	+	++

Thermochemical conversion of polymers and plastics	4-7	-	++	RIA	++	0	+
* regulatory limitations/issues							

The production of bulk chemicals and fuels via **electrochemistry** shows a high versatility regarding the addressed feedstocks and products which is similar to the results for the fine chemicals product group (see chapter 1.1.1). Valuable hydrocarbons such as alcohols, ethylene, and ethanol can be produced via electrochemical CO_2 reduction on copper (Nitopi et al. 2019). Furthermore other chemicals, hydrogen, and energy can be produced via electrooxidation of various bio-based molecules (Holade et al. 2020). Overall, for organic synthesis the electrochemistry features a high potential due to the relatively mild conditions and high chemoselectivity (Horn et al. 2016). The climate effects can be very positive due to the utilisation of CO_2 as well as the demand for large product volumes in the sector of bulk chemicals and fuels. However, the CO_2 reduction is associated with limitations such as low power efficiency, a poor selectivity, the formation of radical anions, and the occurrence of hydrogen evolution in aqueous environment as a competing reaction (Botte 2014; Möhle et al. 2018; Sun et al. 2017). Overall, limitations can be very specific to the technology and processes, often they are associated with the electrode/catalyst design, electrolyte, and scale-up which may become an issue, especially due to large production volumes (Nørskov et al. 2020). Furthermore, as previously mentioned in the evaluation of electrochemistry for fine chemicals (see chapter 1.1.1), the technologies for CO_2 utilisation and storage still needs to be implemented widely to secure the upstream processes in the value chain. For the production of bulk chemicals and fuels this limitation has to be considered as more serious due to the higher production volumes and therefore higher demand of CO_2. A range of pilot and commercial organic electrosynthesis processes are available (Botte 2014). Due to the wide range of feedstocks, processes, and products the TRL ranges between 3 to 5. In general, a certain retrofitting potential is given due to the availability of both infrastructure and value chains, however, some limitations might occur once higher production capacities are aimed.

The **photochemistry** also provides solutions for the production of bulk chemicals and fuels. Products such as methane, methanol, formaldehyde, and formic acid can be produced through photocatalytic conversion of CO_2 (Al-Saydeh and Zaidi 2017; Ulmer et al. 2019). For the production of bulk chemicals, the climate effects are more positive than for the production of fine chemicals (see chapter 1.1.1) due to larger production volumes and therefore higher demands of CO_2 as feedstock. The versatility for the direct production of bulk chemicals is lower compared to the production of various fine chemicals from various different substances (Oelgemöller 2016). The photochemistry can be realised via the sunlight or via artificial light sources which requires electrical energy. Artificial light sources are often characterised by limited lifetimes and therefore significant maintenance costs (Oelgemöller 2016). Solar photochemistry is limited to the usable range of the solar spectrum (300-700 nm), the discontinuous availability of sunlight, and climatic conditions which are potentially preventing the realisation of industrial solutions (Oelgemöller 2016). Hence, limitations are considered to be high. The TRL of photochemistry for the production of bulk chemicals is at the proof of concept and retrofitting potential is given via existing value chains, the upstream processes such as CO_2 utilisation may be a limiting factor, especially due to the large production volumes and therefore high demand for CO_2 as feedstock. Furthermore, the infrastructure still needs to be established for industrial scales.

Microbial systems are providing very versatile solutions for the production of bulk chemicals (e.g. ethylene glycol, 1,3-propanediol, 1,4-butanediol, 1,3-diaminopropane, succinic acid) and fuels (e.g. ethanol, butanol, farnesene, alkane, fatty acid methyl ester, fatty acid ethyl ester) from CO_2 and biomass. Positive climate effects are expected for the utilisation of biomass while very positive effects are expected for the utilisation of CO_2. Limitations can be the requirements of the process environment to ensure a functional biological system as well as regulatory aspects. The scaling-up of microbial strains from the lab-scale to industrial-scale is linked with issues since the conditions and process requirements in large-scale bioreactors are often not considered. Prominent issues are for instance increased mixing times of chemicals, increased operating pressures due to the increased height of the water column, and increased gas concentration (Wehrs et al. 2019). Systems metabolic engineering (including traditional metabolic engineering, systems biology, synthetic biology and evolutionary engineering) will lead to necessary advances in the enzyme and pathway design in which known processes can be improved and new processes can be established (Ko et al. 2020). For the utilisation of biomass microbial strains need to be developed to primarily convert non-edible biomass to avoid the fuel vs. food competition for edible feedstocks (Ko et al. 2020). Depending on the process, the utilised species, and feedstock the TRL ranges between 4 and 9. The TRL for the utilisation of CO_2 is lower compared to the utilisation of biomass due to the availability of established technologies. The retrofitting potential is given in context of available bioreactor technologies (Liao et al. 2018; Stoll et al. 2020) as well as existing value chains. Nevertheless, retrofitting potential is lower for the CO_2 utilisation since the supply of CO_2 feedstocks needs to be improved through further developments in CO_2 capture.

Beside the direct synthesis of bulk chemicals and fuels the **thermochemical conversion of polymers and plastics** provides an indirect synthesis pathway through the production of syngas and pyrolysis oil. The products can be further processed into specific bulk chemicals and fuels via gas reforming and oil refining. The versatility is very high due to the ability to process various feedstocks based on polymers and plastics as well as the wide range of possible products which can be liquid, solid, or gaseous. Under current conditions the climate effects can be positive (BASF 2020; Bergsma and Broeren 2019) but for the future these remain unclear due to the complexity of possible processes, feedstocks, and products as well as due to the assumed future focus on products based on renewable carbon and renewable energy. Therefore, the evaluation on climate effects can be concluded as non-decisive. Limitations are coupled with different issues (e.g. higher tar content upon gasification of plastics, and problems associated with catalytic cracking in presence of heteroatoms) (Aguado et al. 2006; Lopez et al. 2018). The technologies for the processing of polymers and plastics are partially between lab scale and demonstration with a TRL between 4 and 7. The retrofitting potential is given due to existing pyrolysis-, gasification, and refinery infrastructure. Upscaling might be necessary once large production volumes are aimed; furthermore, upstream processes can be optimised via the supply of more homogeneous feedstocks which ensures a constant product quality.

3.3.2 Polymers

Table 29. Most promising technologies for polymers

Technology	TRL	Limitations	Potential	Research needs and supporting actions	Versatility	Climate effects	Retrofitting potential (Infrastructure/Value chain)
Microbial systems for CO_2 utilisation	4-9	--	++	RIA	++	++	+
Microbial systems for biomass utilisation	6-9	-	+	RIA	++	+	++
Electrochemistry	3-5	-	++	RIA	++	0	++
Thermochemical conversion of polymers and plastics	4-7	-	++	RIA	++	0	+

* regulatory limitations/issues

Microbial systems for the production of biopolymers are characterised by a very high versatility regarding the variety of products and feedstocks. Biopolymers produced from bacteria are relevant for the biotechnological, chemical, cosmetics, feed & food, medical, pharmaceutical, and technical industry (Verma et al. 2020). Prominent examples for biopolymers produced by bacteria are alginate, cellulose, cyanophycin, dextran, epoxysaccharides, gellan, glucan, hyaluronic acid, levan, poly-γ-glutamic acid, polyhydroxyalkanoates (PHA), polylactic acid (PLA), pullulan, and xanthan (Verma et al. 2020). Feedstocks can be either biomass or CO_2 and the synthesis of polymers can be direct or indirect. Here it needs to be highlighted that the outcome of the evaluation for direct and indirect synthesis pathways based on microbial systems are the same due to the complexity of pathways which did not allow a deeper investigation of specific advantages and disadvantages. Furthermore, specific products can exclusively be synthesised on the direct or indirect way, which makes comparisons difficult. PLA for instance can be produced indirectly via microorganisms, which are utilised for the fermentation of biomass to produce lactic acid, which is then isolated and purified. Via polycondensation and depolymerisation lactic acid can be transformed into lactide which is used for PLA synthesis via ring opening polymerisation, alternatively PLA can also be directly synthesised from lactic acid via polycondensation (Masutani and Kimura 2015). Furthermore, efforts were recently made to realise lactic acid production based on CO_2 (Azim et al. 2020). PHA for instance can be produced directly from CO_2 or biomass (Miyasaka et al. 2013; Verma et al. 2020). The climate effects are very positive due to the utilisation of CO_2 as feedstocks while the effects for the utilisation of biomass are lower but still positive. Limitations for the CO_2 utilisation are mainly coupled to the current state of available synthesis pathways and the underlying technologies which are at TRL 4-9. Another limitation would be the availability of captured CO_2, which also limits the full retrofitting potential of technologies that are based on this feedstock. In contrast to that microbial systems based on biomass are partially well established reaching TRLs between 6 and 9. Compared to the utilisation of CO_2 the utilisation of biomass as lower limitations due to the availability of established and optimised processes. However, new developments and discoveries are still coupled with issues and limitations which needs to be optimised. The retrofitting potential is fully given for the biomass utilisation due to the availability of commonly used feedstocks, infrastructure, and value chains.

Polymers such as polyethylene can be indirectly produced with **electrochemistry** via ethanol and ethylene (see chapter 3.3.1). Furthermore, conducting and non-conducting polymers can be synthesised directly via **electrochemistry** or more specifically electrochemical polymerisation (Fomo et al. 2019). Electrosynthetic conducting polymers for instance polypyrrole, polythiophene, and polyanaline can be produced by using potentiostatic and galvanostatic methods (Chen 2011). The utilisation of conducting polymers gains more interest and potential in background of new demands and advances in electronics, usually they find their applications in solar cells, organic light emitting diodes (OLEDs), batteries, sensors and other electronic parts (Fomo et al. 2019). These possible applications are contributing to a high versatility of electrochemical polymerisation. However, electrochemical polymerisation has some limitations such as low yield which prevents large-scale production and poor solubility of its products (Fomo et al. 2019). Due to the limited production volumes the climate effects are non-decisive. However, the climate effects could be very high for indirect polymer synthesis via ethanol and ethylene to polyethylene. The TRL is between 3 and 5 and therefore further development is necessary to establish a demonstration of the technology in a relevant environment. The retrofitting potential is given due to the availability of infrastructure and value chains. However, this might change e.g. through quickly increasing demands and linked shortages due to the dynamic developments in electronics.

Another indirect synthesis pathway for polymers can be realised through **thermochemical conversion** of polymers and plastics into pyrolysis oil or monomers. The pyrolysis oil and monomers can then be further processed back into polymers. The versatility is very high due to the ability to process various feedstocks based on polymers and plastics as well as the wide range of possible products. Under current conditions the climate effects can be positive (BASF 2020; Bergsma and Broeren 2019) but for the future these remain unclear due to the complexity of possible processes, feedstocks, and products as well as due to the assumed future focus on products based on renewable carbon and renewable energy. Therefore, the evaluation of climate effects can be concluded as non-decisive. Limitations are coupled with different issues (e.g. problems associated with catalytic cracking in presence of heteroatoms) (Aguado et al. 2006; Lopez et al. 2018). The technologies for the processing of polymers and plastics are partially between lab scale and demonstration with a TRL between 4 and 7. The retrofitting potential is given due to existing pyrolysis- and refinery infrastructure. Upscaling might be necessary once large production volumes are aimed; furthermore, upstream processes can be optimised via the supply of more homogeneous feedstocks which ensures a constant product quality.

3.3.3 Proteins (food & feed)'

Table 30. Most promising technologies for proteins (food & feed).

Technology	TRL	Limitations	Potential	Research needs and supporting actions	Versatility	Climate effects	Retrofitting potential (Infrastructure/Value chain)
Microbial systems for CO_2 utilisation	4	--*	++	RIA	++	++	+
Microbial systems for biomass utilisation	9	0	+(+)	CS		+	++
Plant system (traditional breeding)	9	0	+	CS	++	+	++
Plant system (advanced, GMO)	6	--*	++	RIA		++	
Insects	9	-*	+	IA	+	+	+
Stem cells (artificial meat)	4	--*	+	RIA	0(+)	+(+)	+
* regulatory limitations/issues							

For the protein product group **microbial systems** are representing highly versatile systems which are capable to accept a range of feedstocks based on renewable carbon such as CO_2, methane, methanol or biomass (e.g. sugar or municipal waste). Due to this, a range of feedstock sources can be considered such as wastewaters, industrial and agricultural residues (e.g. off-gases, biogas, agricultural wastes, food wastes, cellulosic biomass), and bioindustry by-products (e.g. brewery residues, starch processing waters, biogas). Positive climate effects can be expected due to smaller cultivation area and especially due to the utilisation of CO_2 as feedstock which further increases the potential of such technologies in comparison to those based on biomass. Furthermore, at the current time the feedstock supply in form of CO_2 may be a limiting factor for the microbial systems, since the technologies for CO_2 utilisation and storage needs to be implemented widely to secure the upstream processes in the value chain. In contrast the biomass utilisation has no significant limitations due to the availability of such feedstocks. Other limitations for CO_2 utilisation are coupled with the early developmental stage and low capacity of the process itself. Genetic engineering and the utilisation of genetically modified organisms (GMOs) may push the development but then regulatory aspects need to be considered. Therefore, the TRL needs to be further improved to establish the utilisation of CO_2 in commercial scale. The microorganisms can be used for different purposes such as single cell protein for feed and food or for upgrading proteins. Single cell protein strains are capable to produce a high protein content of 50-80 % together with essential amino acids, vitamins, phospholipids, and other components (Anupama and Ravindra 2000; Jones et al. 2020; Matassa et al. 2016; Ritala et al. 2017). Furthermore, via microbial fermentation functional feeds can be produced which have a higher quality in terms of an improved digestibility or nutritional value (Kim et al. 2019; Sugiharto and Ranjitkar 2019). The retrofitting potential is partially given in case of required bioreactors (such as aerobic-, anaerobic-, gas-, and photosynthetic bioreactors as well as open cultivation systems) and downstream processing (such as cell wall degradation and nucleic acid removal). Nevertheless, existing technologies/infrastructures and value chains may need to be adapted due to upscaling capacities as well as feedstock and product streams.

Plant systems are already representing a very important protein source and will probably gain even more attention in the future. A review by Henchion et al. (2017) summarised that cereal proteins are currently covering the major portion of global dietary protein intake and that technological development and new emerging sources of protein will position plant-based protein as a desirable option from a sustainability perspective. Biotechnological innovations in genomics and plant breeding are very versatile. A differentiation can be made between plant systems created via traditional plant breeding methods (e.g. selection via traits such as phenotyping, recombination of favourable alleles via cross-breeding) and advanced plant systems based on genetically modified organisms (GMOs) created via genetic engineering (e.g. gene editing/knockout, cis-/intra- genesis) (Ahmar et al. 2020; Breseghello and Coelho 2013; van de Wiel et al. 2010). Traditional and advanced plant breeding can be tailored for specific environmental conditions and requirements in background of conventional cultivation on the field and new cultivation concepts such as soil-less growing and indoor farming. Further innovations will improve abiotic stress tolerance, growth rate, habitus, product quality, resistance against insects and diseases, pollination control, herbicide tolerance, and yield which is also controlled by all these factors. Positive climate effects are therefore mainly based on the replacement of meat as food protein source and the overall improvement of protein yields in plant systems. With advanced breeding the generation of plants is more efficient than traditional breeding since favoured traits (increased resistance, increased protein content etc.) can be achieved in a more specific and time efficient manner. Therefore, the potential and climate effects are expected to be more positive for advanced plant breeding. However, similar to microbial systems the utilisation of GMOs is associated with regulatory issues (which e.g. prevents the cultivation on open fields) as well as a lower technology readiness level. The retrofitting potential is very high, as the expected successes accommodate and relieve the established infrastructure and value chains.

Insects are representing a potential and versatile protein source that can be utilised for different food and feed applications. Although insect farming is well established the time to enter and establish on market is expected to be long, which is mainly related to European and national legislation for food and feed (van der Spiegel et al. 2013). For food applications crickets, lesser mealworm, and yellow mealworm are considered while black soldier fly, common housefly, and yellow mealworm are considered for feed applications (van der Spiegel et al. 2013). Positive climate effects can be expected due to lower greenhouse gas emissions and lower use of land compared to the generation of other proteins such as milk, chicken, pork or beef (Oonincx and de Boer 2012). A certain retrofitting potential is given but this strongly depends on the development of market and required production capacities.

The production of artificial or *in vitro* meat via **stem cells** creates a new protein source. Technological progress may also contribute to other related sectors focussed on tissue engineering or artificial organs, which indicates certain versatility aspects. Positive climate effects primarily based on the saving of greenhouse gases including CO_2, CH_4, and N_2O in comparison to conventional cattle systems. However, such relative impact strongly depends on the availability of decarbonised energy generation (Lynch and Pierrehumbert 2019). The TRL has much room for improvements. In 2013 the first burger based on artificial meat was produced at the University of Maastricht including costs of around £ 200,000 and a development of two years. Limitations are mainly coupled to larger production scales, efficiency, the need of sterile production environments. Furthermore regulatory issues needs to be considered including GMOs and the utilisation of hormones, nutrients, and other chemicals which need to be of food-grade (Henchion et al. 2017). A retrofitting potential is given with regard to downstream processing value chains, infrastructure with regard to available bioreactors is also given but improvements in efficiency and upscaling to larger capacities might be necessary.

3.3.4 Hydrogen

Table 31. Most promising technologies for hydrogen.

Technology	**TRL**	**Limitations**	**Potential**	**Research needs and supporting actions**	**Versatility**	**Climate effects**	**Retrofitting potential (Infrastructure/Value chain)**
Alkaline electrolysis	9	--	++	RIA /IA	0	++	+
Battolyser (nickel-iron accumulator-based electrolysis)	4	--	++	RIA	0	++	+
Polymer exchange membrane electrolyser (PEM)	7-9	--	++	RIA /IA	0	++	+
Photochemistry	3	-	++	RIA	0	++	+
* regulatory limitations/issues							

The production of green hydrogen is based on the hydrolysis of water into hydrogen and oxygen via electrolysis powered by renewable energy. In general, the hydrogen production via **electrolysis** is characterised by a non-decisive versatility regarding the ability of processable feedstocks and uses of the product (e.g. as energy carrier or feedstock for other chemicals). The potential however is very high and very positive climate effects can be expected because green hydrogen enables the storage of renewable energy as well as the direct CO_2 utilisation via carbon capture and utilisation (CCU) and Power-to-X technologies. The retrofitting potential is given in view of the future availability of an infrastructure for renewable energy (e.g. powerlines). However, for upstream processes different aspects such as hydrogen -storage, -safety, and utilisation still needs to be established. The TRL of the specific electrolysis technologies ranges from 4 in case of the battolyser technology to 9 in case of alkaline electrolysis and polymer electrolyte membrane electrolysis. Limitations of electrolysis are the high energy-demand, purity of produced hydrogen, and electrode wearing. For instance the **alkaline hydrolysis** is the most energy intensive electrolysis process with the lowest purity (Keçebaş et al. 2019), the efficiency is about 62-82 % (Dawood et al. 2020). In contrast **Polymer exchange**

membrane electrolysers can be seen as an derivative of the alkaline hydrolysis using a more advanced diaphragm while the electrolysis process is characterised to be more efficient (Keçebaş et al. 2019) which is about 67-84 % (Dawood et al. 2020). The **battolyser** represents an emerging technology which combines both the storage of electrical energy as well as the production of hydrogen via electrolysis once the full capacity of the battery is reached. An overall efficiency of 76-90 % can be expected (Dawood et al. 2020).

Another method for green hydrogen production can be covered via **photochemistry**. The photoelectrolysis decomposes water directly into hydrogen and oxygen using sunlight (El-Shafie et al. 2019). Similar to the electrolysis the versatility is non decisive and climate effects as well as the potential are very high. The performance of photolelectrolysis depends on the utilised photoelectrodes and the semiconductor, compared to the electrolysis the photoelectrical technologies are characterised by an efficiency of 0.5-12 % (Dawood et al. 2020; El-Shafie et al. 2019). Currently the TRL is at the experimental and proof-of-concept stage and maturity can be expected in the long-term (El-Shafie et al. 2019). Limitations may be coupled to the current developmental stage; however, they are expected to be lower compared to electrolysis since a separate power generation is not necessary. The retrofitting potential is given. However, for upstream processes different aspects such as hydrogen -storage, -safety, and utilisation still needs to be established

1.1.1 *Fine chemicals*

Table 32. Most promising technologies for fine chemicals.

Technology	TRL	Limitations	Potential	Research needs and supporting actions	Versatility	Climate effects	Retrofitting potential (Infrastructure/Value chain)
Microbial systems for CO_2 utilisation	3-9	-	++	RIA /IA	++	++	+
Microbial systems for biomass utilisation						+	++
Plant system (traditional breeding)	6-9	--	+	RIA	+	+	++
Plant system (advanced, GMO)	6	--*	+	RIA	++	++	++
Extraction from biomass	6-9	-	+	RIA	++	+	++
Chemical conversion of biomass	6-9	--	+	RIA /IA	+	+	++
Electrochemistry	3-4	-	++	RIA	++	+	++
Photochemistry	3	--	++	RIA	++	+	+

Thermochemical conversion of biomass	5-7	0	0	RIA/ IA	+	0	+
Thermochemical conversion of polymers and plastics	4-7	--	0	RIA	+	0	+
* regulatory limitations/issues							

Microbial systems and more specifically the fermentation offer a versatile tool for the production of different products from different feedstocks such as gas (e.g. syngas or CO_2) and biomass. Depending on the aimed feedstock and product the climate effects can be positive or very positive, especially when CO_2 is utilised as feedstock. The TRL ranges between proof of concept and systems proven in operational environment, in general fermentation processes can be improved via metabolic engineering and synthetic bioengineering (Hara et al. 2014). Limitations can be the requirements of the process environment to ensure a functional biological system as well as regulatory aspects. The scaling-up of microbial strains from the lab-scale to industrial-scale is linked with issues since the conditions and process requirements in large-scale bioreactors are often not considered. Prominent issues are for instance increased mixing times of chemicals, increased operating pressures due to the increased height of the water column, and increased gas concentration (Wehrs et al. 2019). Systems metabolic engineering (including traditional metabolic engineering, systems biology, synthetic biology and evolutionary engineering) will lead to necessary advances in the enzyme and pathway design in which known processes can be improved and new processes can be established (Ko et al. 2020). The retrofitting potential is given in context of available bioreactor technologies (Liao et al. 2018; Stoll et al. 2020) as well as existing value chains. Nevertheless, the supply of CO_2 feedstocks may need to be improved through further developments in CO_2 capture.

Plants are representing another source for the production of biogeneous fine chemicals that can be used in a wide range of applications. A range of secondary metabolites are considered for the fine chemicals production. Although a certain versatility is given, the abundance of certain secondary metabolites can be specific to plant species. Pyrethrins, rotenone, and nicotine for instance can be utilised in pesticides (Balandrin et al. 1985). Furthermore, steroids and alkaloids are used in drug production such as sapogenins, *Digitalis* glycosides, anticancer *Catharanthus* alkaloids, belladonna alkaloids (e.g. atropine, hyoscyamine, scopolamine, cocaine, colchicine, opium alkaloids (e.g. codeine, morphine, papaverine), physostigmine, pilocarpine, quinine, quinidine, resperine, and d-tubocurarine (Balandrin et al. 1985). Recently cannabidiol (CBD) got into focus for several consumer products including food, supplements, and cosmetics. The climate effects are positive due to the photosynthesis activity and CO_2 fixation, the utilisation of advanced GMO plant systems could contribute to higher yields and versatility and therefore to very positive climate effects. However, other useful applications for the plant residues needs to be considered due to the fact that only a fraction of the plant is used for the production of fine chemicals, which leaves considerable amounts of biomass waste. Depending on the specific production process the TRL ranges between demonstrated in relevant environment and systems proven in operational environment. Overall, the TRL of traditional plant breeding systems is higher than advanced systems based on GMO. Several fine chemicals from plants mentioned before where partially utilised back in the 1800's, associated extraction processes may be therefore known and well established. In view of recent developments around regulations and bans of synthetic pesticides and herbicides the demand for products made of biogeneous fine chemicals might increase as well as some formerly known fine chemicals and their extraction processed might be rediscovered. Due to the advances of genetic engineering, further progress can be expected with regard to more positive climate effects and versatility. However, this might be coupled with limitations for the cultivation of GMOs in the field. The retrofitting potential is fully given for both, the infrastructure as well as the value chains.

The **extraction from biomass** includes a range of physical/mechanical/thermal and (bio)chemical methods, which can be categorised into disruption and separation/purification processes to obtain fine chemicals from biomass. Physical or mechanical disruption technologies are covering processes such as freezing, grinding, and ultrasonication while (bio)chemical technologies are covering for instance chemolytic or enzymolytic processes. Those processes are often used in the pre-treatment of biomass to make it suitable for further technological steps. Physical or mechanical separation technologies are covering for instance sieving, filtration, centrifugation, field-flow fractionation, dialysis, distillation, and preparative chromatography. All these technologies are very versatile and partially well established with non-decisive limitations on the technical side. Limitations are expected regarding the feedstock whereby the availability of targeted substances might be limited. This may be solved via genetical engineering and the introduction of genetically modified organisms that produce elevated amounts of the targeted substance. Another limitation can be the presence of other substances with similar physicochemical properties which might hamper the extraction and separation processes. However, the extraction of fine chemicals from biomass can be used to extract other substances in the same process which increases the amount of valuable components which can be obtained and therefore the versatility of the process. Due to this, the climate effects are expected to be positive. Depending on the technology the TRL is between 6 and 9. A high retrofitting potential is given for existing value chains and infrastructures.

Chemical conversion of biomass includes the use of conventional chemical reaction systems, catalysts and energy input to convert biomass into various products as e.g. chemicals, gases, polymers or synthetic fuels. Typical chemical processes use chemical reaction systems and chemicals together with catalysts for the conversion processes that can be assisted by heat and pressure. Various processes may be considered for the chemical conversion including oxidation, hydrogenation, hydrolysis, hydrodeoxygenation, esterification, etherification, and isomerisation. The versatility is partially given but specific chemical conversion processes are strongly depending on the chemical nature of targeted substances. However, a combination of different processes allows a certain versatility. Positive climate effects are expected due to the development of more efficient conversion processes. Depending on the technology the TRL is between 6 and 9. Limitations are depending on the specific process and/or product. For instance, the requirement for enantiomeric purity or complex functional groups might include limitations since catalysts can be limited regarding their regio- stereo-, and enantiomeric- selectivity which then requires the introduction of protecting groups. Similar to the extraction from biomass, the chemical conversion of biomass can be limited due to the availability of addressed target substances. A high retrofitting potential is given for existing value chains and infrastructures.

Electrochemistry can be very versatile due to the capability to process various feedstocks such as CO_2 (e.g. off-gases) or biomass (e.g. wastewaters or biopolymers) into fine chemicals (Panizza 2018; Zirbes and Waldvogel 2018). For organic synthesis the electrochemistry features relatively mild conditions and high chemoselectivity (Horn et al. 2016). Due to the utilisation of CO_2 the climate effects can be positive but not very positive due to the limited production capacities of fine chemicals and therefore limited amounts of processed CO_2. Furthermore, at the current time the feedstock supply in form of CO_2 may be a limiting factor for the CO_2-based electrochemistry, since the technologies for CO_2 utilisation and storage need to be implemented widely to secure the upstream processes in the value chain. There is a range of electrochemical technologies available with a high TRL. However, aside from available technologies the electrochemistry is barely used in fine chemicals production, which gives lower TRLs in this case (Horn et al. 2016). Nevertheless, this may change due to advantages regarding sustainability aspects in comparison to conventional organic synthesis (Horn et al. 2016). In general, the retrofitting potential is high due to the availability of both infrastructure and value chains.

The **photochemistry** is capable to produce fine chemicals which are usually fragrances, flavours, and vitamins (Oelgemöller 2016). Photochemistry can be very versatile, different fine chemicals can be produced from various substances through the initiation of different reaction mechanisms such as addition, cycloaddition, bromination, acyclation, oxygenation, isomerisation, dehydrogenation, oxymation, cyclisation (Oelgemöller 2016). Examples show that photochemistry for the production of fine chemicals is technically feasible and environmentally sustainable (Oelgemöller 2016; Ravelli et al. 2011). However, regarding sustainability the waste disposal needs to be addressed due to the use of solvents in photochemical processes (Ravelli et al. 2011). The photochemistry can be realised via artificial light sources which requires electrical energy or via sunlight. Artificial light sources are often characterised by limited lifetimes and therefore significant maintenance costs (Oelgemöller 2016). Solar photochemistry is limited to the usable range of the solar spectrum (300-700 nm), the discontinuous availability of sunlight, and climatic conditions which are potentially preventing the realisation of industrial solutions (Oelgemöller 2016). The TRL of photochemistry for the production of fine chemicals is at the proof of concept and retrofitting potential is given via existing value chains while the infrastructure still needs to be established for industrial scales.

Thermochemical conversion includes the use of heat energy to convert various feedstocks including CO_2, biomass, polymers, and plastics into various products, e.g. chemicals, gases, polymers or synthetic fuels (Aguado et al. 1999; Higman and van der Burgt 2003; Speight 2019). The conversion can be assisted by the use of catalysts. It needs to be highlighted that the production of fine chemicals will mainly be a subsidiary aspect for the thermochemical processes due to their complexity, requirements, and processed volumes. The versatility is given due to the capability to process a large spectrum of different feedstocks into a wide range of other valuable product beside fine chemicals. However, it is not clear how versatile the product range of fine chemicals can be via thermochemical methods. For the production of fine chemicals, the climate effects are non-decisive due to the complexity of the available thermochemical technologies and their targeted (main)products. The potential for thermochemical conversion is non-decisive since this strongly depends on the specific process. Limitations are specific to the processed feedstock. While the thermochemical conversion of biomass is coupled with non-decisive limitations, the limitations for the processing of polymers and plastics is coupled with specific issues (e.g. higher tar content upon gasification of plastics, and problems associated with catalytic cracking in presence of heteroatoms) (Aguado et al. 2006; Lopez et al. 2018). The gasification and pyrolysis processes are validated and demonstrated for biomass processing with TRLs between 5 and 7 while the technologies for the processing of polymers and plastics are partially between lab scale and demonstration with a TRL between 4 and 7. The retrofitting potential is given but can be improved on the side of upstream via the supply of more homogeneous feedstocks which ensures a constant product quality. The retrofitting potential is given due to existing pyrolysis-, gasification, and refinery infrastructure as well as established value chains.

3.4 Feedback from experts

The interviewed experts gave a wide range of feedback which was considered for the implementation of the work package. Regardless of the expert, the feedback was particularly related to the complexity of the topic. For example, it was emphasised that the classification of technology systems including limitations and potential is too generic to allow a detailed assessment. For this reason, the product groups were chosen and evaluation criteria were explained to provide concrete examples and background information. As acknowledged by the experts, further generalisations/categorisations could not be excluded as this is outside the framework of an overview of the most promising technology areas. It should also be mentioned that there are many transfer interfaces for very specific technologies and a certain generalisation ensures that certain technologies are not excluded.

A further indication of the experts referred to concrete technologies which are more indirectly related to the synthesis of the product groups, i.e. processes which are more upstream or downstream in relation to production (e.g. CO_2 capture such as the condensation of chimney gases). These technologies play an equally important role in a carbon economy and should again be considered separately. For this reason, this report refers exclusively to the synthesising processes.

The experts confirmed the evaluation oft he TRLs and other evaluation criteria. With regard to the evaluation criteria, it was pointed out that the availability of raw materials and the efficiency of their use are also important. For this reason, the possible raw materials and their utilisation were mentioned as examples at appropriate points and possible limitations in the value chain were briefly discussed. However, it was not possible to establish criteria such as carbon efficiency, economic feasibility, and energy consumption (per mole carbon) since this strongly depends on the specific technology which requires a more detailed approach. Furthermore, the mentioned technology areas are partially at lower TRLs which are not suitable for a final detailed evaluation due to the lack of large-scale units.

After the experts' feedback some of the results of the evaluation were partly reconsidered and adjusted also explaining the background of some critical points in more detail for the short-list.

3.5 Discussion and conclusion

Through short-listing some technologies could be identified which can be used across many product groups. Depending on the product group the evaluation shows different outcomes for the same technology regarding the selected evaluation criteria. For some product groups one technology may be particularly suitable which allows the identification of key areas in which the technologies can be particularly advanced and further developed to meet the needs of a shift of carbon supply and use. This may open up further fields of application both within and outside the carbon economy. The short-listing also showed that other technologies may find their major importance for only one product group which does not make them less important.

The electrochemistry and microbial systems are providing technologies which were capable to cover four out of the five defined product groups. The evaluation showed that the **electrochemistry** is a very promising technology which finds its key areas in the field of polymers and fine chemicals. Furthermore, hydrogen is another key area where electrochemical technologies will find its role as enabling technology for renewable energy and energy/hydrogen demanding processes which therefore has an indirect impact on the carbon economy. In contrast to electrochemistry wide key areas for **microbial systems** were identified. The evaluation showed that technologies based on such systems are nearly equally promising for bulk chemicals & fuels, polymers, proteins, and fine chemicals. Regarding the utilised feedstock (CO_2 vs. biomass) an opposite trend was identified for the evaluation criteria climate effects and retrofitting potential. This trend is mainly based on more positive climate effects from the fixation of CO_2 and the current status of the value chain while the utilisation of biomass is not coupled to such very positive climate effects or limitations with feedstock supply.

Photochemistry and thermochemical technologies were capable to cover three of the defined product groups. The **photochemistry** cannot be clearly focused on a single key area and is therefore equally important for the production of bulk chemicals & fuels, fine chemicals, and hydrogen. Climate effects are expected to be very positive for the production of bulk chemicals & fuels due to the replacement of fossil feedstocks as carbon source while a very high versatility is expected for the production of fine chemicals. The production of hydrogen via photochemistry can be concluded as enabling technology for renewable energy and energy/hydrogen demanding processes, therefore has an indirect impact on the carbon economy. **Thermochemical conversion** of polymers and plastics finds its key areas in the production of bulk chemicals & fuels and polymers. Less potential was attributed to the production of fine chemicals since the production of fine chemicals will mainly be a subsidiary aspect for thermochemical processes due to their complexity, requirements, and processed volumes. It needs to be highlighted that gasification is also capable to cover the hydrogen production but this should always be the least preferable option for e.g. plastics and polymer waste because there is a range of other options available which are likely more resource efficient. Additionally, the hydrogen production via electro- and photochemical technologies in combination with renewable energy would have definitely more positive climate effects.

Plant systems are covering two product groups. The production of proteins for food and feed could be the key area especially due to the steadily increasing demand. In general, the utilisation of GMOs has more positive climate effects due to the potential for more efficient cultivation (e.g. higher yields). In contrast, the GMOs are coupled to higher limitations due to regulatory aspects which implies limitations for the cultivation on the fields and later food/supplement applications.

Insects and **stem cells** are covering only one of the analysed product groups. Other key areas may exist such as the production of artificial organs and tissues via stem cells or alternatives for insecticides/pesticides through the introduction of insects in crop fields.

Both technologies **extraction** and **chemical conversion** were able to cover the production of fine chemicals as only product group of the selected ones. Also, here different key areas may be covered by these technologies.

WORK PACKAGE 4: CASE STUDIES

1 Introduction

The bioeconomy encompasses the production of renewable biological resources and their conversion into value added products, further covering biological waste and side streams.[156] The bioeconomy and circular economy encounter strong overlaps in their targets, in particular achieving a more sustainable and resource efficient world with a low carbon balance. While the circular economy is achieving this through keeping products and components at their highest utility, thus reducing the use of additional fossil carbon, the bioeconomy substitutes fossil carbon by renewable biogenic carbon. Circular bioeconomy is understood as the intersection of both approaches, having the utilisation of organic waste streams as an important focus.[157]

Cities are already today major hubs for economic activity and growth, generating 80% of the GDP and concentrating both materials and nutrients. Cities are aggregators of inputs from rural areas, producing 1.3 billion tonnes of solid waste per year, 50% of which is organic, resulting in an imbalance between in- and outflows. This figure is expected to double by 2025 due to continued rural exodus and urbanisation, population growth and increasing affluence. Against the backdrop of these figures and trends, cities present a major opportunity to realise the potential that the circular bioeconomy holds, i.e. bringing in- and outflows of biomass in balance and effectively valorising waste. Apart from the large concentration of biomass and waste material, urban settings offer a high concentration of relevant stakeholders in proximity, as well as a well-educated and tech-savvy workforce.

1.1 10 case studies of bio-waste valorisation in Europe

The case studies form part of the broader project *Studies on support to R&I policy in the area of bio-based products and services – Carbon Economy* which aims at identifying future policy directions, emerging technologies, societal demands, challenges and opportunities in the bioeconomy. This study is based on the realisation that some parts of our economy cannot be decarbonised, making it necessary to seek alternatives to fossil carbon to support the objectives of the Paris Agreement and beyond. A feasible substitute here is biogenic carbon, indicating that a shift towards the bioeconomy is a necessary steppingstone towards the low carbon economy.

The case studies of ten cities and regions contribute to the overall objective by bringing the issues surrounding the integration of green carbon sources into the Carbon Economy to a local context. More specifically, the case studies seek to provide precise recommendations for local planners, decision- and policymakers on how to operationalise the circular bioeconomy on the city level. This is achieved by exploring the current biological resources availability and valorisation strategies, as well as circularity approaches on city level and extrapolating potential future strategies. This objective unfolds in the following overall research questions for each of the cases:

- What is the availability of biological resources and in how far are these currently valorised?
- How does the circular economy governance find expression on the local level in terms of business models and outcomes? What is the role of biological resources here?
- How can existing approaches towards bioresource valorisation and circularity be improved and what potential strategies could be realised in the given context?

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[156] European Commission (2012). Innovating for Sustainable Growth – A bioeconomy for Europe. Publications Office of the European Union, Luxembourg.

[157] Carus, M., & Dammer, L. (2018). The circular bioeconomy—concepts, opportunities, and limitations. Industrial biotechnology, 14(2), 83-91.

The figure below maps the ten cases, analysed in this study: Cluj-Napoca (Romania), Emilia-Romagna (Italy), Flanders (Belgium), Łódź (Poland), Maribor (Slovenia), Milan (Italy), Nantes (France), Oslo (Norway), Rotterdam (Netherlands), and Turku (Finland).

To ensure a diverse selection of cases with progressive initiatives and strong potentials for value chains, the following criteria were applied to reach at the final selection of eight cities and two regions (in close coordination with EC DG RTD):

- **Diversity:** Case studies represent a broad range of regions, countries and societies within Europe and cities of different sizes and socio-economic structures;
- **Waste valorisation:** Case studies cover sufficient population equivalent to produce a critical amount of bio-waste/wastewater sludge as feedstock for refining;
- **Technological innovation:** Case studies host pilot projects and avantgarde related to the development and production of bio-based materials and products;
- **Institutional innovation:** Case studies demonstrate the political and industrial will to transform production systems, value chains, business models and consumption patterns, visible in innovative initiatives.

Figure 43. Map showing the 10 case studies analysed. Own illustration using SmartDraw.

The case studies have been developed using both desk study and semi-structured interviews with decision makers from municipalities and other relevant stakeholders. The semi-structured interviews were structured according to a template that has been created in cooperation with the European Commission DG "Research and Innovation" and including inputs from the Urban Agenda Partnership on Circular Economy.

1.2 European R&I projects on the circular bio-economy

On November 19th, 2008 the European Parliament and the Council published a Waste Management Hierarchy (Figure 44) under the EU Waste Framework Directive 2008/98/EC, illustrating that the main strategy to close down landfills is to prevent waste production in the first place[158]. With the directive, the 'polluter pays principle' and the 'extended producer responsibility.' In its most recent update, a new recycling and recovery target for 2030 was set to 65% re-use and recycling of certain waste materials from households. Additionally, member states are required to adopt waste management plans and waste prevention programmes.

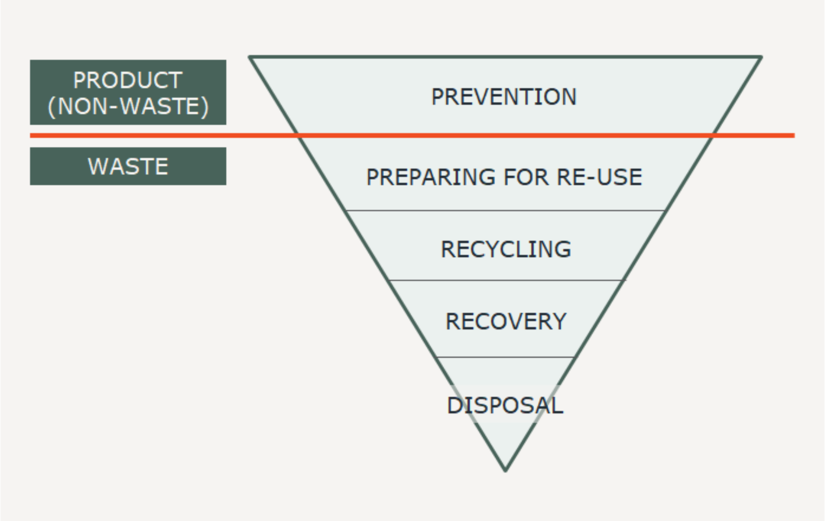

Figure 44. Waste Management Hierarchy from the European Framework Directive 2008/98/EC

In 2002, the Waste-to-Energy Research and Technology Council (GWC) was founded and provided a platform for stakeholders to explore the possibilities to reach 'zero waste' through the hierarchy presented in Figure 44. The initiative highlights the necessity for different entities to work together and combine science, business and policy. The development of new technologies and research in the bio-based sector is important to reach the objectives of both the bioeconomy as well as the circular economy. The valorisation of food waste and wastewater sludge, as presented in the case studies are directly impacted by the availability of technologies.

There exist wide opportunities for natural bioactive compounds from agri-food waste and by-products, their isolation and potential applications in a number of industries, including food, pharma and cosmeceuticals. The different industries are also classified by the different valorisation pathways and methods of processing. Achieving zero-waste must occur through four different avenues such that after waste has been separated and the different fractions re-used based on their purity and potential, the leftover landfilled waste is still utilised for biogas (see Figure 45). Coupling landfills with district heating is one way to ensure the 'zero-waste' target.[159]

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[158] European Commission. Waste prevention and management. https://ec.europa.eu/environment/green-growth/waste-prevention-and-management/index_en.htm

[159] Ben-Othman S, Jõudu I, Bhat R. Bioactives From Agri-Food Wastes: Present Insights and Future Challenges. Molecules (Basel, Switzerland). 2020 Jan;25(3). DOI: 10.3390/molecules25030510.

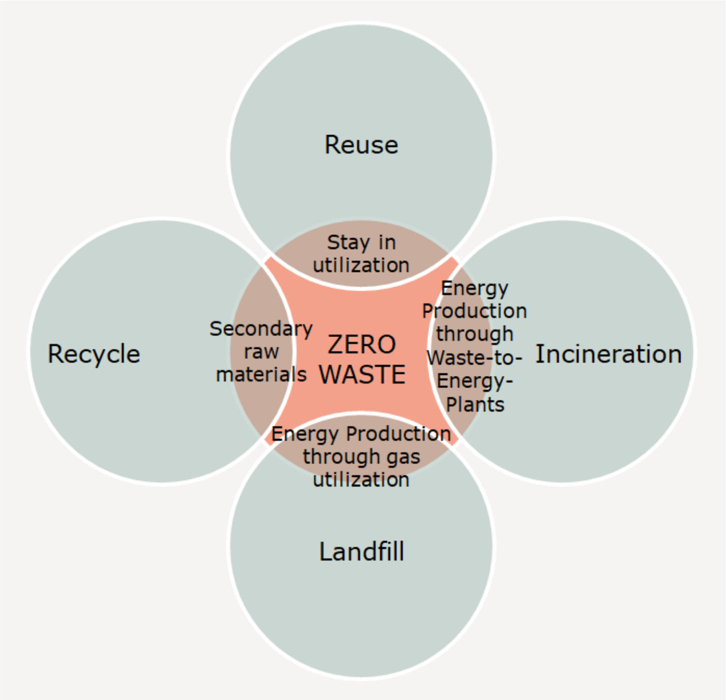

Figure 45. The use of reusing, recycling, incinerating and landfilling to achieve zero-waste. (modified from WtERT Germany GmbH and Bauer and Vielreicher at mater 2019). Source: MatER Study Center. 2019.

The research and innovation landscape in Europe is quite broad. However, there are major differences between regions which require individual approaches to each of the different areas for potential applications of agri-food wastes and by-product valorisation. The European Commission's CORDIS data system lists EU-supported R&D projects including publications, projects and results. Searching the system for projects related to the circular economy yielded 158 different projects. Further narrowing down the search to projects based in waste management, recycling, bioeconomy, compost, bioplastics, biofuels, wastewater, and environmental engineering resulted in 55 projects directly connected to the bioeconomy and waste usage.[160]

Of the 55 projects, 14 are still ongoing with both Spain and the Netherlands prominent in coordinating bioeconomy projects. The size of the budget for bioeconomy projects varies greatly, with URBIOFIN and TO-SYN-FUEL being the two projects with the highest budgets that are still ongoing; both projects work on the conversion of waste into bio-based products and biofuels, respectively. In general, the projects cover a high variety of different topics and strategies related to waste (re-)usage – from consumer behaviour (education) to actual biorefinery projects. Most projects have a running time of four years, giving enough time of gathering practical insights and for succeeding with the implementation of those projects. However, only four of the ongoing projects are categorised under 'waste management'/'compost'/'wastewater', which seems to be a rather small number, given the urgency of this topic.

Apart from this research, it seems that the innovative arena in the 'bioeconomy' industry is mainly based upon cluster networks within each European country and internationally, between different European universities, business and cities. The case studies presented below provide more detailed information about ongoing attention to waste management and the bioeconomy across the EU. They cover geographies within different stages of waste management according to the Waste Management Hierarchy. Following the case studies, a broad overview of recommendations and conclusions is presented through a comparison of the case cities and regions and their waste strategies.

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[160] Projects are listed in Appendix 7.

2 Case study of the city of Cluj-Napoca

Cluj-Napoca is the fourth largest city in Romania. Located in the Someşul Mic river valley and the larger Cluj County, Cluj-Napoca is the unofficial capital of the historical region knows as Transylvania. With a brief economic dip in the 1990s, Cluj-Napoca is now considered a key academic, cultural, and business hub in Romania. Since Romania's entry into the EU, the country and its cities are also making additional effort in the environmental sector. The city has recently made an attempt to increase green infrastructure through a 50% reduction of local taxes for the construction of green buildings (i.e. LEED certified).

Table 33. General information on Cluj-Napoca.

City	Cluj-Napoca
Country	Romania
Geographical location	North-Western Romania (Transylvania), Cluj County
Population	316,748
Population density (inhabitants per km²)	1,766
GDP (EUR)	EUR 5.8 billion (2015) [A]
GDP per capita (EUR)	EUR 16,635 (2015) [A]
Green urban areas (%, Area)	20-30% [B]
Number of operating research centres promoting the bioeconomy	
Babes-Bolyai University - Faculty of Biology: Management of protected areas and local resources; - Faculty Environmental Engineering: Sustainable Development and Environmental Management; - Faculty of Environmental Science: Risk Assessment and Environment Safety, Environmental Quality and Energy Sources; - Faculty of Economics: Sustainable Regional Development	
Sources:[161] [A] Teleport, 2020; [B] Fuller & Gaston, 2009	

In terms of waste management, Cluj-Napoca has made strides to intensify waste separation through the introduction of fines. The system of fines is in partnership with the threat of an increased collection tariff. The fine and tariff plan was introduced in 2019 following new EU regulations so results are yet to be fully reported or measured on their effectiveness.[162] In addition, Cluj is participating in a Food Waste Combat program through which excess food headed for disposal is redistributed to homeless shelters and lower income areas in the city. Seven tonnes of food were re-directed in 2018 with the programme.[163]

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[161] Teleport, 2020. https://teleport.org/cities/cluj-napoca/; Fuller, R. A., & Gaston, K. J. (2009). The scaling of green space coverage in European cities. *Biology letters*, *5*(3), 352–355. https://doi.org/10.1098/rsbl.2009.0010

[162] Recycling and Waste Disposal, https://cluj-napoca.xyz/services-information/house-home/recycling-and-waste-disposal-cluj-napoca/]

[163] https://circulareconomy.europa.eu/platform/en/good-practices/providing-those-need-food-we-waste-food-waste-cluj-leading-pack-socio-circular-innovation-romania

2.1 *Analysis of the municipal waste generation scheme, trends, and future milestones*

This chapter contains information on Cluj's waste sources with emphasis on municipal bio-waste and wastewater sludge.

2.1.1 *Availability of municipal bio-waste as feedstock*

The city of Cluj-Napoca and the surrounding county of Cluj county has seen a steady increase in organic waste and wood waste. Most recently, the city made the collection of waste into four categories mandatory starting 1 July 2019 (see section 2.2.1). As bio-waste is not an assorted category, it forms part of household waste.[164]

Table 34. Bio-share of municipal solid waste generated in Cluj-Napoca for 2010, 2014, and 2018. Source: http://www.ecometropolitancluj.ro/colectare-selective-deseuri-cluj

Year	2010	2014	2018
Bio-waste	16,654	33,681	80,251
Household waste	191,799	199,465	157,810
Total	**208,453**	**233,146**	**238,061**

While Cluj-Napoca does not participate in separation of bio-waste, a SWOT analysis of the waste streams in Cluj County estimated that roughly 55-61% of the household waste is biodegradable waste. This estimation was from 2010 and the lower bound is estimated for rural areas while the upper bound is estimated for urban areas.[165]

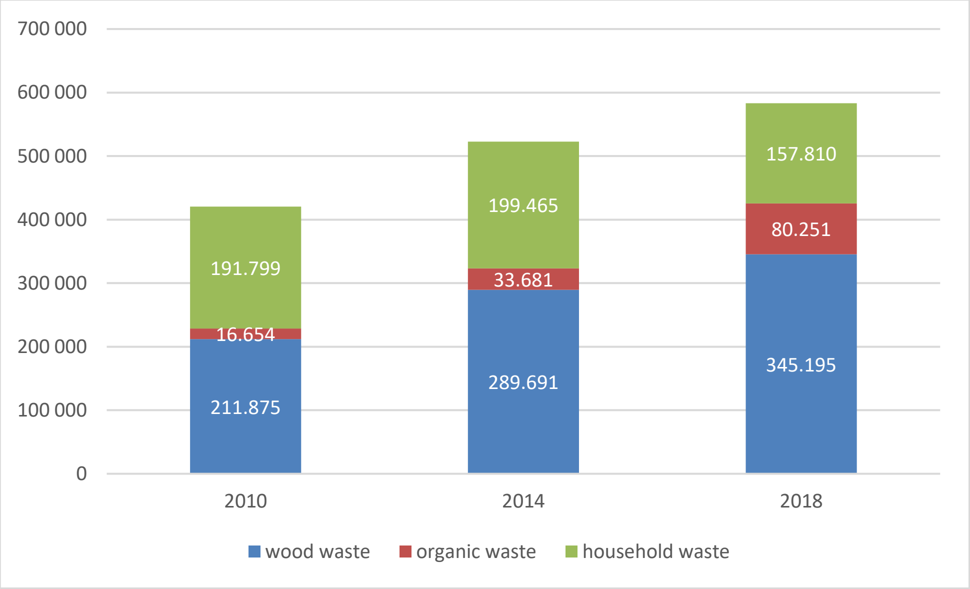

Figure 46. Cluj-Napoca bio-share year perspective.

2.1.2 *Availability of municipal wastewater sludge as feedstock*

The data for Cluj-Napoca wastewater sludge is taken from Eurostat and reported on a countrywide level for EU and EEA countries. For each region or city, the population for the relevant year is multiplied by the kilograms per capita in order to get a close estimate of the waste sludge for the municipality or region. The kilograms per capita for Romania went from 3.84 in 2008 to 14.42 in 2017 (latest available data) with the sharpest spike between

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[164] Separate collection of waste in the City of Cluj-Napoca: https://primariaclujnapoca.ro/salubritate/colectarea-selectiva-a-deseurilor/

[165] Waste Management Plan of Romania : https://www.cjcluj.ro/assets/uploads/Planul%20judetean%20de%20gestionare%20a%20deseurilor.pdf

2012 to 2014. The sludge data for Cluj-Napoca based on population statistics for the years 2010, 2014 and 2017 are presented in Table 35 below. There is a sharp difference between the sewage sludge data reported across the case studies, probably due to the fact that management, measuring and disposal methods are highly variable across the different member states.

Table 35. Wastewater sludge data for Cluj-Napoca for the years 2010, 2014 and 2017.

Year	2010	2014	2017
Wastewater Sludge (dry matter, t)	1,223	2,930	4,412

2.2 *Valorisation of Biological resources*

2.2.1 *Background on the local waste management system*

At the national level, waste management is governed by the Ministry of Environment, Waters and Forests and the National Agency for Environmental Protection, through the specialised departments aimed at waste management. At county level, the waste management activity is the responsibility of the Cluj County Council and the Cluj Environmental Protection Agency. At local level, waste management is the responsibility of Cluj-Napoca City Hall - Urban Ecology and Green Spaces Department.

The waste management of Cluj is delegated to private operators since 2010.[166] Private operators obtain a lease for at least eight years. As of 2020, two private operators own the lease for waste collection: S.C. Brantner Veres and S.C. Rosal group S.A. The two companies are responsible for different areas of the city.

Households must individually pay for "sanitation services", and thus directly finance the waste management.[167] Incorrect separation of household waste can lead to fines, in the range of EUR 210 – EUR 525.[168] Non-compliance may furthermore lead to an increase of waste collection fees of up to 25%. The monitoring for incorrect separation is done through the use of transparent bags so that collection workers are able to see if waste is separated correctly. Rather than fining noncompliance, the incorrectly sorted waste is simply left behind so the residents are then responsible for re-sorting and keeping their recyclables until the following week.[169]

Cluj introduced a new waste collection system in 2019 in response to new national requirements, which increased the number of sorting fractions from two to four, and an obligation for households to conduct waste separation.[170] Even though the national waste management plan foresees the introduction of separate collection as well as treatment of bio-waste, the newly introduced waste system does not entail a separate collection of household bio-waste.[171] The fractions entail paper and cardboard, plastics and metals, glass, and residual waste (termed general waste). Residual waste thus consists of bio- and other non-recyclable waste.

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[166] Pop et al., 2017, Life cycle analysis in evaluation of household waste collection and transport in Cluj-Napoca, Romania

[167] https://www.rosal.ro/noul-parteneriat-dintre-paypoint-si-rosal-grup-faciliteaza-plata-facturilor-pentru-salubritate/

[168] Recycling and Waste Disposal, https://cluj-napoca.xyz/services-information/house-home/recycling-and-waste-disposal-cluj-napoca/]

[169] Confirmed in an interview with key stakeholder.

[170] Recycling and Waste Disposal, https://cluj-napoca.xyz/services-information/house-home/recycling-and-waste-disposal-cluj-napoca/]

[171] European Commmission, (2019). The Environmental Implementation Review 2019 https://ec.europa.eu/environment/eir/pdf/report_ro_en.pdf

Furthermore, the special waste collections occur for gardening waste, bulky waste, textile waste, construction waste, and Waste Electrical and Electronic Equipment (WEEE). The gardening waste from green areas is temporary stored in containers and subsequently collected. For gardening waste from households, operators do pick-ups against fees. Only biodegradable waste from the maintenance of parks and green spaces, located in the public domain, is collected separately and regularly. In the case of waste from the private sector, biodegradable waste from gardens is collected at the request of the generator.

In low-rise buildings, the collection of recyclable waste is done from door to door. The sanitation company distributes free bags for collection and regularly collects the waste fractions. For high-rise buildings, waste is collected in neighbourhood containers and is typically done daily due to the higher generation rate from blocks of flats. There are around two or three collections per week for individual family households, but they are also able to drop off their recyclables at the coloured bins placed around the city.[172] To date, an additional 89 buried neighbourhood containers have been built (for the collection of the four fractions).

Prior to the introduction of the new waste management system, most of the non-recyclable household waste ended in a landfill, referred to as Pata-Rat. There is currently no evidence that suggests that this situation has changed under the new waste management system. Based on dated literature, there has been a plan to establish a new landfill that is supposed to enable biogas production by 2013.[173] No literature evidence could be identified that confirms that this plan has been realised, but only that the EU Commission has demanded the closure of the local landfill.[174] Romania foresees to close all its landfills by the end of 2020.[175]

Furthermore, the update to the waste collection was accompanied by a rigorous campaign to educate the citizens of Cluj-Napoca on how to correctly sort waste. The campaign included mail-in leaflets to all the households in the city, flyers as well as press releases from the mayor's office. New bins were placed all around the city, replacing the more hidden trash bins.[176]

Cluj-Napoca relies on two private companies S.C. Brantner Veres and S.C. Rosal group S.A for their waste pickup. The companies charge fees for pre-collection, collection, transport and storage of sorted municipal waste. The fees as of 2019 were 9.88 Leu (EUR 2.03) per person each month excl. VAT and 61.82 Leu (EUR 12.68) per m^3 for public institutions and economic agents. As they are private firms and the process for getting the rights to collection involves a bidding process, the evidence points to a profitable collection system from the fees.

Based on evidence from the old waste management system, recycling has been a profitable activity for S.C. Brantner Veres in 2013 (which is one of the two current waste operators), where bottles were sold to Romanian companies and carton to an Austrian company.[177] Furthermore, the sale of recycled paper and plastic was equally a profitable activity. No

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[172] Pop et al., 2017, Life cycle analysis in evaluation of household waste collection and transport in Cluj-Napoca, Romania

[173] Romanian Regional Development Programme. TRACE City Energy Efficiency Diagnostic Study https://esmap.org/sites/esmap.org/files/DocumentLibrary/TRACE_Romania_CLUJ%20NAPOCA_Optimized.pdf

[174] Phys.org, (2019). Residents split on future of Romania's trash heap 'time-bomb'. https://phys.org/news/2019-03-residents-future-romania-trash-time-bomb.html

[175] European Commmission, (2019). The Environmental Implementation Review 2019 https://ec.europa.eu/environment/eir/pdf/report_ro_en.pdf

[176] Confirmed in an interview with key stakeholder.

[177] Romanian Regional Development Programme. TRACE City Energy Efficiency Diagnostic Study https://esmap.org/sites/esmap.org/files/DocumentLibrary/TRACE_Romania_CLUJ%20NAPOCA_Optimized.pdf

evidence on the business model for the processing of separately collected bio-waste (i.e. gardening waste) could however be identified.

2.2.2 Description of currently used and potentially available (ready to implement) technologies

The collected bio-waste (e.g. from public spaces) is either composted or incinerated for energy recovery. No biogas plants are currently operational for municipal bio-waste. In 2014 however, a private biogas plant was put operational as part of a hotel (city Plaza).[178]

Overall, the waste management in Cluj is supposed to be supported by an Integrated Waste Management System (CMID), that was partially funded through the European Regional Development Fund (ERDF) back in 2013. As of today, however, reports claim that although the CMID has officially opened, it is de-facto not functional, with an incomplete construction and depleted funds.[179]

An existing waste water treatment plant was rehabilitated in 2013 (Cluj-Napoca), enabling the production of biogas, intended for co-generation of electricity and generation of hot water, with an installed capacity of 1 MW and a maximum capacity of 23 MW.[180] It is unclear, to which extent the plant produces biogas or alternatively valorises the wastewater sludge in other forms following the completion of the rehabilitation.

There is currently a second on-going construction (Cluj-Salaj), which was initiated in early 2019 and is expected to be completed by 2023. The plant will serve several agglomerations, including outside Cluj, and will enable sludge drying and energy recovery.[181]

2.2.3 Existing support from research organisations and other stakeholders

Based on the literature evidence and interview with Cluj municipality, it remains unclear whether, and to which extent, there is a stakeholder network that actively supports the local authorities in promoting a bioeconomy model.

The local **Babeș-Bolyai University**, of which particularly the Faculty of Environmental Science and Engineering, is engaged with environmental research on the local waste management issues, particularly those associated with the local landfill.

Two bioeconomy-related clusters in which Cluj is a part of could be identified:[182]

1. **IND-AGRO-POL**, which is engaged in with the agriculture and food industry;
2. **AgroTransilvania**, which is engaged in the same sectors as above. The latter cluster has 80 members within sustainable value chains in differing parts and levels of involvement in the bioeconomy. Most notably, the producers and local government are involved in and hoping to see a ramping up of the conversion of

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[178] Interreg. Framework Conditions for Cluster Development in bio-based industry in Romania http://www.ipe.ro/Country%20Report%20Romania.pdf

[179] Ziar de Cluj, (2020). https://www.ziardecluj.ro/activist-de-mediu-despre-acrobatiile-juridice-ale-consiliului-judetean-privinta-deseurilor-vrei-sa-pornesti-cmid-ul-n-ai-cu-ce

[180] UTI, Cluj-Napoca Water Treatment Plant. https://www.uti.eu.com/business-lines/construction-installations/general-contracting/portfolio/cluj-napoca-water-treatment-plant/

[181] European Commission, (2019). https://ec.europa.eu/regional_policy/en/projects/romania/regional-project-for-developing-water-and-wastewater-infrastructure-in-cluj-and-salaj-counties

[182] Bio-based Industrites Consortium. Mapping the Potential of Romania for the Bio-based Industry. https://biconsortium.eu/file/1929/download?token=gEfE5Esw

bio-waste into compost. The municipality is also a member of the AgroTransilvania cluster indicating a high level of interaction between sectors.

2.2.4 *Legal environment, enablers & barriers*

Next to the recently formulated national Action Plan for a Circular Economy, the introduction of the new National Waste Management Plan and waste prevention programme in 2017 provides the grounds for the introduction of the new waste management system.[183] It is worth mentioning that this plan has been introduced with significant delay, and the Romanian government ought to introduce a new plan by 2025 according to the Waste Framework Directive. As the 2019 EU Environmental Review concludes, several waste provisions are missing to ensure a more sustainable waste management in general, including an improved separation of bio-waste. There is reportedly no known bio-waste collection other than small tonnages associated with the collection from municipal gardens and parks, as referred to above. It is however also relevant to underline that many local waste management systems are in the process of being changed in response to the national waste management plan. Accordingly, the situation may have changed by 2020.

2.3 Valorisation of Biological resources in 2030

A major part of the plans for Cluj are in the works or, more specifically, are in the foundering stages. As correct waste separation is still the main ambition of the municipality, new technologies are still unavailable in the region as Romania has been labelled a 'technology-taker' by an interview partner. The gap in technology is very large and expensive, but as the waste separation and reduction has already proved successful there is a lot of hope for the next ten years for ramping up separation of bio-waste and then valorising it.

2.3.1 *Future management of the waste streams in 2030*

The waste management is expected to evolve in line with the 2030 national strategy for a sustainable development of Romania which, by and large, consists of the targets set forth by the Waste Framework Directive on recycling and waste separation. Bio-waste is therefore intended to be separated by 2023 and measures are foreseen on (food) waste prevention down to 50%.

In order to achieve the mandatory targets on bio-waste, residual waste with biodegradable content will be treated, by composting and mechano-biological treatment (for the further purpose of material- and energy recovery). Their treatment is respectively foreseen at the PHARE CES (Dej) composting plant and the CMID Cluj-Napoca (with an annual capacity of 207,000 tonnes).

At the Dej composting station, primarily gardening waste from public spaces will be processed to obtain compost that is suitable as a soil improver for agriculture. The CMID mechanical-biological treatment plant will treat household- and business bio-waste. To the extent that bio-waste enters the CMID plant as a separate fraction, it will be used to obtain compost for further use in agriculture.

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[183] European Commmission, (2019). The Environmental Implementation Review 2019 https://ec.europa.eu/environment/eir/pdf/report_ro_en.pdfhttps://ec.europa.eu/environment/eir/pdf/report_ro_en.pdf

2.3.2 *Description of future technological potential available (ready to implement) for bio-waste processing)*

The local public administration authority and the County Council are promoting the use of home-composting units of household bio-waste (especially vegetable gardening waste), with the objective that all rural households apply home composting within 10 years. Up until then, rural households can dispose bio-waste together with the residual fraction. This system is already in place for 21,000 households and is combined with a prohibition of disposing bio-waste into the collection system.

According to the Regulation of the sanitation service of Cluj County, an operator that ensures the activity of biological waste treatment has an obligation to take care of the recovery of compost resulting from waste treatment, to take care of energy recovery of refuse-derived fuel (RDF) and solid recovered fuel (SRF) type residues.

The designated sanitation operators, together with the local public administrations, take measures to inform, make responsible, educate and raise awareness of the population regarding the separate collection of waste, as well as the ways to prevent the generation of waste. Information and awareness are achieved through information and awareness campaigns, the distribution of leaflets, brochures, posters, through educational activities, as well as radio and television commercials.

2.3.3 *Future legal environment, enablers & barriers*

The main regulatory needs are support for implementation of new technologies as much of the country is very behind in comparison to other EU MS. The region is sceptical with regards to biogas facilities as it is considered very expensive and not efficient enough. There are only a few research studies and not a high attention to technological development in general, even in Cluj which is considered a leader within the country.

3 Case study of the region of Emilia Romagna

Emilia Romagna is located in northern Italy and is the fourth richest region in Italy following the Lombardy region, Lazio region and Veneto region. Its capital is Bologna, which has one of the highest quality of life indices in Italy as well as strong social services. The region has grown with regards to urban areas over the past centuries and the agricultural land has diminished as a result of this.

The region is divided into nine provinces, but still has a strong central data reporting system, especially with regard to waste data. In addition, Emilia-Romagna has a high standard for recycling aiming to reach a recycling target of 70% by 2020, which is higher than the 50% target set by the EU. This goal is outlined in the most recent Waste Management Plan which also aims to reduce down to 5% the disposal following landfill dumping.[184]

Table 36. General information for Emilia-Romagna.

City/Region	Emilia-Romagna
Country	Italy
Geographical location	Northern Italy
Population	4,459,477
Population density (inhabitants per km²)	198 inhabitants per km²

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[184] Regione Emilia-Romagna, http://www.regione.emilia-romagna.it/notizie/2016/gennaio-1/meno-rifiuti-piu-riciclo-e-recupero-di-energia-ecco-il-piano-regionale

GDP (EUR)	EUR 154 billion (2016) [A]
GDP per capita (EUR)	EUR 35,300 [A]
Green urban areas (%, Area)	5-15% [B]
Number of operating research centres promoting the bioeconomy	
Alma Mater Studiorum Universitá de Bologna Faculty of Economics & Management • Resource Economics and Sustainable Development Faculty of Agricultural and Food Science • Marketing and Economics of Agro-industrial system • Planning and Management of Agro-territorial, forest and landscape Faculty of Engineering and Architecture • Civil Engineering -Environmental Engineering	
Sources:[185] [A] Europa Database, 2020, [B] Fuller & Gaston, 2009	

3.1 *Analysis of the municipal waste generation scheme, trends, and future milestones*

3.1.1 *Availability of municipal bio-waste as feedstock*

The waste data from Emilia-Romagna is published in a yearly waste report that is easily accessible online through the region's website. One key feature of Emilia-Romagna's waste sorting programme is that domestic composting is voluntary. This domestic compost is made up of both kitchen waste as well as garden waste. Generally, waste separation has achieved 50% across the entire region signifying compliance with recent EU regulations (countrywide), but with certain municipalities making up for those that may be at a lower rate (e.g., 65% vs. 35%. Table 37 below provides the overview of waste separation in the region. Organic waste increased nearly two-fold from 2014 and 2018 and garden waste increased significantly as well. This is likely related to the increase in composting facilities as well as anaerobic digesters.[186]

Table 37. Breakdown of the bio-share of municipal solid waste in tonnes generated for the Emilia-Romagna region for 2010, 2014 and 2018. Source: La getione dei RIFIUTi in Emilia Romagna, 2019[187]

Year	**2010**	**2014**	**2018**
Organic waste	212,725	263,751	457,170
Garden waste	355,983	418,659	608,259
Wood waste	127,977	128,352	116,862
Vegetable and animal oils and fats	669	1,068	1,467
Total	**697,354**	**811,830**	**1,183,758**

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[185] European Commission, Emilia Romagna Region, https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/base-profile/emilia-romagna#:~:text=one%20(7.8%25).-,With%20a%20total%20GDP%20of%20about%20154%20billion%20%E2%82%AC%20in,subsidized%20Alpin%20regions%20and%20provinces

[186] Fondazione per lo Sviluppo sostenible and Fise Unicircular. (2019). 2019 L'Italia del Riciclo.

[187] Regione Emilia-Romagna, (2014). https://ambiente.regione.emilia-romagna.it/it/rifiuti/documenti/filiera-inerti/volume-snap/@@download/file/volume_SNAP_web.pdf

The visual representation of the data provides a better overview of the data in Figure 47 and the total increase over the eight-year span.

Figure 47.Year perspective on waste make-up of Emilia-Romagna region for 2010, 2014 and 2018.[188]

Concerning agro-industrial waste, the region produces approximately 20 million t of biomass per year, thereof only a small portion is being used for energy recovery. The production of high added value materials from agro-industrial residues is even more limited.[189]

According to Arpae in 2018, 42% of the “wet” bio-waste (i.e. food scraps) has not been separated, constituting significant potential with regards to future valorisation. For green and wood waste, non-separated fractions are smaller, 9% and 11% respectively.[190]

3.1.2 Availability of municipal wastewater sludge as feedstock

Data for wastewater sludge from Emilia Romagna is not very consistent potentially due to the regional constraints associated with weighing and monitoring dry sludge. Eurostat has data for Italy only for the year 2010 for kilograms per capita which can then be multiplied by Emilia-Romagna's total population for 2010.[191] In addition, a Statista report for wastewater sludge generation by region in Italy has data for 2017.[192] The data collected

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[188] ASTER, (2014), Project "Green – Simbiosi Industriale - Modelli di gestione integrata, sostenibile e innovativa delle aree produttive: filiere per il trattamento e la valorizzazione di biomassa da scarti agro-industriali, ASTER S. Cons. p. A., Available at: http://www.aster.it/tikiindex.php?page=SimbiosiIndustriale.

[189] ASTER, (2014), Project "Green – Simbiosi Industriale - Modelli di gestione integrata, sostenibile e innovativa delle aree produttive: filiere per il trattamento e la valorizzazione di biomassa da scarti agro-industriali, ASTER S. Cons. p. A., Available at: http://www.aster.it/tikiindex.php?page=SimbiosiIndustriale .

[190] Arpae. (2019). La gestione dei rifiuti in Emilia-Romagna. Report 2019.

[191] Eurostat, https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_ww_spd&lang=en

[192] Statista, https://www.statista.com/statistics/874235/wastewater-sludge-generation-by-region-in-italy/

from both sources for 2010 and 2017 are reported in Table 38 below. The variance between the years could be due to different reporting methods between Eurostat and Statista or measurement changes in the country.

Table 38. Wastewater sludge data for Emilia-Romagna measured in tonnes of dry matter for the region Emilia-Romagna.

Year	**2010**	**2017**
Wastewater Sludge (dry matter, t)	80,239	445,000

3.2 Valorisation of Biological resources

3.2.1 Background information on the local waste management system

The collection and transport of separate and undifferentiated urban waste, street sweeping and other urban hygiene services (for example cleaning of green areas, market areas, beaches, etc.) are carried out by the companies to which the Emilia-Romagna territorial agency for water and waste services (Atersir) has entrusted the urban waste management service, like the Regional Agency for Prevention, Environment and Energy (Arpae) or waste managers (see Figure 48). However, on the regional territory some marginal activity of those services is carried out directly by the municipality, with either its own staff or private firms; these quantities amounted for 0.5% of the total collection in 2018.

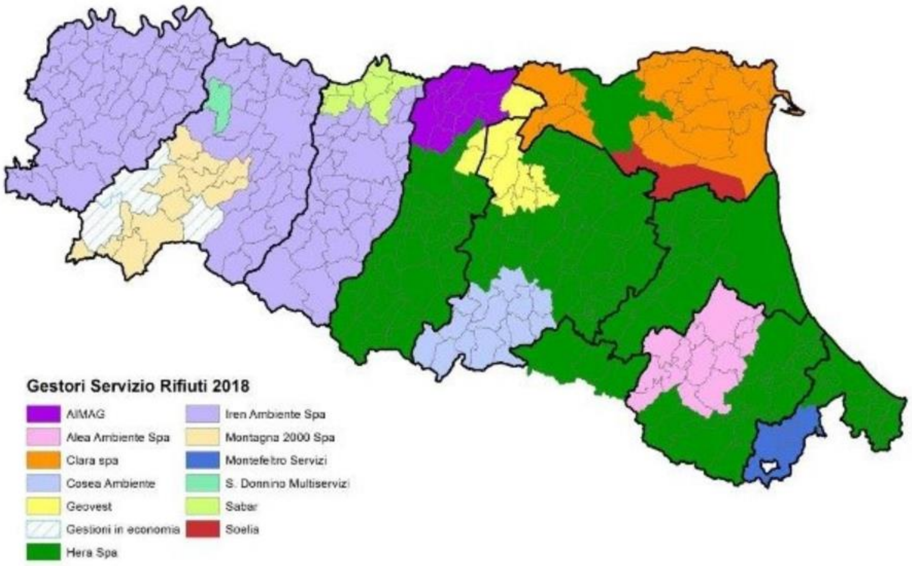

Figure 48.Multi utility companies responsible for waste management in Emilia Romagna (https://ambiente.regione.emilia-romagna.it/it/rifiuti/temi/servizio-gestione-rifiuti-urbani/gestori-del-servizio).

Since 1 January 2014, waste tax (TARI) has been introduced by Law No 147/2013, intended to finance the costs of waste collection and disposal services, to be borne by the user. There are still some exemptions that are made with regards to the tariff and it can be reduced for seasonal dwellings or non-continuous use (i.e. for residents who are more than six months a year abroad).[193]

In order to incentivise waste reduction, the region implemented punctual fees ("paying as much as dumped"), and the incentivisation fund established by the Regional Law 26/2015.

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[193] Regione, Emilia-Romagna, (2014), https://ambiente.regione.emilia-romagna.it/it/rifiuti/temi/servizio-gestione-rifiuti-urbani/la-tassa-sui-rifiuti-tari

By 2017, 48 municipalities have implemented punctual measurement systems, 16 of them have a punctual tax in place and 32 municipalities the corresponding tariff. Aimag, Clara, Iren Environment and Hera have already implemented punctual charging systems from the multi-utility site.[194]

MSW collection in Emilia Romagna is based on a number of collection systems: door to door, containers and pneumatic systems collection for separate waste and only dumpsters for unsorted waste. The traditionally most widespread collection system in Emilia Romagna for separate collection is still street containers (33%) (being collected by public service-managers), while the door-to-door system of separate waste collection accounts for 19%. Other collection systems made up 16% of separate collection, and 4% of waste was collected upon call / reservation.

The collection system traditionally mostly used for the collection of undifferentiated urban waste is street containers (63%), while the "door / home" system accounts for 26% and all "other collection systems" (for example street sweeping or abandoned waste, etc.) for 11%, respectively.

In 2018, 369 waste collection centres were active, uniformly distributed throughout the region. the collection centres integrate the differentiated collection services present in the area and continue to provide an indispensable contribution to support them. They are mainly used for the collection of particular types of waste, for which it would be onerous and technically demanding to provide a capillary collection service in the area, such as: mineral oils, vegetable oils, tires, construction waste and demolition of domestic origin, WEEE (waste of electronic electrical equipment), cells and batteries, bulky, green, cartridges and toners, other "dangerous" urban waste (dangerous containers labelled T / f, drugs, etc.). In mountain municipalities, characterised by a very low population density, collection centres represent the most economical solution to guarantee the differentiated collection of many fractions.

Considering the final destination, 813,975 tons were sent to incineration plants, 62,257 tons were sent to bio-stabilisation for the production of compost, 84,143 tons were landfilled, 3,181 tons were made up of waste from selective collections sent for disposal and 1,136 tons are homogeneous commodity fractions sent for material recovery. The area has four treatment plants with mechanical biological treatment , one biological treatment only plant , three mechanical treatment plants , eight incinerators with energy recovery (one of which is dedicated to the combustion of cdR / css), six landfills for non-dangerous waste, and 15 storage / transhipment platforms.

About 38% of the total costs of the service are linked to the macro-item CGIND (Costs of managing the cycle of services on undifferentiated RSu including sweeping costs), 40% of the costs relating to CGD (Management costs of the deferred funding cycle) and the remaining 22% attributable to common costs and costs of using the capital.

3.2.2 Description of currently used and available (ready to implement) technologies

Currently, organic waste that is obtained from the separate collection or from waste that is mechanically separated from household waste is delivered to HERAmbiente's composting and bio-stabilisation plants. The compost plants transform the separately collected waste into agricultural soil improver, while the second, due to its higher possibility for impurities is bio-stabilised to be used for other purposes. This helps the region to shift away from using raw materials that could be replaced by these bio-stabilised waste, e.g. used for covering landfills. HERAmbiente produces high-quality compost from roughly 150,000 tonnes per year of separately collected organic waste. The unseparated waste which

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[194] Arpae. (2018). La gestione dei rifiuti in Emilia-Romagna. Report 2018.

undergoes an accelerated fermentation process results in a bio-stabilised material or non-conforming compost used for a variety of environmental uses.[195]

The Industrial Symbiosis within the agroindustry performed as part of the *Green Economy and Sustainable Development* (see section 1.1.2) suggested the following circular solutions for bio-waste flows;

- **Food waste** - anaerobic digestion; energy recovery in biomass plants; recovery of materials for packaging; transformation for the production of pharmaceuticals and cosmetics; biopolymers.
- **Sludge** - chemical products manufacturing; energy recovering in biomass plants; manufacture of products for farming; products for the manufacture of coke and petroleum refining.
- **Waste wood processing** – energy recovery in biomass plants; energy recovery
- **Biochar** – Production of compost fertiliser.[196]

Waste Management Facilities treated 568,365 tons of waste and produced 124,982 tons of compost through it (p.108 Arpae Rifuti report, 2019). Looking at plant numbers, Ravenna and Bologna are the two strongest regions in composting.

In addition, domestic composting is a common practice in the region with 133 out of 331 communes having domestic composting implemented (in accordance with DGR 2218/16). In 2018, 20,487 tonnes of compost where produced, the table below shows the provincial split.

Table 39. Overview of domestic composting in Emilia Romagna. Source: Regional Waste Report 2019.

Province	No. of communes	No. of communes with report in place	Tonnes of compost produced
Piacenza	46	4	197
Parma	45	12	1,367
Reggio Emilia	42	16	1,318
Modena	47	22	3,878
Bologna	55	31	4,438
Ferrara	23	22	5,000
Romana	18	16	2,507
Forli-Cesena	30	3	859
Rimini	25	7	992
Total	**331**	**133**	**20,487**

HERAmbiente S.p.A. of Bologna (BO) has started the implementation of a biodigestion plant with production of biomethane from the organic fraction of waste, at the composting plant of Sant'Agata Bolognese. From the organic waste collected biomethane is thus produced in a differentiated way which can be delivered straight into Italian homes as gas.[197] From approximately 135,000 tonnes of waste per year, the plant aims to generate 7.5 million m³ of biomethane. Beyond using it in Italian homes through the gas network, it will possibly be used to fuel methane vehicles as well.

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[195] HERAmbiente – Plant25s (gruppohera.it)

[196] Cutaia, L., Scagliarino, C., Mencherini, U., & Iacondini, A. (2015). Industrial symbiosis in Emilia-Romagna region: results from a first application in the agroindustry sector. Procedia Environmental Science, Engineering and Management, 2(1), 11-36.

[197] Fondazione per lo Sviluppo sostenible and Fise Unicircular. (2019). 2019 L'Italia del Riciclo.

Two of the key companies within the Emilia-Romagna region that are dedicated to the bioeconomy and the expansion of existing technologies towards 2030 are HERAmbiente and Ca.Vi.Ro. Both are heavily involved with using waste to produce bioproducts including polythenol, biopolymers, bio-aromatics, etc. These companies are participating in both research and market expansion and are in varying levels of TRL with their projects. Ca.Vi.Ro. collaborates with local wineries to use grape waste to produce, among other products, alcohol-based fragrances and aromas. HERAmbiente has been a key leader in biomethane production and is heavily contributing to the biofuel market in Italy. Figure 49 below provides an overview of the projects undertaken by Ca.Vi.Ro. and HERAmbiente alone and in cooperation with other sector stakeholders (e.g. Climate Kic).

Figure 49. Overview of existing and potential technologies and TRLs utilised by key companies, HERA and Ca.Vi.Ro. in the Emilia-Romagna region.

Generally speaking, PHA production presents the highest barriers as it is brittle and fragile. VFAs as substrate is a processing method that has more and more uptake and also has potential for wastewater sludge conversion.

1.1.2 *Existing support from research organisations and other stakeholders*

The **Agrifood Clust-ER** is an association of 71 public and private organisations, i.e. companies, research centres, training institutions that share skills, ideas and resources to support the competitiveness of the sector (see table below). Agrifood Clust-ER is one of the seven thematic clusters set up by the Emilia-Romagna Region to support collaborations in strategic R&D sectors to boost the regional innovation potential. Together with the Technopoles and the High Technology Network laboratories, the Clust-ERs are key players in the regional innovation ecosystem coordinated by ASTER, the Emilia-Romagna consortium for innovation and technology transfer.

Table 40. Composition of the Agrifood Clust-ER.

Stakeholder group	Number	Example
Companies	29	CAVIRO, Tetra Pak Italiana, Granarolo, Cynagen
Research organisations, technology networks and training centres	39	Universities of Bologna, Ferrara and Parma, ENEA, CNA Innovation, Confindustria Emilia Romagna

Other	3	CREATES, INNOVACOOP, Association of Food Technology Emilia Romagna, Tuscany, Marche and Umbria

The cluster focuses on three strategic lines of research and innovation, one of them being valorisation of agrifood by-products and waste to improve the sustainability – both economic and environmental - of the food production processes (SPES). Trough advancing on concepts of biorefinery, the Agrifood Clust-ER aims is to obtain high added value components.

PARMA University is member of the Agrifood Clust-ER and plays a major role with regards to innovation in the agro-food industry as well and have ties with both Barilla and Ferrero, two major Italian food producers. The University is working on developing and using bioproducts for the formulation of new foods. Within the Ravenna and Ferrara region, there are two conventional refineries that are not partially converted to biorefineries. They are trying to boost production of biodiesel from exhausted oil fractions as well from fish waste. The benefit of these plants and their conversion is the elimination of the need to build new plants, an essential barrier with biofuel and oil production. [198]

The *Green Economy and Sustainable Development* project promoted by Unioncamere Emilia-Romagna and ART-ER (formerly ASTER), with technical and scientific coordination of ENEA has as objective to develop cross-relations between production sectors, industrial research and territory and boosting circular economy. The first industrial symbiosis concerned the agroindustry and involved 13 companies and seven laboratories that were invited to focus groups and shared information of resource use and waste/by product generation. Here, focus lied on the chain of reuse and enhancement of agroindustrial waste and residues, in particular if resulting in high-value materials. The project identified eight main resource streams, 28 feasible destinations, and 90 potential synergies involving a broad range of companies in the region.[199]

The project on sustainable agriculture (*CSA Project*) initiated by Rimini Province, AUSER ER, together with University of Bologna studied agro-waste management and emerging options for producing selected compost.

3.2.3 Legal environment, enablers & barriers

The Legislative Decree 22/97 issued in 1997 is the centre piece of Italian waste legislation, shaping the national waste management system, introducing targets about separate collection of municipal waste and establishing the National Packaging Consortium. Furthermore, the decree replaced the old waste tax by a new waste tariff. In 2006, the decree has been replaced by Legislative Decree 152/2006 which embraced most of its provisions.[200]

In April 2006, Legislative Decree 152 (the "Consolidated Environmental Act") came into force, profoundly altering the rules on environmental impact assessments and strategic environmental assessments, soil protection, water pollution prevention and water resources management, waste treatment and management, reclamation of contaminated sites, and pollution towards more innovative approaches. According to the act, installation and management of new plants will be authorised only if the relative combustion process

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[198] Confirmed in interview with key stakeholder.

[199] Cutaia, L., Scagliarino, C., Mencherini, U., & Iacondini, A. (2015). Industrial symbiosis in Emilia-Romagna region: results from a first application in the agroindustry sector. Procedia Environmental Science, Engineering and Management, 2(1), 11-36.

[200] Malinauskaite, J., Jouhara, H., Czajczyńska, D., Stanchev, P., Katsou, E., Rostkowski, P., ... & Anguilano, L. (2017). Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe. Energy, 141, 2013-2044.

ensures a high level of energy recovery, effectively approving the conversion of these plants from simple incinerators into modern waste-to-energy plants.

Italy does not have National Waste Management Plan as planning is mandated to regions with the obligation to devise their Management Plans every 2-3 years or subject to regulatory changes from the EU. In addition, the National Programme for Waste Prevention focuses on sustainable production with changes in raw materials and technologies, green public procurement, re-use, research, and awareness raising and education on waste prevention.[201]

In 2011, Italy enforced a ban on non-compostable single use plastic bags in shops, therefore households can easily obtain compostable and biodegradable plastic bags (cost 1-3 cents) and reuse them for their bio-waste.[202]

With the 2016 Waste Management Plan, Emilia Romagna shifted the focus from the end of the waste stream (disposal) to the beginning (prevention and preparation for reusing). Those ideas are in line with the European waste hierarchy[203] (recycling at least 70% of all paper, metals, plastic, wood, glass and organic waste by 2020, and reducing down to 5% the disposal following landfill dumping). The goal for the region is to have only three landfill sites, which should mainly be used for special waste, and to start delivering sorted urban waste.

The region ER has inserted Industrial Symbiosis in their strategic plan, as a tool to reduce waste and increase regional sustainability, material reuse and raw material saving. In this context, five technological specialisations most relevant for growth were determined, amongst agrifood.[204]

One of the barriers identified in the regulatory realm is the lack of stringency towards landfills to recover biogas. While the biogas chain is almost entirely realised there is still needed to enforce the partnership between landfills and district heating.

4 Case Study of the region of Flanders

Flanders is situated in the northern part of Belgium. Its capital is Brussels, a hub for the EU and international institutions and companies. The Brussels Capital Region, despite being located in Flanders, has its own regional government and the Flanders' government is only responsible for the cultural and educational sectors in Brussels. Flanders has the highest population between the three regions of Belgium despite having a smaller area. Flemish is the main language of the region, although French is the main language spoken in the city of Brussels.

The Flemish region claims the highest waste diversion rate in Europe with a nearly 75% recycling, reuse, and compost rate. To achieve this, the government has introduced subsidies that encourage companies to participate in re-use programmes or initiatives. The Flanders Public Waste Agency (OVAM) is responsible for overseeing the policies and legislation developed by the 308 Flemish municipalities. The municipalities update their waste policies every four to five years, resulting in a highly functional and modern system

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[201] Malinauskaite, J., Jouhara, H., Czajczyńska, D., Stanchev, P., Katsou, E., Rostkowski, P., ... & Anguilano, L. (2017). Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe. Energy, 141, 2013-2044.

[202] Milano Recycle City, (2016). https://issuu.com/giorgioghiringhelli/docs/food_waste_recycling_the_case_study

[203] Regione Emilia-Romagna, (2014). https://ambiente.regione.emilia-romagna.it/it/rifiuti/temi/piano-rifiuti/piano-rifiuti-approvato

[204] Invitalia, (2014), La mappa delle specializzazioni tecnologiche. Il quadro regionale, Agenzia nazionale per l'attrazione degli investimenti e lo sviluppo d'impresa SpA, On line at: https://www.researchitaly.it/uploads/7553/Mappatura%20specializzazioni_Il%20quadro%20regionale_1.pdf?v=801f04a

of waste management. Flanders is one of the rare examples of economic growth without an increase in per capita waste generation per year.[205]

Table 41. General information on Flanders.

<table>
<tr><th>Region</th><th>Flanders</th></tr>
<tr><td>Country</td><td>Belgium</td></tr>
<tr><td>Geographical location</td><td>Northern part of Belgium</td></tr>
<tr><td>Population</td><td>6,589,000 (2019) [A]</td></tr>
<tr><td>Population density (inhabitants per km^2)</td><td>484 inhabitants per km^2</td></tr>
<tr><td>GDP (million EUR)</td><td>EUR 270,886.01 [B]</td></tr>
<tr><td>GDP per capita (EUR)</td><td>EUR 35,300 [B]</td></tr>
<tr><td>Green urban areas (%, Area)</td><td>40-46% [C]</td></tr>
<tr><td colspan="2">Number of operating research centres promoting the bioeconomy</td></tr>
<tr><td colspan="2">Ghent University Faculty of Science
- International Master of Science in Marine Biological Resources (Global Ocean Change)
- International Master of Science in Marine Biological Resources (Applied Marine Ecology and Conservation)
- International Master of Science in Marine Biological Resources (Management of Living Marine Resources)
- Faculty of Bioscience Engineering
- International Master of Science in Environmental Technology and Engineering
- International Master of Science in Rural Development
- International Master of Science in Soils and Global Change (Physical Land Resources and Global Change)
- International Master of Science in Soils and Global Change (Soil Biogeochemistry and Global Change)
- International Master of Science in Sustainable and Innovative Natural Resource Management

University of Antwerpen Faculty of Science
- Master of Biology: Global Change Biology
- The Sustainable City: An Integrated Perspective (SummerSchool)
- Postgraduate of Energy and Climate: profile
- Master of Biology: Biodiversity, Conservation and Restoration</td></tr>
<tr><td colspan="2">*Sources*[206]*:*
[A] Statbel (2020), [B] Eurostat (2018), [C] Fuller & Gaston (2009)</td></tr>
</table>

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[205] Gaia: no-burn.org/wp-content/uploads/ZW-Flanders.pdf

[206] Fuller, R. A., & Gaston, K. J. (2009). The scaling of green space coverage in European cities. Biology letters, 5(3), 352–355. https://doi.org/10.1098/rsbl.2009.0010; EuroStat, 2018: https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=de&pcode=tgs00003&plugin=1; StatBel, 2020: https://statbel.fgov.be/nl/themas/bevolking/structuur-van-de-bevolking#news

4.1 Analysis of the municipal waste generation scheme, trends, and future milestones

4.1.1 Availability of municipal bio-waste as feedstock

The availability of municipal bio-waste feedstock is the backbone for a region or city's potential to expand upon their existing measures towards the bio-economy. The data in Table 42 and Figure 50 below show the quantities of selectively collected household waste in the Flemish region. The green waste is collected by the municipalities and has expanded over time from just 'mixed garden waste' and 'pruning wood and tree stumps' to include kitchen waste and food scraps. Tea bags and coffee pads are no longer collected as they may contain plastics (OVAM, 2019). The update to the requirements for the classification of wastes within the Flanders region could explain why in some cases the organic waste collection went down between 2010 and 2018, as the sorting has gotten stricter or more advanced.

Table 42. Municipal bio-waste and type of waste for 2010, 2014 and 2018. Source. OVAM, 2019.

Year	**2010**	**2014**	**2018**
Organic waste	266,215	274,713	254,157
Garden waste	470,745	464,518	420,579
Wood waste	156,521	161,963	186,199
Vegetable and animal oils and fats	6,371	6,980	6,371
Total	**899,852**	**908,174**	**867,306**

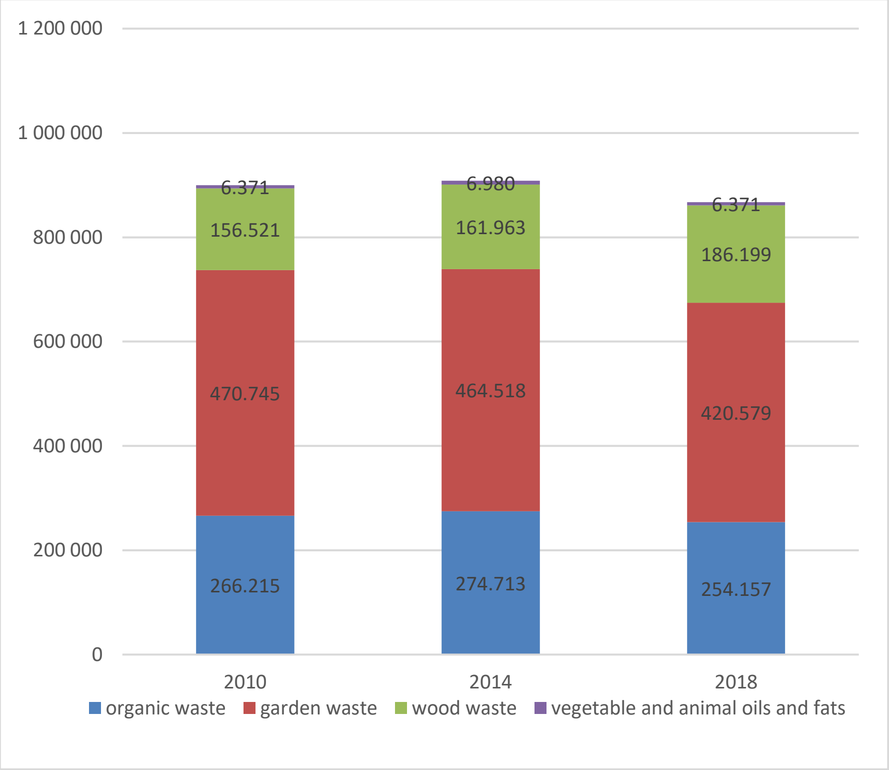

Figure 50.Overview of municipal green waste by type. Source: OVAM, 2019

4.1.2 Availability of municipal wastewater sludge as feedstock

The data available for the Flanders region wastewater sludge is minimal and only reported for 2008 and 2010 under Eurostat. The population for the years 2008 and 2010 is multiplied by the kilogram per capita for the entirety of Belgium in order to produce an estimate of the data. Table 43 reports these numbers.

Table 43. Wastewater sludge data for 2008 and 2010.[207]

Year	2008	2010
Wastewater Sludge (dry matter, t)	81,963	100,187

4.2 *Valorisation of Biological resources*

4.2.1 *Background information on the local waste management system*

The policy framework is set by the Public Waste Agency of Flanders (OVAM), which establishes for example the obligations and frequency of separate collection, the framework of eligible collection tariffs (e.g. price floors/levels), and possibly applicable waste taxation.

In Flanders, (inter)municipalities, i.e. small groups of municipalities, are responsible for the waste collection of household waste. The organisation of waste collection varies among the municipalities between entirely public organisation and public-private partnerships, where waste collection and/or waste valorisation are privately organised.

The financing of the waste collection is determined on the municipal level and can be in the form of i) municipal funding, ii) flat-rate taxes, or iii) fee-based collections.[208] Waste collectors are, next to the regular waste collection of fractions, obliged to provide additional collection of selected waste fractions (e.g. asbestos) free of charge.

Flanders applies a modulated waste collection fee (called DIFTAR), which incentivises the separation of waste at source, by making e.g. residual waste collection more expensive than other separated fractions. In Flanders, modulated fees have been applied for 20 years, and have led to a reduction of residual waste. The regional government incentivised municipalities to apply modulating fees that are effective by providing rewards to those who achieved targets on residual waste per inhabitant that were individually determined for the intermunicipalities. It is OVAM's experience that kg-based collection fees lead to the most effective reductions of residual waste.

According to OVAM, the application of modulated fees for organic waste (vegetable, fruit, and gardening waste – VFG) needs to be done with care, as an improper setting can lead to contamination with other fractions or illegal dumping, respectively reducing the quality and quantity of the available bio-waste – which is key to ensuring a circularity of bio-waste. OVAM further states that modulating fees need to be coupled to a high level of service for all waste fractions to reduce the incentives for households to avoid the production of waste.

The tariffs are set to reflect the polluter-pays-principle, but the collected revenues are not enough for a financially self-sufficient waste management system, owing to the high cost of separate door-to-door collection and treatments, as well as the costs of existing recycling parks. The municipalities provide the remaining financing as part of their annual budgets and use subsidies for investments in collection materials and anaerobic digestor (AD) plants.[209]

Municipal solid waste from households is collected in several fractions, and during the course of 2020, the collection will undergo small refinements, ending with the following fractions: glass, paper/carboard, packages (plastic bottles, metal, and drinking cartons, including from 2021 all sorts of plastic packaging), VFG, small dangerous waste, WEEE,

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[207] Eurostat, 2020 https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_ww_spd&lang=en

[208] https://www.vlaanderen.be/afvalinzameling-en-sorteren

[209] For subsidies, see here: https://www.ovam.be/subsidies-voor-lokale-besturen

green waste (i.e. larger gardening waste), and residual waste. [210, 211] Furthermore, home composting is encouraged in all regions. Bio-waste is thus collected as VFG waste and gardening waste. As of 2020, about two-thirds of VFG waste is collected separately, with the aim of achieving 100% by 2023 (cfr. Waste Framework Directive).

Businesses are also required to separate waste. With respect to bio-waste, larger food businesses (e.g. schools, restaurants, prisons, hospitals) will be required to separate food waste from 2021. By 2023, also small food businesses will be required to separate food waste (cfr. Waste Framework Directive).

Food waste in the form of animal residues (incl. food leftovers) has only been part of the organic waste collection since 2019, due to initial concerns about the risk of BSE contamination in the reuse as animal feed. Research has however shown that there is no such risk associated with the existing processing capabilities in Flanders, eventually leading to a simplification of organic waste collection.[212]

The use of electric or biomethane fuelled trucks in collection is insignificant in Flanders. Whereas municipalities are interested in making the collection more sustainable, the cost barriers are too high. With respect to using biomethane fuelled trucks, the regulatory framework provides only little incentive on using e.g. biogas for heavy transport.

A few intermunicipalities are nevertheless engaged in either testing alternatively fuelled collection trucks (e.g. hybrid or natural gas), which are more economic and quieter in operation, or upgrading biogas into biomethane.

In 2015, most of the separated bio-waste streams were valorised within Flanders by private bio-waste processors.[213] Private bio-waste processors as well as the intermunicipal waste associations and the Flemish government service for waste, materials, and soil, are represented by a membership association (VLACO), with more than 80 members.[214]

VLACO provides quality assurance for bio-waste processing, laboratory testing, and marketing and communication to support bio-waste circularity – and hence serves as an important actor in the promotion of bio-waste processing, not only in the form of promoting business interests, but also supporting the development of a well-functioning market for bio-waste.

Many processing steps at the regional composting and biogas facilities are automated. For the transforming 20,000 – 60,000 tonnes of waste per year, about 5 persons are reportedly needed. The processing is increasingly automated along the various waste management stages.

The waste collection is supported by electronic chips to calculate the weight of collected waste per household (as part of implementing modulated collection tariffs); similarly at recycling parks, the fee calculations are automated.

For AD plants, pre-treatment and treatment processes are fully automated; manual labour is however required for some of the prior treatment steps. Also for composting, manual labour is needed for some parts of the process. The post-treatment in AD is often automatised, such as the upgrading of biogas, treating the digestate (e.g. biological

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[210] Vlaanderen, https://www.vlaanderen.be/afvalinzameling-en-sorteren

[211] De Nieuwe Blauwe Zak, https://www.denieuweblauwezak.be/nl/wat-verandert

[212] OVAM, 2019: https://www.ovam.be/sites/default/files/atoms/files/Voortgangsrapportage_actieplan_duurzaam_beheer_van_biomassareststromen_2015-2020.pdf

[213] OVAM, 2017: https://www.ovam.be/sites/default/files/atoms/files/Supply%20and%20destination%20of%20biomass%20residues%20for%20the%20circular%20economy%20in%20Flanders%20.pdf

[214] https://www.vlaco.be/over-vlaco-vzw/wat-doet-vlaco-vzw

treatment). Parts of the monitoring of the different treatment processes can be followed remotely online.

4.2.2 Description of currently used and potentially available (ready to implement) technologies

92% of all food (waste) residues were valorised in 2015, corresponding to 3.2 million tonnes.[215] Most of the residues were further valorised locally in Flanders. The majority (43%) is used as feed. Composting accounts for 6%, and anaerobic digestion for 21%, and have reportedly experienced significant growth. Finally, the remaining 8% are either incinerated (6%) or disposed (2%). To the largest extent, the bio-waste is thus being recycled into new uses, of which most dominantly as animal feed, soil improver, or compost. The use of more advanced applications like bio-based products or biofuels is comparably very small (<1%).

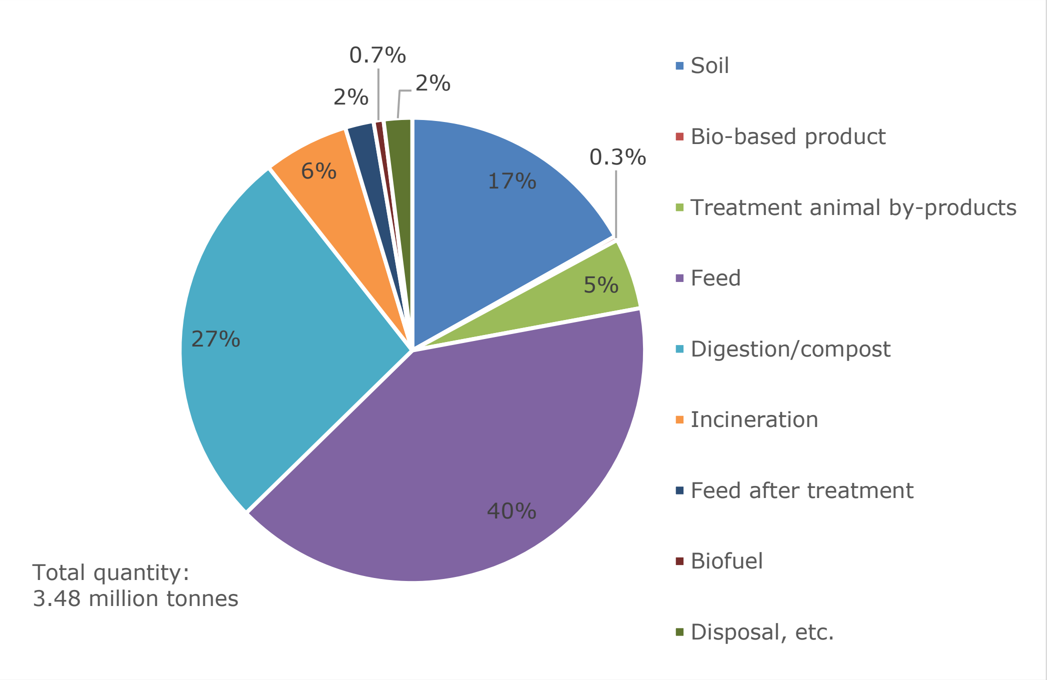

Figure 51.Overview of the valorisation of food waste/residues in Flanders, 2015. Source: https://www.ovam.be/sites/default/files/atoms/files/Supply%20and%20destination%20of%20biomass%20residues%20for%20the%20circular%20economy%20in%20Flanders%20.pdf

Figure 51 above presents the valorisation of organic (waste) residues in 2015 per sector. As is evident, the food industry, households and agriculture sector are the largest sources of organic (waste) residues. The pattern of valorisation diverges strongly for the latter two sectors: Nearly three-quarters of the agricultural organic (waste) residues are used as soil, whereas household organic (waste) residues are primarily composted, used as animal feed, or incinerated. Incineration is particularly applied for food wastes from the hospitality sector and households. The waste from green and open space management is primarily composted or used as firewood.

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[215] OVAM, 2017: https://www.ovam.be/sites/default/files/atoms/files/Supply%20and%20destination%20of%20biomass%20residues%20for%20the%20circular%20economy%20in%20Flanders%20.pdf

Table 44. Overview of the valorisation of food residues per sector in Flanders, 2015.

Sector	**Animal Feed**	**Organic-based**	**Soil**	**Fermentation**	**Composting**	**Energy**	**Incineration with energy recover**	**Landfill/discharge**	**Unknown use**	**Total (tonnes)**
Fishing industry	-	-	-	-	-	-	-	100%	-	10,402
Agriculture	11%	-	70%	4%	4%	1%	-	4%	6%	449,352
Auctions	36%	-	28%	11%	17%	-	-	-	8%	15,277
Food industry	55%	0%	11%	26%	-	7%	0%	-	-	2,349,445
Retail	3%	2%	-	49%	16%	-	29%	-	-	64,828
Hotel, restaurant, pub	-	-	-	31%	-	-	69%	-	-	67,450
Catering	-	-	-	24%	-	-	76%	-	-	60,098
Households	28%	-	-	6%	40%	-	24%	3%	0%	468,305
Total chain	**43%**	**0%**	**17%**	**21%**	**6%**	**5%**	**6%**	**1%**	**1%**	**100%**

Source: https://www.ovam.be/sites/default/files/atoms/files/Supply%20and%20destination%20of%20biomass%20residues%20for%20the%20circular%20economy%20in%20Flanders%20.pdf

Figure 52 below presents the valorisation of organic (waste) residues that could not be utilised for other circular applications e.g. animal feed or bio-based products, and thus was either composted or digested in 2018. As is evident, about two-thirds is processed into biogas and one-quarter is composted. Organic household waste is both composted and fermented, but about three-quarters is composted. Notably all gardening waste is composted (due to incompatibility of wooden parts with biogas) and all organic business waste as well as energy crops are turned into biogas.

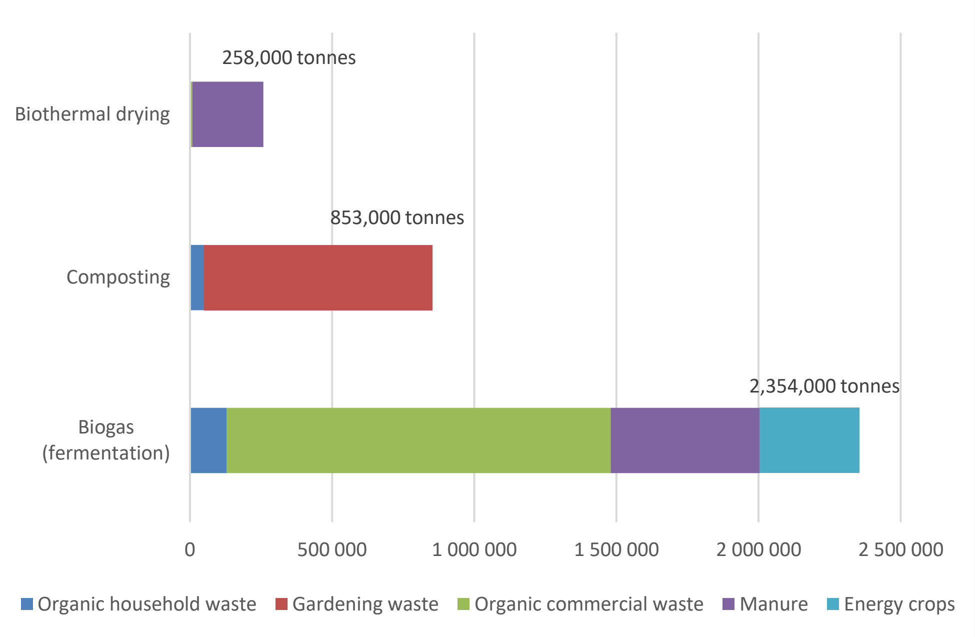

Figure 52. Overview of valorisation of bio-waste residues in 2018, by form of valorisation (drying, composting, and biogas), per residues stream (navy – organic household waste, gray – gardening waste, orange – organic commercial waste, green – manure, blue – energy crop). Source: https://www.vlaco.be/nieuws/trends-in-selectieve-inzameling-en-verwerking-in-vlaanderen

There are currently about 40 ADs in Flanders that produce energy and digestate (for the further purpose of fertilisation).[216,217] There are a variety of ADs available, such as dry and

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[216] Vlaco. https://www.vlaco.be/digestaat-gebruiken
[217] ECN Country Report 2018

wet digestors. Most ADs are used to produce fuel for cogeneration. As mentioned above, one intermunicipality started upgrading biogas into biomethane.

As pre-treatment for ADs, the raw digestate is separated (through centrifuges or screw press), and/or the solid fraction of the raw digestate dried, and/or the liquid fraction of the raw digestate biologically treated.

The digestate from biogas and compost are sold across Flanders by individual companies. The compost and digestate are offered in various formats that vary by the contained waste fractions (e.g. purely from organic household waste, gardening waste, including/excluding manure), and consistency (e.g. pelleted/dried/semi-dried/fluid digestate, or highly concentrated digestate).[218] Both are sold to private- and professional users and are mainly used as fertiliser and (top) soil improver. The digestate is however mainly used as a fertiliser in the regional agriculture. Due to high surpluses in manure in Belgium, a significant share of the solid or dry digestate is exported to neighbouring countries. Pelleted dried digestate is exported on a global level.

The residual water resulting from the post-processing of the digestate can and is used for different applications, such as process water. OVAM is currently researching to which extent the water discharges can be used as irrigation water. Furthermore, the discharge water from e.g. cleaning the exhaust air of digestate drying is used as fertiliser.

Next to the composting of collected bio-waste, households are encouraged to do home composting. In 2012, 58% of garden owners were practicing home composting.

There are thus a variety of products and applications that result from the bio-waste valorisation. According to OVAM, the use of product differentiation is important in ensuring that as much residual product is valorised as possible, as it ensures that the products fulfil the needs of the customers.

As mentioned above, the production of bio-based products was insignificant in 2015. As of 2020 there is no evidence suggesting that the production of these advanced applications has gained significance, which has also been confirmed in an interview with OVAM.[219] The barriers behind this aspect are discussed in more detail below.

All wastewater sludge is primarily being incinerated, as part of waste incineration, on its own, or in cement furnaces.[220] Before sludge can be incinerated, a variety of treatments are necessary. These range from thickening, through fermentation (to produce biogas) and dewatering (to lower the moisture content), to drying (to produce pellets that can be burned).[221] The local and publicly funded wastewater treatment provider, Aquafin, is currently investigating the possibility to reorient its sludge treatment policy towards nutrient and fibre recycling technologies, which could be added to the current thermal treatment or anaerobic digestion of sludge.

Some of the wastewater sludge from the food industry is used in AD installations in combination with manure. The resulting digestate is then used as fertiliser. Sewage sludge is not allowed to be used as fertiliser due to hygienic reasons, as contamination microplastics, pharmaceutical residues, POPs, and emerging contaminants such as PFAS in human wastewater pose a concern to crop production.

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[218] Vlaco: https://www.vlaco.be/verkooppunten/professionelen

[219] Ovam: https://www.ovam.be/inzet-in-chemische-industrie

[220] Aquafin, (2018): https://www.aquafin.be/sites/aquafin/files/2018-11/Verwerkingstechnieken%20voor%20slib.pdf

[221] Aquafin, (2018). https://www.aquafin.be/sites/aquafin/files/2018-11/Verwerkingstechnieken%20voor%20slib.pdf

4.2.3 *Existing support from research organisations and other stakeholders*

The Flemish government established in 2011 an interdepartmental working group for the bioeconomy, which ensures the development of a coherent bioeconomy policy, as well as developing the overall vision and concrete actions.[222]

The realisation of the bioeconomy is driven by the cooperation of several policy initiatives, such as **Circular Flanders** (a partnership of governments, companies, civil society, and the knowledge community).[223] Moreover, clusters are equally driving this development, covering the most relevant sectors, like **Catalisti** (a spearhead cluster for the chemical and plastics industry, composed of businesses, research institutes and universities, examining opportunities for waste valorisation), **Flanders' Food** (an innovation platform for the agro-industry), and **The Blue Cluster** (a blue growth cluster). [224, 225, 226]

The **BIG-Cluster** (Bio Innovation Growth mega cluster) is a relevant cross-border initiative in this area, spanning across Flanders, the Netherlands and North Rhine-Westphalia in Germany. Striving for leadership with regards to bio-based innovation growth in Europe, the cluster's aim is to trigger a comprehensive feedstock change with a focus on regionally available bio-based and sustainable raw materials. In order to achieve this objective the cluster manages a number of projects, among other to coordinate education and training in the field of circular bioeconomy, and research advances on bio-feedstock valorisation technologies.

There is further a knowledge platform, **CEEBIO**, which gives an overview of the knowledge, expertise, and activities in the Flemish bio-based economy.[227] One of the platform's objective is promoting cooperation between companies and researchers. All major research institutions are supporting this platform: Ghent University, the KU Leuven, the University of Antwerp, the Flemish Institute for Biotechnology (VIB), the Institute for Agricultural and Fisheries Research (ILVO), VITO and the Development Agency East Flanders.

Finally, there are also more local platforms supporting bio-based activities, such as the Flanders Bio-based Valley, a local bio-based platform for the Ghent area.[228]

There is thus wide support from regional stakeholders across the private sector, research institutions, and governing bodies, which all seek to contribute by sharing knowledge, establishing cooperation, and participating in the policy developments.

4.2.4 *Legal environment, enablers & barriers*

The basis for Flanders' ambition is the Flemish government's vision and strategy for a Flemish bioeconomy in 2030, which was made public back in 2013 and was the result of an interdepartmental working group.[229] A variety of relevant stakeholders (e.g. business associations, civil society organisations, and research institutions) were invited to provide comments and suggestions on the formulation of actions, which may indicate a broad support for this strategy.

The above strategy gave rise to the Action Plan for the Sustainable Management of (Residual) Biomass Streams 2015-2020, which covers organic waste streams from the

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[222] EWI: https://www.ewi-vlaanderen.be/onze-opdracht/ondernemende-economie/bio-economie

[223] Vlaanderen: https://vlaanderen-circulair.be/en/about-us

[224] https://catalisti.be/

[225] https://www.flandersfood.com/over-ons

[226] https://www.blauwecluster.be/about

[227] http://www.ceebio.be/en

[228] http://www.fbbv.be/en/who-is-fbbv/mission

[229] Vlaanderen, (2014). https://www.vlaanderen.be/publicaties/bioeconomy-in-flanders-the-vision-and-strategy-of-the-government-of-flanders-for-a-sustainable-and-competitive-bioeconomy-in-2030

agriculture-food-consumer chain, streams from green and open space management, and wood streams from industry and households.[230] With respect to organic waste streams, the action plan has the following three aims:

- Prevent food losses,
- Separately collect organic waste from primary production, municipalities, and the hospitality sector, and
- Improve the recycling of organic waste by promoting
- nutrient recovery,
- bio-based products,
- use of biomass in agricultural sector (incl. feed),
- biorefining for the food industry, pharma, and green chemistry,
- biological processing (compost, digestate, biomethane) and sale.

For streams from green and open space management, the action plan foresees actions on improving the management and use of wooden and non-wooden waste, such as closing the material cycle.

The Flemish government is currently further engaged with the preparation of a new action plan for 2021-2025.[231]

The legal basis for the Flemish waste policy are the Materials Decree and VLAREMA (the Flemish Regulation for the sustainable control of material loops and waste), which aim to close the materials cycles through, among others, regulating transport, collection, registration, and extended producer responsibility (EPR).[232] The most recent revision of VLAREMA came into force back in July 2019, and introduced new rules that seek to improve the supply of sorted waste, incl. bio-waste. In terms of bio-waste from households, stricter enforcement has been introduced and the range of waste products allowed in the bio-waste fraction has been expanded.[233] Furthermore, a limited range companies and institutions (primarily composed of restaurants and supermarkets) will be obliged to separate kitchen-, and food waste from 2021 on.

Despite a rich amount of clusters and stakeholder engagement, a recent study identified that there is no overarching cooperation across the sectors, leading to a loss in opportunities.[234] Adding to it, the study concluded that the link to Europe is underutilised, leading to missed opportunities for spin-offs and SMEs, as the clusters are regionally focused.

With respect to the production of novel bio-based materials, costs and quality are the primary barriers behind further market development. The cost of producing bio-based materials are generally higher than their fossil alternatives. According to OVAM, incentive mechanisms might be required to further spark demand for bio-based products; such as VAT reductions for bio-based over fossil materials.

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[230] Ovam, (2018) https://www.ovam.be/sites/default/files/atoms/files/Action%20Plan%20for%20the%20Sustainable%20Management%20of%20Biomass%20Streams%202015-2020.pdf

[231] Ovam, (2018). https://www.ovam.be/afval-materialen/specifieke-afvalstromen-materiaalkringlopen/biomassa/actieplan-duurzaam-beheer-van-biomassareststromen-2015-2020

[232] Ovam, https://www.ovam.be/vlaamse-wetgeving-0

[233] Ovam: https://www.ovam.be/vlarema-wijziging-7

[234] EWI: https://www.ewi-vlaanderen.be/sites/default/files/bestanden/abstract_09032017_eng_web.pdf

Quality is a further barrier, as an economically viable production of bio-based products requires a consistent, i.e. homogeneous, quality. Bio-waste is however of heterogeneous quality, as its composition is inconsistent and affected by impurities. These impurities are of chemical nature (e.g. heavy metal contamination, herbicide-, pesticide-, and other residues such as PFAs) as well as physical nature (e.g. other waste fractions like plastics, and microplastics).

For the application on an industrial scale, potential users seek for homogeneous, clean, and large biomass volumes; bio-waste is therefore not suited for direct processing. According to OVAM, the use of intermediate conversion steps can however help overcome this barrier, such as thermal treatment, bioconversion through fermentation, or the use of insects. As of this date however, no such technology is available.

Finally, OVAM states that the currently high incentives for renewable energy production in Flanders and neighbouring regions constitute a barrier to the development of novel bio-based products, as the supply of biogas for energy production is economically more viable, creating an uneven level playing field for the different end-applications of bio-waste.

4.3 Valorisation of Biological resources in 2030

4.3.1 Future management of the waste streams in 2030

As mentioned above, Flanders will require bio-waste separation for large food businesses, and a complete bio-waste separation for all households and businesses by 2023. OVAM is furthermore considering to adjust the modulated collection fee, increasing the price difference between residual- and recyclable waste fractions further to incentivise better separation at source.

4.3.2 Future available methods/technologies for processing methods for managing separated bio-waste streams in 2030.

A mid-term evaluation of the Action Plan for the Sustainable Management of (Residual) Biomass Streams 2015-2020 has concluded that the use of biomass for bio-based products can be expected to remain constant (and thus marginal) for the coming years.[235] The food sector increasingly succeeds in a safe and profitable valorisation of food-waste within the food chain. The evaluation assesses that the economic feasibility of 2nd generation feedstocks largely is a question of the costs for logistics. A rationale for focus on bio-based products from 2nd generation feedstocks is only given for locations with a high abundance of local supply. Furthermore, bio-based products are primarily focused on the extraction of high-quality components from feedstocks, such for the production of bio-aromatics.

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[235] Ovam, (2018). https://www.ovam.be/sites/default/files/atoms/files/Voortgangsrapportage_actieplan_duurzaam_beheer_van_biomassareststromen_2015-2020.pdf

4.3.3 *Description of future technological potential available (ready to implement) for bio-waste processing)*

OVAM does not expect any new large-scale technologies will become available by 2030. Possibly towards the end of the 2030's, the current research project Steelanol, will lead to the large-scale production of bio-ethanol from residues from steel production. The bio-ethanol could be used as an ethylene source to produce e.g. bio-based plastics.

In the absence of promising technologies on the horizon, Flanders focuses therefore on further innovating on the existing treatment technologies and further diversifying the product palette derived from compost and digestates, as well as providing discharge water as irrigation water.

Aquafin, the Flemish wastewater treatment provider, is currently researching alternative recovery methods of wastewater sludge. There are three recovery methods that are of particular interest.[236]

1. The fermentation of sludge to produce volatile fatty acids, which can be processed into bio-plastics, oils, and omega-3 fatty acids. Aquafin is a research partner in the Horizon 2020 project Volatile, which investigates the conversion of solid waste and wastewater sludge into volatile fatty acids.[237]

2. Hydrothermal carbonisation (HTC), a process involving treatment with elevated pressure (15-20 bar) and high-temperature (170-270 °C). This process reduces the water content, and therewith facilitates the drying of sludge. Moreover, it increases the availability of phosphorus.

3. Sub- and super-critical oxidation, involving very high pressure (165–240 bar) and very high temperatures (300-600 °C). This process increases the availability of nitrogen, CO2, water, and ash (from which additional materials could be recovered).

There is though no evidence which points to specific technologies that will be developed with certainty.

5 Case Study of the city of Łódź

The city of Łódź is located in the Łódźkie Voivedeship in Central Poland and is the third largest city in Poland. It is both a cultural and academic hub, but also used to be a key industrial centre primarily in the textile industry. Around 2010, the city picked up after a period of economic decline. There are two main research centres within Łódź that help nourish the cultural side of city as well as its relationship to the bioeconomy and environmental protection. Both the University of Łódź and the Łódź University of Technology have programmes in the fields of environmental science and protection.

With regard to waste and sorting, the amount of green waste has risen significantly in Łódź, which can be in part attributed to the EU regulation to reach a 50% recycling rate by 2020. In 2017, the entirety of Poland sat at 26% and began implementing new recycling programmes across the biggest cities with Łódź starting in July 2018. Between 2010 and 2017 the percentage of recycling from municipal waste in Poland rose very slightly starting

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[236] Aquafin, (2018). https://www.aquafin.be/sites/aquafin/files/2018-11/Verwerkingstechnieken%20voor%20slib.pdf

[237] http://volatile-h2020.eu/

at 21% in 2010[238]. Beyond the EU and countrywide regulations, Łódź has developed an innovative waste sorting and disposal system, although it is relatively recent, only taking off at the end of 2019. The city has established an internet search engine which tells residents how and where to sort their waste properly. Since its implementation, the city of Łódź has seen an increase in the amount of waste being sorted as well as an increase in an interest for correct waste disposal.[239]

Table 45. General information on Lodz.

City	Łódź
Country	Poland
Geographical location	Łódzkie Voivodeship, Central Poland
Population	682,679 inhabitants
Population density (inhabitants per km²)	2328
GDP (EUR)	EUR 10,200,000 [A]
GDP per capita (EUR)	EUR 14,645 [A]
Green urban areas (%, Area)	8-10% [B]
Number of operating research centres promoting the bioeconomy	
Łódź University of Technology • Science in the Faculty of Biotechnology and Food Sciences • Science in the Faculty of Civil Engineering, Architecture and Environmental Engineering University of Łódź • Faculty of Biology and Environmental Protection • Faculty of Chemistry (Environmental Chemistry) • Faculty of Geographical Science	
Sources:[240] [A] City Strategy Bureau, 2017, [B] Fuller & Gaston, 2009	

5.1 *Analysis of the municipal waste generation scheme, trends, and future milestones*

This chapter contains information on Łódź' waste sources with emphasis on municipal bio-waste and wastewater sludge.

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[238] Environmental Energy Agency, 2013 https://www.eea.europa.eu/ds_resolveuid/CF1HVRI8Y7

[239] The Mayor, (2020). https://www.themayor.eu/en/a/view/lodz-launches-waste-segregation-search-engine-4172

[240] City Strategy Bureau, 2017 https://rewitalizacja.uml.lodz.pl/files/public/dla_biznesu/doc/Destination_Lodz.pdf

5.1.1 *Availability of municipal bio-waste as feedstock*

According to the annual report of municipal waste management, in 2018, 236,560.8 t of municipal waste was collected from property owners and 3,719.1 t at selective collection points.[241] In comparison, in 2014, 213,015.7 t municipal waste was collected from households and 1,580.4 t at selective collection points. In 2018, the compost facility handled 6,311.9 t biodegradable waste (12,551.2 t in 2014). As regards household waste, 162,963.7 t waste was unsorted, representing 70.4 % of all collected waste. The biodegradable waste including food waste was representing 21,2 % of the total collected waste (28,312.64 t). In comparison in 2014 it was 24,001 t. The reported data clearly shows that the rate of selectively collected waste is growing as well as an increasing collection of biodegradable waste, thus potentially available for further processing. The below graph presents the share of waste categories in overall mass of municipal waste in 2014 and 2018.

Table 46. Breakdown of the bio-share of municipal solid waste in tonnes generated for Lodz for 2014 and 2018. Source: Analiza stanu gospodarki odpadami komunalnymi w Łodzi za 2014,2018 rok.

Year	**2010**	**2014**	**2018**
Biodegradable kitchen and canteen waste	-	20,395	22,097
Organic waste	2,730	3,156	6,216
Total	**-**	**23,552**	**28,313**

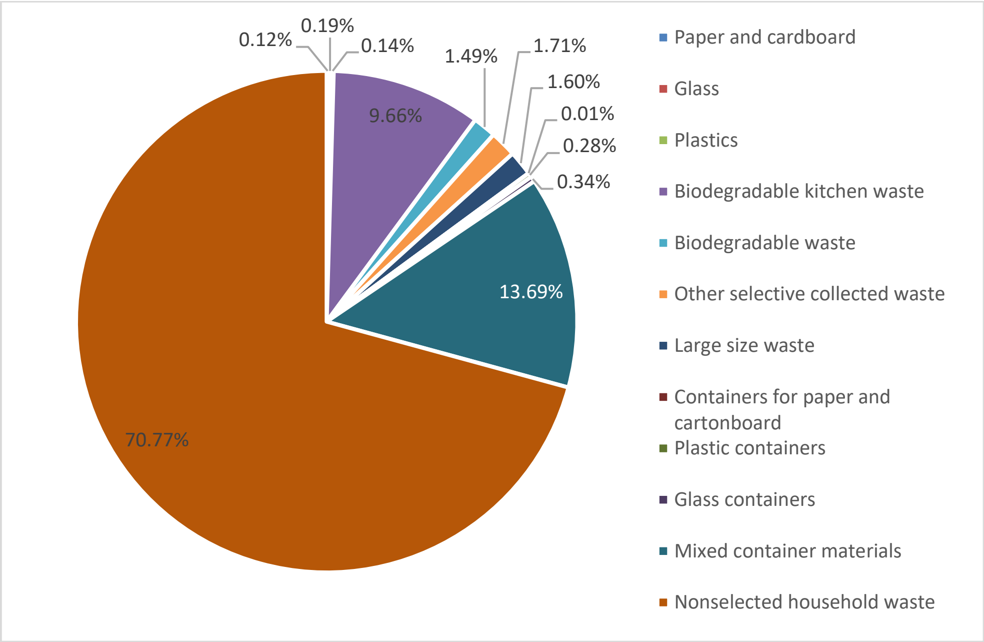

Figure 53. Composition of non-recyclable fraction of household waste in 2014. Source: Analysis of the state of municipal waste management in Łódź in 2014, published in April 2015.

The latest data on the structure of solid waste received from the townhall of Łodź can been seen on the graph below.

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[241] The annual report of municipal waste management contains data on the amount of collected expired drugs, mercury thermometers, used electrical and electronic equipment, batteries and accumulators, data from composting plants on the amount of green waste received and data on the amount of municipal waste collected from city.

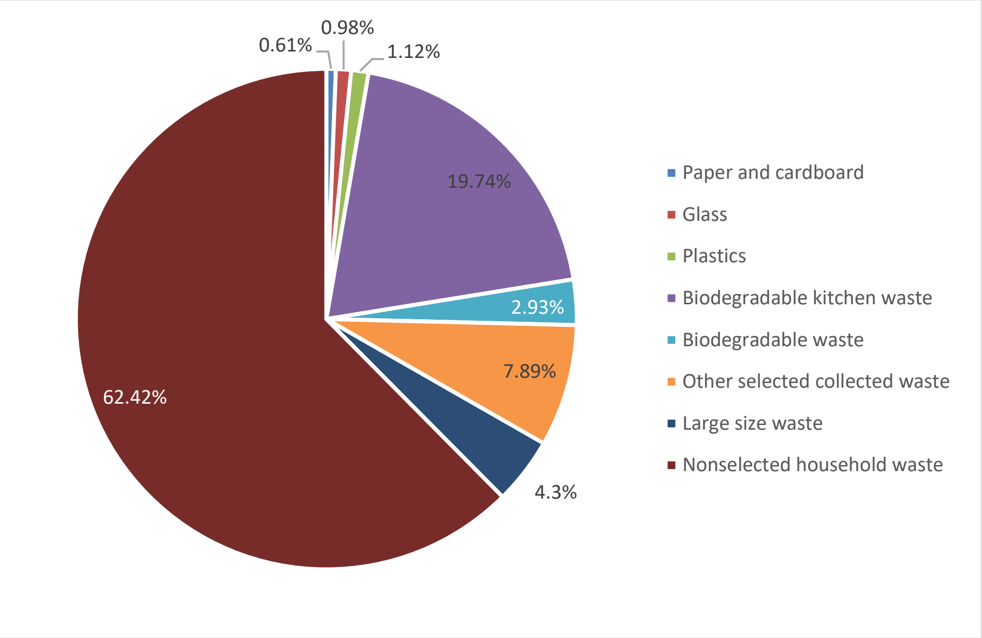

Figure 54. Composition of non-recyclable fraction of household waste in 2018. Source: Analysis of the state of municipal waste management in Łódź in 2018, published in April 2019.

5.1.2 Availability of municipal wastewater sludge as feedstock

The wastewater sludge data for Łodź is thorough and reported through the government statistic database, BDL[242]. The data is broken down within the categories of environmental protection, municipal wastewater cleaning data, then into production of sludge in tonnes of dry matter. The data for 2010, 2014, and 2019 (latest available) are presented in the table below. The sludge data includes both thermally transformed and temporarily stored sludge. The small spike in tonnes over 9 years could possibly point to an increase in the benefits of using sludge for biogas or bio-products. In 2003, Poland developed and put into practice the National Urban Wastewater Treatment Programme (NUWTP) and in 2016 the EU passed a directive prohibiting the landfilling of sewage sludge. Up until 2016 21% of sewage sludge was landfilled meaning that Poland is in the process of finding new disposal methods for the remainder of the sewage sludge.

Table 47. Volume of wastewater sludge for the municipality of Łodź for 2010, 2014, 2019.

Year	2010	2014	2019
Wastewater Sludge (dry matter, t)	14,623	14,110	17,374

5.2 Valorisation of Biological resources

5.2.1 Background information on the local waste management system

Since 2012, waste management in Łodź is divided into five zones for the provision of municipal waste collection services from households. The operators got the lease based on the open procurement procedure. In general, the outcomes of the procurement show the combination of the operators for private and municipal companies. Each of the zones has dedicated a different operator. Two of the zones were managed by a municipal company and three were managed by private companies.

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[242] BDL: https://bdl.stat.gov.pl/BDL/start

Since 1st of July 2018 Łódź has implemented the 5-container system of selectively collecting waste (mixed, paper, plastics, biodegradable, glass).[243]

The households must pay an individual waste fee that covers the collection of the waste. From December 2019 the municipal council has increased this fee: for selected waste the payment is equal to PLN 24 (approx. EUR 5.2) and for unselected PLN 48 (approx. EUR 10.5) per month. The municipal waste management is supervised and financed by self-government which includes setting the level of payment for collecting the waste from the city area.

From the collected fees, the city covers the costs of collection, transport, collection, recovery and disposal of waste, creation and maintenance of Selective Waste Collection Points, environmental education, removal of illegal dumps, and administrative service of the system.

In the city, there is a sorting plant with a shipment station managed by a municipal company and a municipal composting plant managed by the city's budget plant. In addition, the city built four Selective Waste Collection Points, which are managed by the city's budget plant. In the city-owned installations, bulky, selectively collected and green waste are managed. Waste remaining after segregation and bio-kitchen waste are managed in commercial installations located in the country. Cars transporting waste are powered by traditional fuel.

In terms of wastewater the payment is attached to the use of the household's cold water. The wastewater system is operated by the municipal company dealing with Water Supply and Sewage and operates a water treatment plant.

The system of bag fees (recycling payment) is functioning in Poland since and it is regulated by the state. Service points and shop owners are responsible to collect the fee and transfer it to the state budget. Thus, the self-government does not receive any direct income for this fee.

Łódź has introduced a new waste collection system in mid-2018 in response to the new national regulation which increased number of sorting fractions form three up to five, introducing the obligation to sort the solid waste. The city council is establishing the payment for waste collection. The last change of the waste collection regulation entails a relatively high rise of these payments that bring no social satisfaction.

The local household waste management process consists of six elements:

- **Sorting, pre-collection -** Household waste is sorted prior to collection into paper and cardboard, plastics and metals, glass, biodegradable (food waste and green waste) and residual (mixed) waste. The waste collecting entities are obligated to deliver the dedicated containers or bags for waste collection. Furthermore, large scale waste (i.e old furniture) is also collected separately. The waste electronical equipment is being collected in the dedicated collection points free of charge. Citizens are obligated to dispose their construction waste themselves and cover the additional costs. Incorrect separation of household waste can lead to fines equal to doubled payment for the waste collection.

- **Collection -** Waste collection is carried out though a “door-to-door” system for single family houses and surface container systems for condominiums, according to a fixed schedule. The collection of waste is provided to households living in single and multifamily buildings, real estates that are not inhabited but generate solid waste (i.e offices), country houses and recreational areas (within the city borders).

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[243] Based on the resolution of the Minister of the Environment of December 29, 2016 on the detailed selective method collecting selected waste fractions.

- **Sorting, post-collection -** The companies which are operating in Łódź have their own sorting facilities called PSZOKs (points of selective collection of municipal waste) or composting facilities. Łódz has currently 3 PSZOKs.

- **Destination -** The solid waste collected from property owner's solid waste such as: paper, glass, plastics, metals and biodegradable waste are sent for cleaning or sorting in sorting plants, and then for recycling.

Based on the resolution of the Minister of the Environment from December 15th, 2017 on reducing the deposition of biodegradable waste on landfills in 2018 to only 40% (in 2020 will be 35%). Łódź is fulfilling this requirement with a level of 29.68%.

According to the of the solid waste management in Łódź, 30% is required to be recycled in 2018. The Municipality has achieved the 35.8% of collected solid waste that were selected and sent for recycling.

Green waste is directed to installations for the treatment of selectively collected green waste and the production of fertilisers from them. Biodegradable waste from households and waste remaining after segregation are transferred to installations for mechanical and biological treatment of municipal waste and separation from the mixed municipal waste fractions suitable in whole or in part for recovery.

The Townhall of Łódź representatives are not taking part in managing those installation therefore they have no knowledge on the business model used by these installations to profit from the separation of bio-waste streams.

5.2.2 *Description of currently used and potentially available (ready to implement) technologies*

The biodegradable waste is being composted for fertiliser production. Biodegradable waste is directed to the installation where it undergoes composting processes in piles and in specialised chambers. Biodegradable kitchen wastes are transferred to installations where they are initially subjected to sorting processes and then to disposal processes (recovery or disposal).

Łódź has one water treatment plant with the capacity expressed in population equivalent to 978,585. The water treatment sludge processed under the methane fermentation in closed fermentation chambers. The biogas is burned in the energy aggregates (3 items with 0.933 MW installed capacity each). The post fermented sludge is dried and burned. The energy is used for the water treatment process. The installation for managing the sludge has a capacity of 80,000 Mg per year.

There are some research projects conducted by the Technical University of Łódź on bio drying of the wastewater sludge. This practice would lead to get a dry matter of the sludge, and more importantly, the category of the waste can be changed which would lead to wider utilisation possibilities of the sludge.

5.2.3 *Existing support from research organisations and other stakeholders*

One of the main platforms in Łódź is the 'Bioenergy for the Region' cluster, which has 84 members. The cluster covers sustainable development and regulation of the biomass market in Central Poland. The members include companies, SMEs, research institutions, as well as local authorities in order to promote the collection, processing and use of biomass. The cluster is coordinated by CBI ProAcademy, which is a non-profit research institution and has carried out numerous projects in the bioeconomy sphere. Among these projects is SUPERVALUE, which assessed the feasibility of a small bio-refinery based on supercritical water gasification (SCWG) process to transform wet waste from the agri-food industry. The project combined the work from CBI, TUDelft and Freshworld.[244]

The BioNanoPark is another hub for biotechnology research and innovation. It acts as a readily available laboratory for companies that do not want to invest their own R&D into laboratory testing or building. The park can support businesses that may be lacking in the testing stage of their research process; it is a tool for collaboration as many different ideas are developed and tested in the park. While no bio-waste projects are being developed there currently, it could still play a role in the development of biotechnologies in the region.[245]

The European Bioenergy Congress established in 2016 is one of the largest bioenergy conferences in central and Eastern Europe. It takes place annually in Łódz. Each year the conference brings together hundreds of participants from all over Europe including local governments, business representatives as well as NGOs. In 2018 the topics were focused among other things, around modern technologies in bioeconomy and digitisation.

5.2.4 *Legal environment, enablers & barriers*

The Polish government has adopted the roadmap for Circular economy on September 10th, 2019. The document contains the list of legislative tools which will create a proper ground for the implementation of the circular economy concept.

There is no local strategy for the Łódzkie region focusing on circular bioeconomy however the concept of the bioeconomy is emerging in many strategic documents guiding the paths of development for the regions.

The region of Łódź has become a leader in developing the circular economy already in 2015 when the regional parliament established the Region of Łódź as the first bioregion in Poland. A bioregion signifies the transformation of the region into one where the sustainable bioeconomy is a strategic and integrated approach. Further the first International Bioeconomy Congress was held in October 2016. This was a real acceleration of the development and proposing the circular economy principle in the region and in city of Łódź.

From the information gathered from interviews with NGOs and research organisations the cooperation in the region seems promising. The townhalls and the self-government of the region are involved in different events prompting bioeconomy and circular economy. According to one active stakeholder (NGO), the wheels promoting the bioeconomy in the region are turning and aiming in good direction. Also, the National Centre of Research and Innovation promotes and provides grants to the development of the bioeconomy.

The most important enabler in the context of Łódź is increasing awareness. Only with getting acceptance of society the bioeconomy will be developing in the region and in the country.

The important element might be the development of a pilot installation that might trigger familiarisation of the principles of bioeconomy. Currently the social acceptance for bioeconomy and transformation of household waste is relatively low, which is blocking the rapid growth of the concept.

There is a set of possible incentives that could be implemented by national government to stimulate the development of the bioeconomy, i.e. tax exemptions, or green procurement schemes, adjusting the legislation to the current challenges of the bioeconomy

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[244] http://www.proakademia.eu/projekty/100.html

[245] http://bionanopark.pl/en/about-us/

stakeholders and alleviation of barriers. However, the concept of bioeconomy is still not on the top priority list of the Polish government.

Other set of measures would focus on increasing the level of awareness or changing the lifestyle. This would also include the responsibilities of producers to take active role in the development of the bio-waste circle.

From an industry perspective the larger barrier is the lack of certainty on supply site. There are not proper systems for estimation and ensuring flow of the bio-waste to the processing plant. This is an important factor that halts the industry from investing in plants. Furthermore, the bio-waste streams should be carefully distinguished creating the opportunity for better assessment of the volume and quality of the waste that would be subject of procession.

5.3 Valorisation of Biological resources in 2030

5.3.1 Future management of the waste streams in 2030

The digitalisation and automatisation of processes will be important factor to the development of the concept alongside with adjustments in logistics, e.g. increasing efficiency of the storage facilities.

There is no fully operational pilot site with biorefinery yet. Constructing such an installation would bring new opportunities for transforming the bio-waste contributing to promotion and familiarisation of the bioeconomy concept in country.

A private company operating on the Łódź waste management market has completed the project of extension of a mixed waste sorting plant with a biological part (tunnel composting plant for processing the biodegradable fraction of municipal waste produced in the existing mechanical part of the installation). At the moment of preparing this report efforts are underway to obtain all necessary permits to enable the operation of the installation.

6 Case Study on the city of Maribor

Maribor is the second largest city in Slovenia located on the Drava River near the Austrian border. Maribor is the capital of the Štajerska region and is surrounded by the Pohorje wine-growing area, which is home to the oldest vine in the world. The Pohorje region is a major producer and exporter of wine. With regards to the environment, the country and the region surrounding Maribor have multiple national parks and Slovenia has a long history of nature management and protection; 56.9% of the sea and land in Slovenia is under nature protection measures. Maribor is also participating in a strategy for the transition to circular economy within seven sectors starting in 2018.

Table 48. General information on Maribor.

City	Maribor
Country	Slovenia
Geographical location	148 km² (2019)
Population	112,095 (2019)
Population density (inhabitants per km²)	760

GDP in Podravska region[246] (Million EUR, fixed exchange rate)	5,749
GDP per capita in Podravska region (EUR, current exchange rate)	17,838
Green urban areas (%, Area)	7,93 % (11,688,769 m²)
Number of operating research centres promoting the bioeconomy	E.g. Wcycle Institute, Tecos (technology centre), etc.
Sources: - Statisticni Urad Republike Slovenije (n.d.), SiStat. Available at: https://pxweb.stat.si/SiStatDb/pxweb/sl/40_Splosno/40_Splosno__26_kazalniki__10_26400_SLO_pomemb_pregled/2640010S.px/table/tableViewLayout2/ - Wcycle Institute Maribor (2018), Strategy for the transition to circular economy in the municipality of Maribor. Available at: https://wcycle.com/wp content/uploads/2018/10/STRATEGY-WCYCLE_final.pdf - Mestna obcina Maribor (2015), Trajnostna urbana strategija Mestne občine Maribor. Available at: http://www.maribor.si/dokument.aspx?id=28079	

6.1 Analysis of the municipal waste generation scheme, trends, and future milestones

The tables and a graph below present the data regarding the municipal waste in the City of Maribor. Table 49 shows that in 2018, 419 kg of municipal waste was generated per capita, and that around 61% of waste was collected separately. 27% of municipal bio-waste is being recycled through digestion and composting.

Table 49. Data on municipal waste generated in the City of Maribor (for year 2018)

Indicator	**Year 2018**
Amount of municipal waste generated	419 kg per capita
Municipal waste that is collected separately	61.3%
Municipal waste sent to landfill (or other forms of disposal)	38.7%
Municipal waste sent for energy recovery	0%
Municipal bio-waste that is being recycled (through digestion and composting)	27%

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[246] There is no GDP information aggregated at the level of cities in the Republic of Slovenia. The lowest level is the statistical region. Municipality of Maribor is located in Podravska region.

The Figure 55 and Table 50 show the quantities of four main waste groups (residual waste[247], bulky waste, bio-waste and separate collected waste) collected annually in the City of Maribor.[248]

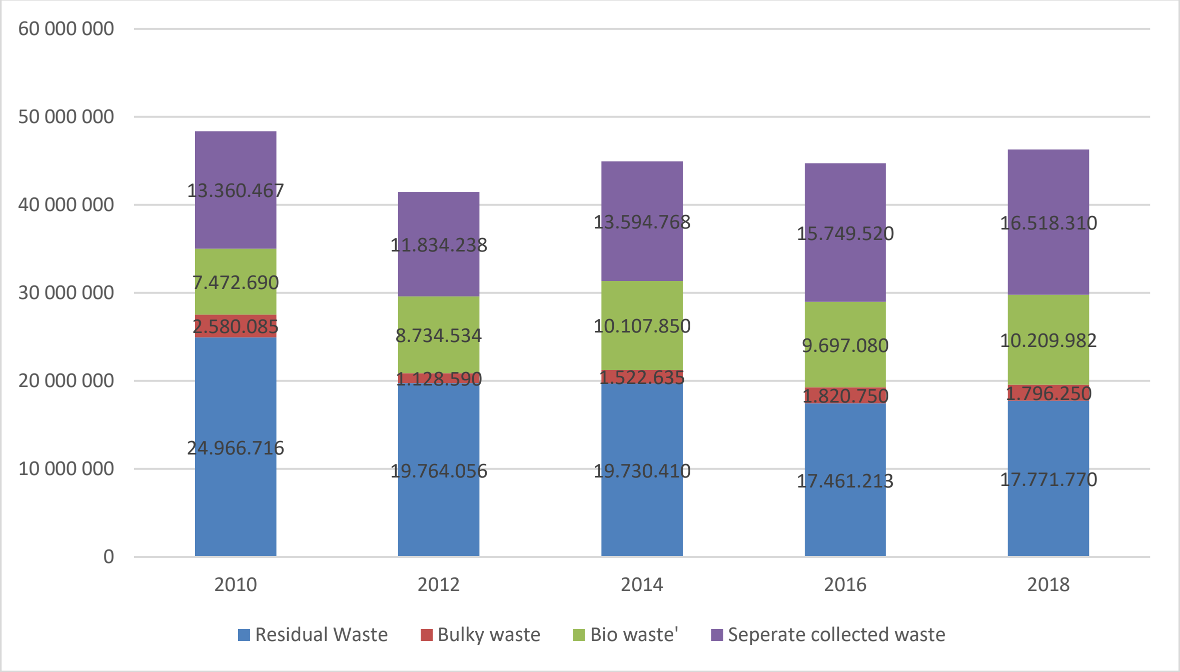

Figure 55. Collected municipal solid waste in Maribor, shown in four main waste groups. Adapted from: Snaga d.o.o. (2018)

Table 50. Collected municipal waste in households (in years 2010, 2014 and 2018). Source: Snaga d.o.o. (2020).

Waste Groups	**2010**		**2014**		**2018**	
	Quantity (kg)	Share (%)	Quantity (kg)	Share (%)	Quantity (kg)	Share (%)
Residual waste	24,966,716	51.6	18,730,410	43	17,841,690	38.4
Bulky waste	2,580,085	5.3	1,522,635	3.5	1,800,330	3.9
Biodegradable waste	7,472,690	15.4	10,107,850	23.2	10,246,422	22
Separately collected waste fractions[249]	13,360,467	27.6	13,594,768	30.3	16,571,045	35.7
Total	**48,379,958**	**100**	**43,576,879**	**100**	**46,459,487**	**100**

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[247] Residual waste is waste left from household sources containing materials that have not been separated.

[248] The graph in Figure 55 does not show a complete picture for the year 2018, as it was made before the final statistics was developed for the year 2018.

[249] E.g. all types of packaging waste, all types of electrical and electronic equipment, plant protection products, waste car tires, paper, metals, flat glass, wood, fractions of hazardous waste, etc.

6.1.1 Availability of municipal bio-waste as feedstock

The information regarding the municipal solid waste is presented in the previous sub-heading. The table below summarises the information regarding the quantity of the bio-waste for the years 2010, 2014 and 2018.

Table 51. Collected municipal biodegradable waste. Source: Snaga d.o.o. (2020).

Year	Quantity (kg)
2010	7,472,690
2014	10,107,850
2018	10,246,422

6.1.2 Availability of municipal wastewater sludge as feedstock

The data regarding the wastewater sludge is available only for the most recent years. The table below describes the quantity of wastewater sludge for the years 2017, 2018 and 2019.

Table 52. Quantity of wastewater sludge (in years 2017, 2018 and 2019). Source: Energetika Maribor (2020).

Year	Quantity (kg)
2017	12,974.26
2018	12,212.06
2019	13,093.88

6.2 Valorisation of Biological resources

6.2.1 Background information on the local waste management system

In Maribor, waste management is embedded in a wider circular economy model, as established with the Strategy for the transition to circular economy in the municipality of Maribor.[250] The strategy was recognised in the study by the European Economic and Social Committee as inspiration for future strategies as regards degree of inclusiveness based on thematic focus and partnerships.[251] It is a holistic strategy that includes the vision to transition to a circular economy, promotes fair access to goods and services, as well as encourages sharing and more resource efficiency, rather than ownership and linear material flows.[252] The strategy was published in 2018 by the Wcycle Institute as a result of a strategic development project in the field of integrated management of all waste generated in the region on the basis of circular economy policy, energy and water management and the use of processed waste as a new resource.

The draft model of circular economy for Maribor has been developed in 2015, and was presented first time to the public in Sustainable Urban Strategy of the Municipality of Maribor in 2016.[253] Further development of the model has been closely linked to the

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[250] Wcycle Institute Maribor (2018), Strategy for the transition to circular economy in the municipality of Maribor. Available at: https://wcycle.com/wp-content/uploads/2018/10/STRATEGY-WCYCLE_final.pdf

[251] European Economic and Social Committee (2019), Circular economy strategies and roadmaps in Europe: Identifying synergies and the potential for cooperation and alliance building. Final Report.

[252] EIT Climate KIC (2019), Municipality-led circular economy case studies. Available at: https://www.climate-kic.org/in-detail/municipality-circular-economy-case-studies/

[253] See https://www.smartcitymaribor.si/en/Projects/Smart_Living_and_Urban_Planning/Sustainable_Urban_Strategy_of_the_Municipality_of_Maribor_TUS_MOM_/#:~:text=for%20its%20residents.-,Sustainable%20urban%20strategy%20of%20the%20Municipality%20of%20Maribor%20(TUS%2DMOM,

Interreg AS Project Greencycle that was approved in the same year. At that time, these processes were led directly by the Maribor City Council, working closely with the public utility companies who founded the Wcycle Institute in 2017:

- Snaga d.o.o. – public waste management company
- Nigrad d.d. – public utility company
- Energetika Maribor d.o.o. – public energy company
- Mariborski vodovod d.o.o. – public water company
- Marprom d.o.o – public transport company

Besides the circular economy strategy, the Wcycle Institute developed an action plan establishing 18 joint projects for the Maribor City and public utility companies in 7 strategic project areas as the pillars of circular efficient resource management in the transition of the city of Maribor into circular economy:

1. Treatment of municipal waste and associated services
2. Use of processed construction and demolition waste and soil in urban construction
3. Managing surplus heat and renewable energy
4. Sustainable mobility - urban transport and joint service
5. Reuse of recycled water and alternative water resources
6. Sustainable management of land and regeneration of degraded areas
7. Cooperating economy network

Individual projects from the action plan are already being implemented through individual project activities, some are ready for implementation, and the remaining ones are still in the conceptual design phase. The operators for specific project pillars are the companies owned mostly by the municipality, which are already carrying out public services for the citizens.

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economic%20development%20in%20the%20EU.&text=This%20is%20oriented%20towards%20the,through%20investments%20in%20urban%20themes.

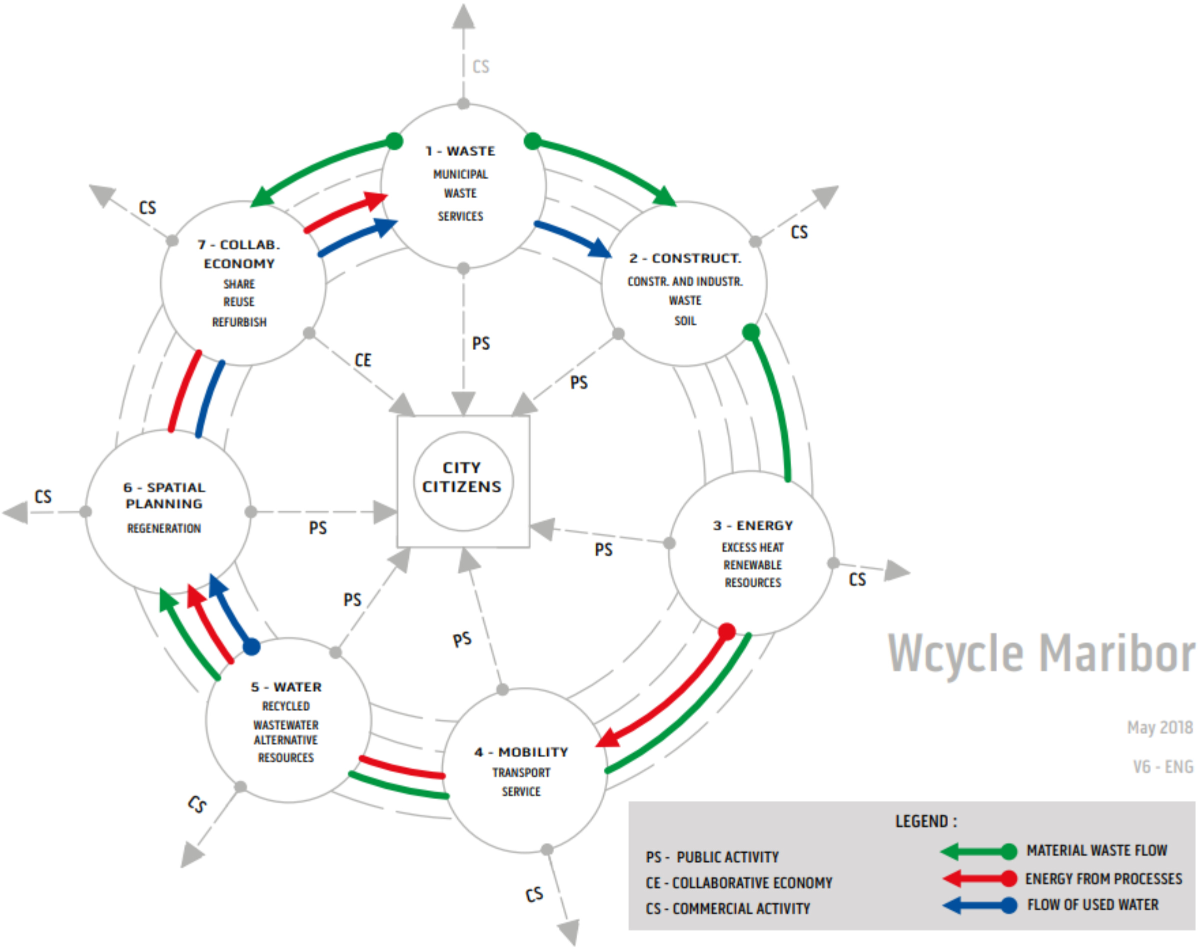

Figure 56. Horizontal organisational model of the Wcycle project with 7 pillars of circular efficient resource management. Source: Wcycle Institute Maribor (2018), Strategy for the transition to circular economy in the municipality of Maribor.

One of the public utility companies is Snaga Maribor, a 100% publicly owned utility company with concession rights to carry out activities related to municipal waste management in Maribor and adjacent municipalities. In 2015, the company adopted the Municipal Waste Management Strategy, which is aligned with the concept of circular economy. Currently, the strategy is being updated and a new version is expected to be published by 2021. The main strategic objectives will include complete separation of the household waste, development of the waste management collection system based on the modern information and communication technology, electronic data collection, the use of sensors, etc.

The municipal waste collection is financed through pick-up fees. The bill for users depends on the volume of a trash bin/ container and the frequency of the waste transport. Households can choose between two different volumes of a container (120 litres or 240 litres) and exceptionally, they can choose a smaller-sized container (60 litres) in case of a one-person household. In the case of multi-apartment buildings, the volumes of the containers are 770 litres and 1,100 litres. The weekly pick-up fees are presented in the table below.[254]

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[254] See Snaga d.o.o. (2020). Fees. Available at: https://www.snaga-mb.si/ceniki/

Table 53. Pick-up feed (weekly transportation). Source: Snaga d.o.o. (2020).

Volume of a waste bin/ container (litres)	Weekly pick-up fee (EUR, incl. VAT)
60	17.45
120	34.91
240	69.82
770	223.99
1100	320.01

In the last one and a half years, the waste collection fees slightly increased following the increase of costs regarding the mixed municipal waste (residual waste) in international markets. The reduction of billing volume in the recent years has also affected the financial performance of the company. As waste separation at source has been improving (at least in theory and statistics), users tend to choose a smaller container to collect the residual waste, which is the main basis for the calculation of waste management costs.[255]

The city is aiming at digitalization of the whole process, in order to ensure also weighing of the waste. The objective is to shape a bill based on the weight of the waste in each bin, ensuring that users producing more waste pay a higher price.

Every household or residential building has two waste bins coloured in different colours. Residual waste is collected in a black bin and biodegradable waste is collected in a brown bin. Moreover, the so called 'ecological islands' or waste destinations are spread across the city, where three categories of waste are collected: paper & cardboard, glass packaging and waste packaging.

Bio-waste originates in households and from maintenance of urban green spaces (i.e. mowing of grass and pruning). Food is considered as organic waste, however there is a special system arranged for restaurants. Restaurants collect separately any excess food and oils used for cooking. This waste is then handed over to companies which process it.

Regarding other categories of waste, there are different collection solutions. For instance, there is a possibility to deliver bulky waste to numerous waste collection centres in the municipality. Once per year, a household may also request from Snaga Maribor a pick-up of bulky waste in front of their home. The company cooperates with a local NGO "Aktiviraj se", which manages a few 'reuse and repair centres' in the city. In these centres, they can repair collected pieces and sell them in their own shops in Maribor to prolong their life cycle. On the other hand, Snaga Maribor does not collect electronic waste. This type of waste is collected by the company Zeos from Ljubljana, specialised for handling of electrical and electronic equipment. As regards textile waste, there are specific containers across the city to collect textile. These are not managed by Snaga Maribor but other organisations (i.e. Humana d.o.o.). Citizens are encouraged to collect clothes and donate them to Red Cross and other organisations as well as to second-hand stores.

In general, the collection scheme is considered to function well, however sometimes users still wrongly use the coloured bins. Therefore, it is necessary to sort out waste once again after it is transported to waste management centres. Recently, the city established control mechanisms, such as a random check of bins to verify whether the waste is sorted out correctly. The mechanism allows for sanctions; however, these have not been so far used on a bigger scale. Instead, the city uses this mechanism mostly to raise awareness among citizens.

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[255] Snaga Maribor (2019), Annual Report 2018.

The transportation of waste collected in waste bins in public spaces is organised with electric vehicles. Other waste is collected with bigger trucks that are not alternatively fuelled.

The second stage, i.e. recycling and other processing of collected and separated waste is not organised at a municipal level. In Slovenia, there are only 2 small incinerators and there is not enough capacity to systematically deal with waste. In Maribor, incineration plants are also not considered as viable solutions, as focus should be on eliminating residual waste. Therefore, the municipality has so far handed over bio-waste and bulky waste to the best bidder selected in a public tender. The winning companies pre-treat waste in Slovenia and then export the fractions and the rest of the waste abroad for energy use and final supply.[256] Since 2018, residual waste (mixed municipal waste) is mechanically sorted, and its light and heavy fraction are then sold in a public tender.

In 2017, Snaga Maribor started to build a centre for the processing of secondary raw materials, which contains a device for a mechanical treatment of residual waste, bulky waste and packaging waste that represents one of the biggest investments in Maribor in recent years for public utility services. The plant is currently one of the most modern waste sorting plants in this part of Europe. In the mid-2018, the new waste sorting / pre-treatment plant became operational and Snaga started to direct all collected residual municipal waste to the new plant for pre-treatment. Thus, Snaga has become independent in the implementation of two of the three public services, which complete the concept of waste management (collection & transportation and treatment of waste). Due to the operation of the device, Snaga increased in 2018 the amount of pre-treated waste fractions placed on the market.[257]

Currently, the separation of waste, including bio-degradable waste, is done at source, i.e. in households. With the development of new technologies and techniques, the manual work in waste management system changes to a great extent. The new waste pre-treatment plant enables much more efficient and accurate waste separation, however, due to the current national legislation that requires waste separation at source, Snaga could so far not continued with a pilot project regarding the integrated collection of residual waste and packaging waste. A solution that would shift the separation of waste from households to the municipal plant would in the view of Snaga contribute to efficiency and decreased emissions into the air, as less logistics would be required (see previous footnote).

Other work processes are being automized and technologically upgraded (e.g. identification of containers with technology solutions such as Radio Frequency Identification, Global Positioning System, etc.). The number of employees at SNAGA is therefore decreasing due to a greater automatisation of processes.

6.2.2 *Description of currently used and potentially available (ready to implement) technologies*

Collected biodegradable waste is mostly sold to third parties, e.g. for compost purposes. The city does not have its own composting plant and most of the collected bio-waste is taken to the composting plant in Ljubljana. A currently ongoing project Urban Soil for Food in the framework of the Urban Innovative Actions (UIA)[258] has shown a potential to use organic waste for producing soil for gardens and green areas in the future. If this project turns to be financially viable, a new model for processing biodegradable waste will be implemented at the level of the municipality.

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[256] Municipality of Maribor (2015), Proposal for consideration at the 5th session of the City Council of the Municipality of Maribor: Information on the situation and the waste management strategy. No: 35900-8/2015-4

[257] Snaga Maribor (2019), Annual Report 2018.

[258] See https://www.uia-initiative.eu/en/uia-cities/maribor

The project Urban Soil for Food researches the possibilities to mix the soil taken form the construction sites with organic waste collected in the city. The main objective is to use the municipal waste to produce and valorise new products using an innovative process to produce urban soil, with the aim to increase local food self-sufficiency and minimise the environmental footprint of the city. The project started at the end of 2017 and is expected to be completed by the end of 2020. It is 80% co-financed by the European funds.

The project partners will develop a safe and certified soil with by-production of energy. The technology will be based on two process, pyrolysis and fermentation. The tests have so far shown that the mixture can turn into a fertile soil that can be used for gardens and maintenance of green areas. The project will be backboned with two key investments: the establishment of a pilot system for urban soil production and the establishment of four urban gardens with the urban soil produced.

The Maribor wastewater treatment plant was built by public-private partnership at the beginning of 2000 and became fully functional in 2002. The partnership was concluded during the years 1996 and 1997. The contract with the private partner will expire in 2024 and from that date onwards, the treatment plant will pass into the ownership of the Municipality of Maribor and its public utility company (i.e. Energetika Maribor), who will be responsible for the management of the plant.

In the last years, the sewer system in Maribor was upgraded. In 2002, when the treatment plant became operational, not all settlements were connected to the system and therefore treatment of urban wastewater was limited. The treatment plant currently ensures adequate standards for all relevant treatment stages, as provided in the Urban Wastewater Treatment Directive. However, in order to be able to further reuse wastewater (e.g. for field irrigation), the plant must be upgraded with higher level of treatment stages.

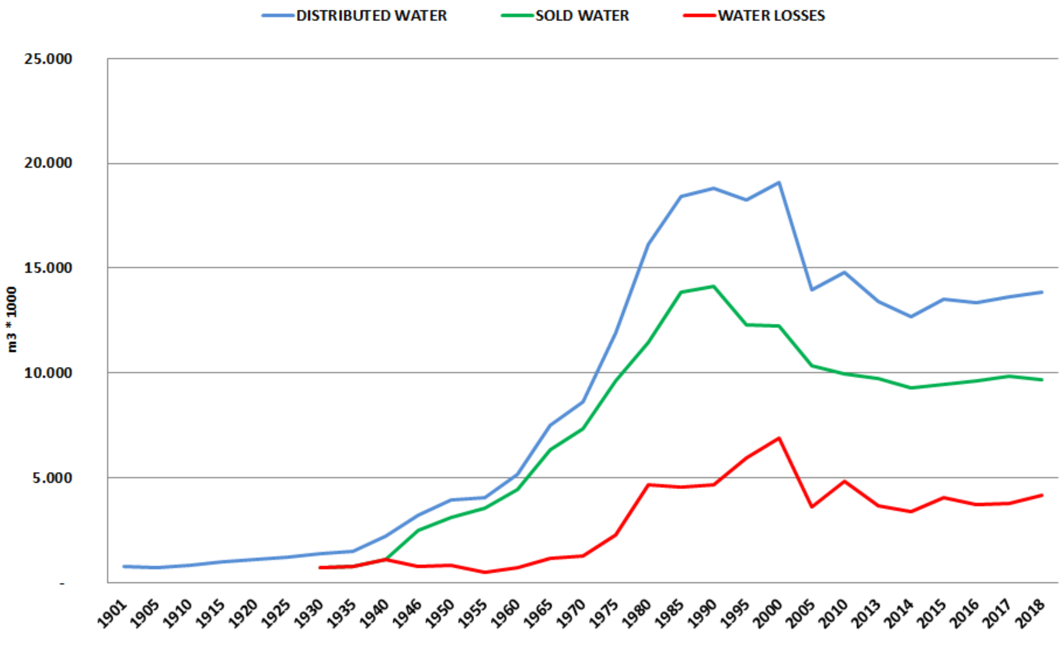

Figure 57. Distributed, sold water and water losses in Maribor over the years. Source: Wcycle Institute (n.d.).

Each year, approximately 10 million m³ of water enters the system for authorised consumption, two thirds of which represent authorised billed consumption (the share of unbilled consumption is negligible). Water losses represent approximately one third of water entering the system. In 2019, 10.16% of wastewater was reused for the purpose of seepage, collection, spillage, garden irrigation, etc. Only recently, the EU legislation[259] was adopted that promotes and encourages water reuse, also in industrial purposes. The city has already developed a model that will in the future allow reuse of treated water, for industrial purposes but also maintenance of green areas, given that the treated water meets the established requirements in the EU Directive. As can be seen in the figure below, the consumption of drinking water has been falling since 2000 due to citizens' awareness and the reuse of processed water for technological purposes. The citizens and companies are now more than ever aware of the importance of sustainable treatment of natural resources.

The responsibility for the management of sludge lies with the utility company Energetika Maribor. The collected sewage sludge is then handed over to a private company and transported abroad (e.g. mostly to Hungary). Due to very low prices of sludge, any other treatment of sludge has been commercially less interesting in Slovenia. In the past year, this has been slowly changing because Hungary has limited the import of sludge. Consequently, the prices have increased, and it has become more interesting to test different solutions for re-use of the collected sewage sludge in Slovenia. Such considerations must take into account careful treatment due to dangerous components of sludge, e.g. heavy metals and other solids. The Wcycle Institute is currently working together with the Slovenian National Building and Civil Engineering Institute on solutions to reuse wastewater sludge in construction.

6.2.3 Existing support from research organisations and other stakeholders

The Strategy for the transition to circular economy in the municipality of Maribor includes a whole section on collaborative economy. The non-governmental sector is very active in the cooperative economy in Maribor and in the past years, an entire network of cooperative economies has been established with new business models aiming at promoting the concept of shared economy. The municipality provides support to such initiatives according to the applicable legislation. The strategy highlights that it is necessary to ensure conditions for a bottom-up approach and to promote cooperative business models that can lead to an urban laboratory, where solutions can be tested for a daily use.

Since the beginning of its establishment, the role of the Wcycle Institute has been to coordinate the research departments within the founding public companies. The goal is to define development needs for specific companies and to determine possible common grounds and better cooperation among them. The Institute has acted as a development platform, investigating possibilities to ensure synergies and develop joint projects. The coordination activities have resulted in an action plan, laying out plans for implementation of 18 projects.

The Institute is functioning also as a consultancy, providing support in applying for tenders, as well as discussing possible systemic financial solutions, in the framework of financial instruments or other sources. Moreover, the Institute supports the implementation of the ongoing projects, either as a partner, a consultancy or an external expertise centre. The members of the Institute have so far successfully cooperated with and connected numerous stakeholders, including at a municipal and government level, national research institutes (e.g. Jožef Stefan Institute), platforms (e.g. Circular Change), NGOs, private and public companies, etc. The Wcycle Institute is run by a team of 5 people, including a PR expert, who recently joined the organisation to expand the awareness raising activities of the Institute. The Institute is not financed by the Municipality of Maribor and must ensure financial sources through its own project work. In the last 3 years, it has won around 10 projects, co-funded by the EU.

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[259] REGULATION (EU) 2020/741 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 May 2020 on minimum requirements for water reuse.

The work of the Institute includes different cooperation activities, including involvement in international partnerships, e.g. Urban Agenda Partnership for Circular Economy, which has been developing circular economy models for cities. The work of the partnership has been feeding into the European processes such as Circular Economy 2.0 and European Green Deal. Additionally, the Institute took part in the ESPON Targeted Analysis 'Stocktaking and assessment of typologies of Urban Circular Collaborative Economy initiatives (SHARING)'. Together with other city's stakeholders the Institute is involved in several EU and cross-border projects, such as the project Urban Soil for Food, the Greencycle project within Interreg Alpine Space and CINDERELA project[260] (New Circular Economy Business Model for More Sustainable Urban Construction). The latter will develop new circular business models for sustainable construction. Moreover, the municipality is profiting from several other European projects, including the project WinPol, which focuses on intelligent equipment and related waste management policies.[261]

The example of Maribor shows that international cooperation may be carried out at different levels and with different tools. It brings opportunities that may arise in the basis of some characteristics related to e.g. size of the urban area, similar industrial and economic environments, etc.[262]

6.2.4 *Legal environment, enablers & barriers*

The Strategy for the transition to circular economy in the municipality of Maribor itself is integrated within the national circular economy strategy of Slovenia. Both strategies were developed in parallel and the Wcycle Institute was involved in both processes. The strategy is also linked to Maribor's Sustainable Urban Development strategy. All these strategic documents are included in a wider national, regional and global circular economy system, based on several regulatory starting points and (binging) documents:

- Directive 98/2008/EC on waste,[263] defining the hierarchy of waste management on the basis of a circular economy in terms of waste prevention, waste reuse, recycling, other use of waste and their disposal.

- Directive 2014/25/EU on public procurement,[264] which allows public contracting authority to make the award criteria do not merely reflect the lowest price, but also the best relationship between quality and price, including environmental and social aspects, giving the public authority a legal basis for the purchase of goods or services in accordance with the principles of a circular economy.

- Environmental Protection Act,[265] which states in its Article 7 that any encroachment on the environment must be planned and carried out in such a way as to minimise the burden on it, which requires the use of best available techniques. Any regulations relating to the management of waste must be designed in line with the principles of a circular economy.

- Public Procurement Act,[266] which reflects the public procurement criteria in Directive 2014/25/EU.

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[260] See https://www.cinderela.eu/The-project/Partners/Nigrad-d.d

[261] See https://www.interregeurope.eu/winpol/

[262] European Economic and Social Committee (2019), Circular economy strategies and roadmaps in Europe: Identifying synergies and the potential for cooperation and alliance building. Final Report.

[263] Directive 2008/98/EC, (2008). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0098

[264] Directive 2014/25/EU, (2014). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014L0025

[265] See http://pisrs.si/Pis.web/pregledPredpisa?id=ZAKO1545

[266] See http://www.pisrs.si/Pis.web/pregledPredpisa?id=ZAKO7086

- An EU Action Plan for Circular Economy,[267] comprising a package of measures to promote competitiveness, job creation and sustainable growth in the context of the transition to the circular economy system.

- Green Public Procurement and the EU Action Plan for the Circular Economy,[268] which represents the basis for the promotion of green public procurement.

- Inception Impact Assessment - Minimum quality requirements for reused water in the EU,[269] adopted in order to promote the use of recycled water.

- Roadmap towards the circular economy in Slovenia, aiming at recognising and connecting circular practices and facilitating the transition of Slovenian economy from linear to circular.[270]

- National strategic documents, such as Waste management program and Waste prevention program of Republic of Slovenia,[271] Slovenian Development Strategy 2030[272] and Vision of Slovenia 2050[273].

- Ordinance on the manner of performing the obligatory local economic public service of municipal waste management in the municipality of Maribor[274]

At the European level, recent important guidance documents represent the European Green Deal,[275] which places the concept of circular economy at the centre of transition into a fair and prosperous society, and Circular Economy 2.0,[276] one of the building blocks of the European Green Deal. The plan inter alia requires revision of the EU waste legislation aiming at halving municipal waste by 2030.

The above-mentioned national and EU strategies and binding documents generally stimulate and strengthen the development of the circular and bio-economy at the local level, however, future development should not be compromised by legislative acts that keep certain provisions not sufficiently aligned with the technological progress. One such example is the national law prescribing separate collection of municipal waste at its source (i.e. in households), which to a certain extent might limit development activities. Namely, the new sorting/ pre-treatment plant in Maribor could be used for a much more efficient mechanical separation of residual waste, minimising the need for manual separation in households and reducing the logistics resulting from separate collection. Any integrated collection of waste is under the current legislation not allowed and the municipality cannot circumvent national rules despite these local specifics.

Additionally, the current business model has some challenges that are specific for public utility companies. As regards the pricing of mandatory public utility services in the field of waste management, the state determines the basic components of the price in the whole

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[267] See https://ec.europa.eu/commission/sites/beta-political/files/circular-economy-factsheet-general_en.pdf

[268] ENVI Committee, (2017) https://www.europarl.europa.eu/RegData/etudes/STUD/2017/602065/IPOL_STU(2017)602065_EN.pdf

[269] European Commission, (2016). https://ec.europa.eu/smart-regulation/roadmaps/docs/2017_env_006_water_reuse_instrument_en.pdf

[270] Roadmap Towards the Circular Economy in Slovenia. https://static1.squarespace.com/static/5b97bfa236099baf64b1a627/t/5c63ed7f9140b7162bf51e9f/1550052836808/kazipot_ENG_26apr_FINAL.pdf

[271] See https://www.gov.si/assets/ministrstva/MOP/Dokumenti/Operativni-programi/op_odpadki.pdf

[272] See http://extwprlegs1.fao.org/docs/pdf/SLV177135.pdf

[273] See https://www.rtvslo.si/files/novice/kako_vizija_slovenije.pdf

[274] See http://www.lex-localis.info/KatalogInformacij/PodrobnostiDokumenta.aspx?SectionID=79e74443-e716-455b-97d1-847493dac730

[275] See https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf

[276] European Commission, (2020). https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN

territory, regardless of specific characteristics of different local and rural areas in Slovenia.[277] Snaga Maribor is also 100% publicly owned and therefore, it is committed to implement contracts under public procurement rules, which limits their competitiveness. The state has been preparing a new regulation regarding long-term concessions, which promises a fairer competition between public and private companies.

The Municipality of Maribor is investing into more sustainable solutions in the area of public utility services, however development at municipal level is often hindered in Slovenia due to lack of finance. There is a need for a change at a state level to ensure a better local development.

In the recent years, the waste business has been facing problems also due to the turmoil in international market. The cost of the mixed municipal waste has been increasing, especially because of the following reasons. First, the existing waste processors in Asia have started limiting the import of waste from Europe, especially the packaging waste. As a result, the European warehouses are overfilled with collected and separated waste. Consequently, the prices for purchasing waste have dropped significantly. Moreover, the capacities of the European energy recovery companies are full and therefore, the prices of energy recovery have jumped from the former EUR 30-40 per tonne to over EUR 100 per tonne. In Slovenia, this resulted in an 80%-increase of the waste treatment costs.[278]

The global shifts and lack of finance are significantly affecting the waste management business at a local level. On the other hand, some of these challenges also represent incentives for new approaches of dealing with waste. The current research activities related to processing of sludge and the project Urban Soil for Food are positive examples that develop new solutions for valorisation of bio- and other waste.

6.3 Valorisation of Biological resources in 2030

6.3.1 Future management of the waste streams in 2030

The public utility companies which founded the Institute, together with another company that is specialised in funeral services, are now forming a City Holding, which will manage these companies as an umbrella organisation by providing joint procurement, finance, accounting and other services. The restructuring of the system also aims at introducing a common municipal bill for the citizens, where the fees of all municipal services would be merged into one. The Holding has been formally established; however, the optimisation of all work processes is expected to be completed in 2021.

The new governance structure is expected to yield positive results by the rationalization of public service management. It is expected to increase the cooperation among the Municipality of Maribor and the six mostly publicly funded utility companies and further enforce the circular economy model, by improving efficiency, cost reduction and increasing transparency.

As regards the municipal waste management, there are some changes to be expected as well. The 2015 Municipal Waste Management Strategy is currently being amended and the new version is expected to be adopted by 2021. In terms of biodegradable waste, the project Urban Soil for Food is currently testing the solutions for production of urban soil, using biodegradable waste and soil from construction sites. This flagship project in the Maribor strategy is in an advanced implementation status, also thanks to UIA financial backing. The next step is to develop a bigger-scale and if possible, a commercially viable production of urban soil for gardens and green urban area in Maribor.

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[277] Snaga Maribor (2019), Annual Report 2018.

[278] Snaga Maribor (2019), Annual Report 2018.

6.3.2 *Future available methods/technologies for processing methods for managing separated bio-waste streams in 2030.*

The main objective is a successful management of all material flows produced in the municipality of Maribor and a wider region, in the so-called 'functional urban area', which includes also adjacent settlements. The same applies to biodegradable waste. The expected business model for this resource is embedded in the project Urban Soil for Food.

Technology and innovation provide opportunities to improve policies related to waste management in a circular economy. Regarding the waste data collection, there is no digitalised system yet in place which would provide publicly accessible data on waste management that can currently be required only 'on demand'. Nevertheless, the data is being collected and a digitalisation process is underway to ensure storing the collection, analysis and presentation of data in the future. This will improve efficiency and the basis for future political decisions. The whole process is challenging, and it will take quite some time to harmonise internal systems of different companies and to build a proper common tool, useful for different users.

Snaga Maribor is currently involved in Interreg project WinPol: Waste Management Intelligent Systems and Policies.[279] The objective of the project is to improve policies for waste management in order to promote the use of intelligent systems and planning derived of it. Also, the project aims through improved management procedures and awareness campaigns at facilitating waste minimisation in European cities and regions. The key goal of the project is a meaningful change of applicable legislation with the purpose to facilitate and strengthen the implementation of the public waste management services.

6.3.3 *Description of future technological potential available (ready to implement) for bio-waste processing)*

The project Urban Soil for Food aims at production of soil using organic waste and soil extracted at construction sites. The goal of the project in the future is to introduce a large local production of soil for maintaining the gardens and green areas in the city. The expected result is reduction of biological waste (2,400 tonnes/year) and mineral waste (2,000 tonnes/year). Moreover, the project seeks to have a wider effect by changing food flows from imported to locally produced food. The objective is to establish 7,398 m^2 of new urban gardens for public use and to establish a label of locally produced food. A food chain leading from local farmer to local consumer for at least 10,000 users is foreseen.[280] In the long run, the involved partners would like to develop the currently pilot project into a commercially interesting solution if possible.

The used technology will uniquely combine two processes: fermentation and pyrolysis. The knowledge generated within the scope of the project will be shared with other stakeholders and will lead to the development of certificates and patents that will ensure international recognition for the urban soil technology.

6.3.4 *Future legal environment, enablers & barriers*

There are no significant changes foreseen in the next years as regards the strategic guidance documents. At the EU level, recently published European Green Deal and Circular Economy 2.0 will dictate the circular economy and green policies in the next decade(s).

The example of Maribor shows that close cooperation between local government, public companies, citizens and industry is an important factor for a successful interconnected system that optimises resources and economic, environmental and social results. Raising

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[279] See https://www.interregeurope.eu/winpol/

[280] See https://www.uia-initiative.eu/en/uia-cities/maribor

awareness is an important activity in order to spread the understanding among various stakeholders, why circular economy is a necessary way forward. As one of the recognised challenges for circular economy is sometimes a slow uptake of new concepts related to circular- and bioeconomy. For example, during the parliamentary session in the Slovenian National Assembly which approved the new EU legislation banning single-used plastics, certain industry representatives protested against these new rules. Shifting mentalities is a long-term process that requires enough time and resources.

An additional important enabler and/or barrier in this field is related to governance and relevant political decisions which is also closely related to shifting mentalities and awareness raising. Lastly, financial means and technological development are important elements that shape future development.

7 Case study of the city of Milan

Milan is the second biggest city in Italy with 1.4 million inhabitants, excluding the metropolitan area. With a population density of 7,700 inhabitants per km², 80% of the households live in multi-story buildings. Milan has been expanding its green space with additional plans to increase number of trees and parks in the Milan area. In 2013 green space was equal to 22 million m² and in 2018 had 24 million m².

Milan is part of the Sharing Cities Initiative and 54% of the generated waste is recycled, a result of the efficient waste collection of the city of over a million inhabitants.

Table 54. General information on Milan.

City	Milan
Country	Italy
Geographical location	Northern Italy, Lombardy
Population	Milan: 1,397,852 Metropolitan area: 4,336,121
Population density (inhabitants per km²)	7,700 inhabitants per km²
GDP (EUR)	EUR 68.5 billion (2018)
GDP per capita (EUR)	EUR 49,000
Green urban areas (%, Area)	13.2 % (24 million m²)
Number of operating research centres promoting the bioeconomy	• Together with three other Italian universities, University of Milan Bicocca offers the Master programme Bioeconomy in the Circular Economy (Biocirce) • Università degli Studi de Milano Statale, Agricultural and Food Sciences • Improvement and Protection of Mountain Environments • Food Service Science and Management • Agricultural Technology for the Environment

	- Agricultural Sciences and Technologies

7.1 *Analysis of the municipal waste generation scheme, trends, and future milestones*

7.1.1 *Availability of municipal bio-waste as feedstock*

As of 2014, Milan had the highest international recycling rate for wet waste according to the annual report for the Association of Italian Compost and Biogas Manufacturers.[281] The value per inhabitant for compost was on average around 92 kilograms and 120,000 tonnes each year prior to 2014. While the data for compost is scattered, Italy has many composting and biogas facilities making incentives for compost very high.

Table 55. Availability of municipal bio-waste as feedstock.

Year	**2010**	**2014**	**2018**
Wood waste	91,985	82,542	73,523
Garden waste	115,090	69,680	110,234
Vegetable and animal oils and fats	no data	no data	71
Biodegradable kitchen and canteen waste	Est 120,000	Est 120,000	148,991
	207,075	152,222	183,757

Since November 2012, Milan has been collecting 1.75 kg of food waste per inhabitant per week, resulting in an annual average of 90 kg per person. This figure is relatively high for a European city. About 25% stem from commercial sources and schools whilst the majority is produced domestically. In total about 130,000 t of Milan's food waste is collected separately and sent for organic recycling. Waste characterisation analyses showed that in Milan the average share of non-compostable materials in the collected food waste remains below 5% with a positive reduction trend.[282]

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[281] http://compost.it

[282] Milano Recycle City, (2016). https://issuu.com/giorgioghiringhelli/docs/food_waste_recycling_the_case_study

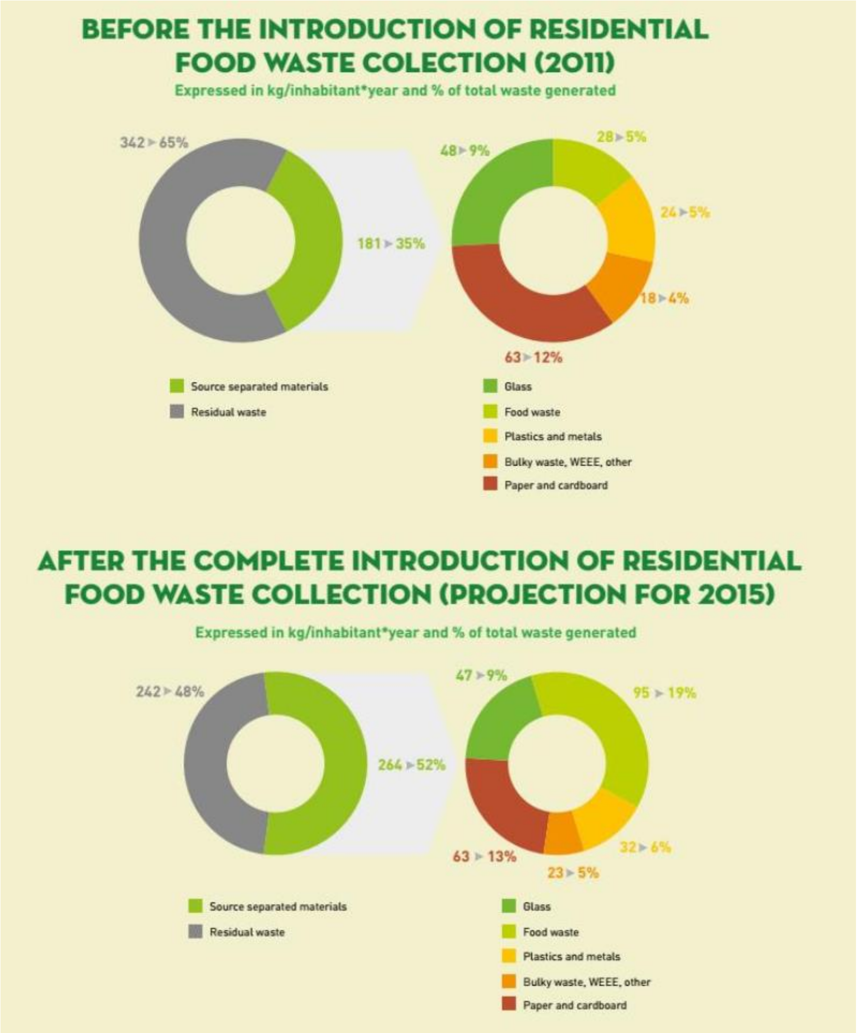

Figure 58. Waste generation in Milan before and after introduction of residential food waste collection. Source: Composti, 2019.

Given the urban structure of Milan the quantity of green waste is rather low, amounting 0.6 kg per inhabitant in 2012.

7.1.2 *Availability of municipal wastewater sludge as feedstock*

Data on wastewater sludge in Milan is nearly non-existent. There is no city-wide reports on wastewater sludge. Eurostat has data for 2010 for Italy in kilograms per capita which can be multiplied by the city population in order to get an estimate of the value for 2010. The amount of wastewater sludge produced in Milan in 2010 was equal to **43,966 tonnes** of dry matter.

7.2 *Valorisation of Biological resources*

7.2.1 *Background information on the local waste management system*

Today Milan is the second most efficient European city for differentiated waste management overachieving the goal of a 65% recycling rate (ER Waste Report 2019).[283]

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[283] Bressa R. 15.September 2016. In: lifegate. Online Resource: https://www.lifegate.com/recycling-milan-europe

The city started to implement recycling plans according to Italian recycling laws in the early 2000’s. The system is financed by the waste disposal tax *TARI*, which is the obligation of every tenant, not the owner of rented property.

Milan has signed a service agreement with the AMSA SpA, municipal company providing a mandate for the management of environmental hygiene services throughout the city. The main services include:

- Curbside collection,
- Household waste recycling,
- Cleaning and washing of the streets and public green areas,
- Emptying baskets,
- And collecting abandoned waste.

AMSA SpA forms part of A2A group and jointly with A2A Ambite, AMSA SpA is responsible for managing the integrated waste management cycle. AMSA SpA serves around 2.3 million inhabitants of Milan and 12 other municipalities. They are currently in the process of building a new plant with a EUR 400 million contract value.[284] The aim of the A2A group is waste collection and recovery of materials, recovery of energy and heat through thermal treatment of non-recyclable waste as well as 'zero landfill' for primary waste.

The market price for treating food waste in Lombardy is about EUR 70/tonne. Considering the average disposal cost for residual waste of EUR 100/tonne, diverted food waste does not only entail environmental benefits, but also pays off.[285]

To help reduce contamination and maximise recycling a mechanism of fines has been implemented.

Sorting, pre-collection

Besides food waste (brown bins), dry recyclables such as paper and cardboard (white bins), glass (green bins), and plastics and metals (yellow bags) are sorted by households. Residual waste is placed in transparent bags. The separately collected recyclables are delivered to specialised installations that provide proper recycling, while residual waste is incinerated.[286]

Food waste comprises both cooked and uncooked waste as well as food-soiled paper towels and napkins.[287]

Collection

The city is divided in four collection areas comprising about 55,000 collection points, encompassing approximately 320,000 inhabitants (see Figure 59). Milan waste management is increasingly oriented towards door-to-door collection integrated with (mobile) amenity sites. The table below shows the garbage pick up frequencies based on type of waste.

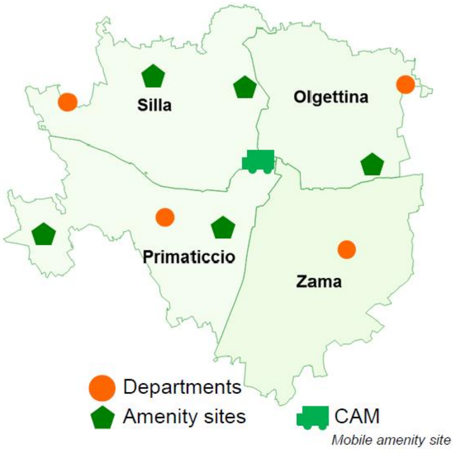

Figure 59. Collection area map of the city of Milan.

In 2011, Milan had an overall recycling rate of 35%, made of dry recyclables such as paper, glass, plastics and metals. Food waste was only collected from commercial producers such as

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[284] Confirmed in interview with stakeholder.

[285] Milan Recycle City, (2016). https://issuu.com/giorgioghiringhelli/docs/food_waste_recycling_the_case_study

[286] EBA (2016). Success Stories: anaerobic digestion of biodegradable municipal solid waste in European cities.

[287] Milan Recycle City, (2016). https://issuu.com/giorgioghiringhelli/docs/food_waste_recycling_the_case_study

restaurants, supermarkets, hotels and schools. Between last quarter of 2012 and mid-2014, residential food waste collection has been introduced in Milan. The collected waste has been sent to an anaerobic digestion and composting facility of Montello, resulting in an increased recycling rate of 52.5% by January 2015. The successful implementation has placed the city among the best performing cities in Europe in terms of source separation and recycling of municipal waste.[288]

Table 57. Garbage pick up frequencies in Milan. Source: a2a Ambiente (2016, January 29th). Municipal Solid Waste Management in Milan.

Type of waste	Pick up frequency
Clear bag (residual waste)	twice a week
Yellow bag (plastic and metals)	once a week
Cardboard	twice a week
Green container (glass)	once a week
Brown container (organic)	twice a week for domestic waste every day for commercial waste

The brown wheeled food waste bins for the curbside contain 120 l. For indoors, households have been provided with 10 l vented bins and 25 compostable bioplastic Mater-Bi bags. The bags are produced by Novamont according to the European standard for biodegradable and compostable packaging (EN 13432). Once used up, households can either purchase new bags in stores or use the compostable shopping bags from stores. Italy has banned non compostable single use plastic bags; therefore shops provide compostable single use or multi use options. Waste characterisation analysis conducted by CIC found that about 50% of the waste bags used for food waste are re-used compostable shopping bags.[289]

All pick-up services are carried out as early as 5:30 am on weekdays and 6:50 am on weekends. The city centre (highest traffic area) is served before 8:15 am. AMSA has optimised its collected waste transport system to treatment centres, taking into account the criticality of a city like Milan (traffic, road conditions, different vehicles for collection, etc.) with a network of transfer stations: this system of second level logistics allows to reduce transfer times, to optimise the use of the vehicles and to reduce logistics costs. It is estimated that the door-to-door system costs roughly EUR 1.4 million.[290]

Calculated by CIC, the Italian Composting and Biogas Consortium based on the Defra (UK) calculation tool (2011) about 130,000 t/year of food waste are now being collected separately and sent to AD for organic recycling saving 8,760 t of CO 2 /year.

Transport

AMSA operates around 1,400 waste collection and street sweeping vehicles, 30% of which are CNG-fuelled. In the city centre, bio-waste in mainly collected using vehicles with a capacity of six m^3 without compaction and powered by methane or biodiesel, whilst larger compaction vehicles (20-23 m^3) are operating outskirts.[291]

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[288] Milan Recycle City, (2016). https://issuu.com/giorgioghiringhelli/docs/food_waste_recycling_the_case_study

[289] Milan Recycle City, (2016). https://issuu.com/giorgioghiringhelli/docs/food_waste_recycling_the_case_study

[290] Confirmed in interview with key stakeholder.

[291] https://issuu.com/giorgioghiringhelli/docs/food_waste_recycling_the_case_study

The bio-waste is transported to two different transfer stations, from where it is forwarded to the anaerobic digestion and composting plant on the same day. This introduction of second-level logistics saves time, optimises vehicle use and reduces cost.[292]

Sorting, post-collection

Milan has an integrated waste management system that is oriented towards increasingly domestic collection systems and integration with other models (amenity sites and CAM – mobile amenity site) in order to maximise the separate waste collection and recovery rate of materials on one hand and waste treatment based on handling of recyclable materials and on the recovery of energy from residual fraction (Zero landfill since 1997) on the other. Through thermal treatment of non-recyclable waste, they also generate energy. An interview with a municipal representative stated that the city's current objective is to reduce bio-waste and valorise what is left over factoring in the market demand for it.

Waste input comes from a variety of services, including:

- Door-to-Door Collection within the whole city
- Amenity sites
- CAM (is the Mobile Environmental Centre - a mobile recycling plant for resident's various waste including electrical and electronic equipment)
- Bring banks (for paper and glass)
- Street bins
- Bulky waste collection services
- On the street
- Free of charge at home
- By paying

Most of those services are covered by TARI, which is a waste tax for not only collection, transport and disposal but also recovery of municipal waste and has been established by Law 27/12/2013 n. 147, and "is due by anyone who owns or has in any capacity premises or open areas used for any use, likely to produce municipal and similar waste, with a bond of solidarity between the members of the household or between those who use the premises or areas in common."[293]

The waste is then either composted (organic waste) or sent to recycling treatment plants, where the waste is transformed into secondary raw materials. Before collection, a dedicated crew of 30 operators is constantly monitoring the quality of all recyclable fractions, and wrong deliveries, which can lead to fines of 50€ (AMSA - ecodellecittà). In order to encourage correct behaviours among the citizens, a control system is in place to ensure correct separation as well as fines on littering.

In Milan, bio-waste is 100% made of food waste and is thus low in impurities; with an average of non-compostable content of 4.3% (Milano Recycle Citiy); and is sent to the anaerobic digestion plant in Montello for composting. The Montello anaerobic digestor and composting facility employs 98 staff and operates entirely automatic, including the separation of unwanted components and biogas production. Laboratory technicians,

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[292] Milan Recycle City, (2016). https://issuu.com/giorgioghiringhelli/docs/food_waste_recycling_the_case_study

[293] https://www.comune.milano.it/aree-tematiche/tributi/tari

managers and other staff is needed since the digesters are fed continuously and need to be maintained at thermophilic conditions.

According to the CIV, for each 1,000 tonnes of organic waste collected and treated, around 1.5 new green jobs are generated.

7.2.2 Description of currently used and potentially available (ready to implement) technologies

The collected food waste is transported the Montello facility that combines anaerobic digestion with aerobic composting. The privately owned plant is located 60 km from Milan and has a capacity of 285,000 tonnes/year. The bio-waste in bags is pre-treated by means of hydropulpers and then digested. The digestate is then mixed with green waste and composted. Montello produces approximately 45,000 tonnes of organic fertiliser per year. The end-products are biogas and compost for land application (sold to famers).[294] The plant has 45,200 m³ digesters with an installed power of 12.8 MW_{el}. Montello is currently developing a biomethane plant.[295]

Montello has been processing organic waste since the 1990s with the objective of having a "sanitation solution" for bio-waste diverted from landfills. In 1997, an aerobic composting treatment was developed to produce "composted mixed soil improver". In the aftermath, new technologies have been implemented, among others the addition of anaerobic digestion phases to optimise the aerobic treatment.[296]

A small initiative worth mentioning here is the city-owned company Milano Ristoranzione that provides schools and other public institutions not only with canteen food but also a lesson on plastic waste, using compostable bioplastic.

7.2.3 Existing support from research organisations and other stakeholders

Table 58. Key Stakeholders in Milan.

Stakeholder	**Information**
CIC	Italian Compost and Biogas Association
Novamont SpA	Italian producer of compostable polymers

The project **Milano Recycle City** involves important stakeholders such as AMSA SpA, CIC, Novamont SpA and the national paper and cardboard recycling consortium COMIECO. The aim of the project is to support the city of Milan in promoting best practices and communication of separate collection to the citizens and other stakeholders. One of the project's key activities has been the facilitation of introducing the door-to-door food waste collection scheme focusing on information campaigns.[297]

The Lombard economy is characterised by a huge variety of bioeconomic specialisations, encompassing traditional as well as high-tech sectors. It is supported by innovative start-ups. In cooperation with the Universities of Bologna, Naples Federico II, and Turin, the University of Milano-Bicocca hosts the first **Master programme in Bioeconomy and the Circular Economy**, attracting strong interest by related industry, amongst the PTP Science Park, located close to Milan. The Bocconi University has also been integral to

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[294] Milan Recycle City, (2016). https://issuu.com/giorgioghiringhelli/docs/food_waste_recycling_the_case_study
[295] EBA (2016). Success Stories: anaerobic digestion of biodegradable municipal solid waste in European cities.
[296] EBA (2016). Success Stories: anaerobic digestion of biodegradable municipal solid waste in European cities.
[297]Milan Recycle City, (2016). https://issuu.com/giorgioghiringhelli/docs/food_waste_recycling_the_case_study

providing research on the bioeconomy and working with the city to plan the future of bio-waste.

A key collaboration within the city of Milan is the fashion industry and the increasing focus it has on sustainability and the city of Milan. For example, Orange Fibre is a Milanese company that uses orange skin to produce textile; nearly 700,000 tonnes of citrus waste is produced in Italy every year.[298] Organic textiles using pure bio-waste also have the potential to reduce the exposure of the skin to toxic or nonorganic materials.

7.2.4 Legal environment, enablers & barriers

For information on Italy's waste legislation, refer to the case study on Emilia Romagna (see section 3.2.1).

On an EU, level, the European Commission's End-of-Waste criteria within the Waste Framework Directive (2008/98/EC) have fuelled Milan's waste 's objectives, namely turning waste into a product. An interviewee highlighted the criteria as crucial in for Milan as they are already in what might be the step beyond waste separation into valorisation and ramping up circularity.

The plan for infrastructural system in Milan and Italy as a whole is the construction of more treatment plants for the food fraction. At the start of 2018 the Italian government published a decree (Decree 02) that encourages production of biomethane from food waste. Subsidies will be provided when biomethane is then implemented into the transport sector.

The objectives of the Regional Waste Management Program are in line with the EU and national regulation which incorporate the circular economy. Starting with waste prevention and then further preparation for reuse and recycling, energy recovery and also disposal is already integrated into Milan's waste focus. By (or as of 2020) the Regional Waste Management Program aimed to recover 65% of waste as matter and 80% as matter and energy. The review of the Plan is ongoing.

With regard to future governance within Milan, there is a plan in the works for the air and climate (PAC) with the vision for the city to achieve zero carbon emissions over the period 2021-2050. It is based on the priority for a clean city which consumes less and more sustainably. The attention can be tied as well to the collaboration with the fashion industry to encourage conscious lifestyles among the citizens.

One of the major enablers is the participation of the community. Milan's high separation rate is due to the fact that the city has a strong participatory approach to waste disposal and there is a general awareness for the value of waste on a community level. Not to mention, the production of compost as a commercialised and valuable resource. The end-user of bio-waste, for example, are either farmers who supply to Milan or Lombardy Region or also the *cascine* that are within the city's borders. *Cascine* refer to traditional Italian homesteads that are surrounded by a large piece of cultivated land, which are then used for urban agriculture. Urban agriculture enables the community to separate their waste and further see its value once it has been transformed into viable compost.

While the reduction of waste is not necessarily associated with valorisation, in Milan these two objectives go hand in hand as they aim to valorise what remains of the waste. One way the city encourages a reduction in waste is through tax breaks/deductions for restaurants and institutions that can prove that they are redirecting their bio-waste. For example, some restaurants that donate expiring food will receive a tax break; last year, the city had an 18% reduction in taxes due to redirected bio-waste.[299]

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[298] http://orangefiber.it/en/impact/

[299] Confirmed in interview with stakeholder.

8 Case study of the city of Nantes

Located at the Loire river, Nantes is the sixth largest city of France with approximately 600,000 inhabitants. Since 2001, Nantes Métropole has been managing issues related to environment and energy, water and sewerage, and waste (among others) for its 24 municipalities.

Framed by Time Magazine as the most liveable city in Europe and European Green Capital in 2013, Nantes is known for being a green city and was the first French city to introduce electric trams. However, Nantes also offers green solutions with regards to waste and wastewater sludge. In 2016, greater Nantes has been recognised as zero waste territory and through several measures the quantity of residual domestic waste and recyclable packaging per resident per year decreased by 17.6% between 2001 and 2013. Here composting bio-waste plays a big role, as Nantes has no bio-waste separation and door-to-door collection system in place. The wastewater treatment plants of Nantes recover for example the sludge for agricultural processes and have since 2011 subjecting it to solar drying, yielding an increased dryness (from 20% to 85%) and reducing the tonnages required for transport.

Table 59. General information on Nantes.

City	Nantes
Country	France
Geographical location	Situated on the Loire River, close to the Atlantic coast, In the west of the country
Population	City of Nantes: 299,682[A] Nantes Metropole: 656,691[B]
Population density (inhabitants per km²)	City of Nantes: 4,415 Nantes Metropole: 1,112[A]
GDP (EUR)	EUR 26.5 billion
GDP per capita (EUR)	EUR 40,375
Green urban areas (%, Area)	Green space (public and private) makes up 41 percent of Nantes' area [C]
Number of operating research centres promoting the bioeconomy	• École Superieure du Bois is specialising in wood science and technologies and their circular economy research focusses on the efficient use of wood with regards to cascading • École de Design Nantes Atlantique is developing new masters' courses on green innovation and supports student projects that valorise bio-waste, f.ex. Poiscaille, Vertuo, etc.
Sources:	

[A] Rodriguez, F., Le Guern, C., Béchet, B. & Gouriten, Y. (2017) Nantes TU1206 COST Sub-Urban WG1 Report. COST(European Cooperation in Science and Technology). Available at: Link
[B] Nantes Métropole. (2018). Rapport Annuel 2018. Available at: Link
[C] https://metropole.nantes.fr/sortir/vie-locale/nature/parcs-jardins

8.1 *Analysis of the municipal waste generation scheme, trends, and future milestones*

8.1.1 *Availability of municipal bio-waste as feedstock*

Waste collection in the city relies on three different systems depending on the region. The city has rigorous collection and separation targets which is not necessarily reflected in the difference in the waste category totals between 2010 and 2018.

Table 60. Breakdown of bio-share of municipal solid waste in tonnes generated for Nantes for 2010, 2014, and 2018.

Year	**2010**	**2014**	**2018**
Organic waste	29,828	32,287	34,745
Wood waste	6,235	7,621	9,007
Household waste	146,678	143,692	140,706
Total	**182,741**	**183,600**	**184,458**

Household waste dropped about 6,000 tonnes across the eight-year span and the percentage of household waste is particularly high in comparison to the other case study regions and cities. Nantes Métropole estimates that the household waste consists of 27% food scraps.[300] The graph below shows the significance of household waste in Nantes.

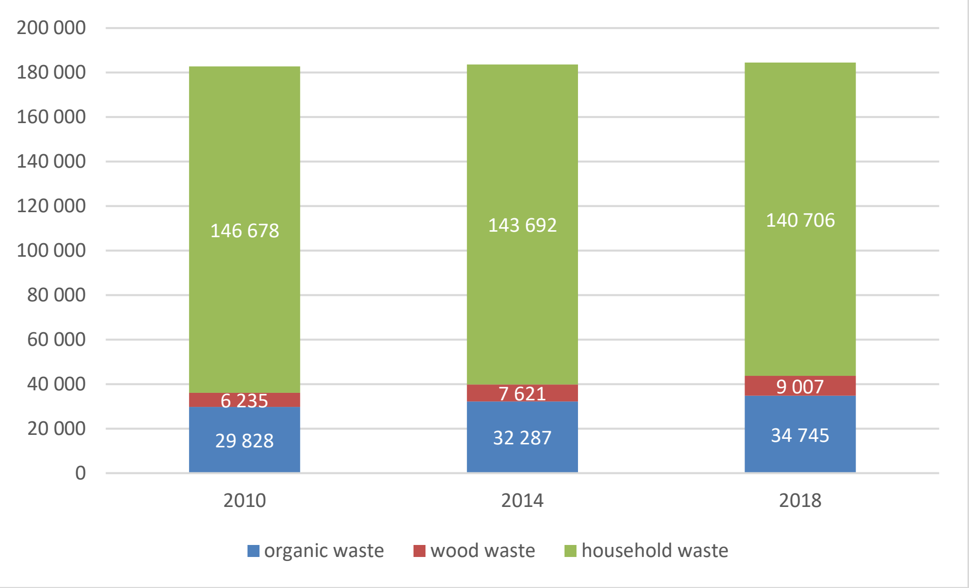

Figure 60. Year perspective on waste make-up of Nantes for 2010, 2014 and 2018.[301]

8.1.2 *Availability of municipal wastewater sludge as feedstock*

The wastewater of Greater Nantes is collectively treated in nine facilities (> 2,000 population equivalent) and 16 facilities (< 2,000 population equivalent), resulting in a total

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[300] Nantes Métropole (2019). Annual Report on Waste.
[301] Nantes Métropole (2019). Annual Report on Waste.

capacity of 840,000 population equivalent. In addition, there are 7,000 autonomous sanitation stations. These facilities produced 12,103 t of wastewater sludge in 2018.

Table 61. Wastewater sludge generated in all wastewater plants of Nantes. Source: Annual reports on water. Link for the 2018 report.

Year	**2011**	**2015**	**2016**	**2017**	**2018**
Wastewater sludge (dry matter, t)	8,143	10,321	10,674	12,304	12,103

8.2 *Valorisation of Biological resources*

8.2.1 *Background information on the local waste management system*

Nantes Métropole is the authority overseeing waste prevention, collection, sorting, treatment and valorisation. Greater Nantes has a door-to-door, selective and simplified household waste collection method managed by the City of Nantes and three municipalities in the southwest (La Montagne, Le Pellerin and Saint-Jean-de-Boiseau). The collection and the waste management is either carried out by public operators or private service providers (for details for collection see Table 62 further below).

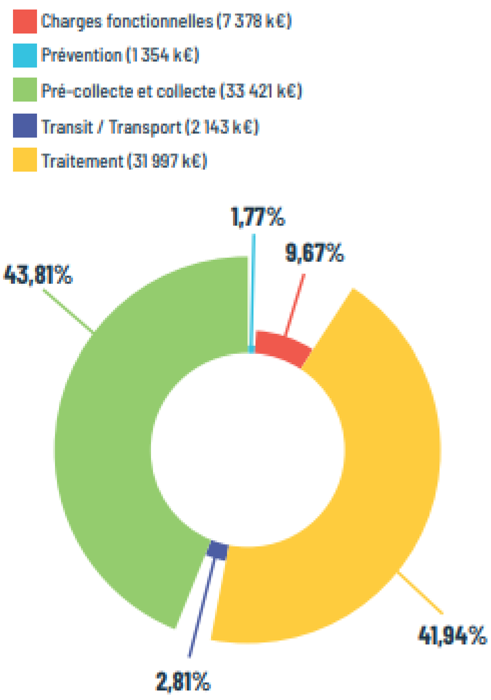

Figure 61. Composition of costs. Source: Nantes Métropole (2019). Annual Report on Waste.

The total budget for waste management amounts EUR 75 million with 273 collection agents. 5.4% thereof is covered by public budget in addition to the contribution of EUR 119 per year and inhabitant.[302] This contribution mainly stems from tax on the removal of household refuse (TEOM), deductible from the land owner (calculated based on the real estate value), thus not dependent on the use of the service or the volume of waste generated. In 2016, a reduction of the TEOM from 10.73% to 7.5% has been decided. Income from TEOM in 2018 amounted to EUR 61,296,608. In addition, EUR 2,293,188 of special royalty has been paid, charging private companies with a higher waste volume than average households EUR 0.514 per weekly collected volume (maximum threshold 1,020 l, including an activity coefficient). According to Nantes Métropole, the yearly cost of one tonne of household waste amounts EUR 215, public budgets are bearing EUR 97 per inhabitant.[303] Figure 61 depicts the cost split, showing that the highest cost occur during (pre-)collection) and treatment. Functional charges consist of central services, study fees, rent, communication, management, as well as wages related to pilot projects and management.

Apart from the special royalty, the system does not incentivise waste reduction, as it is not a function of produced volumes of waste. In addition, there is no sanctioning system in place that penalises incorrect sorting. Nantes Métropole is considering adopting their

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[302] Dumas, T., (2020).https://www.mediacites.fr/enquete/nantes/2020/01/30/rates-de-trisac-et-du-recyclage-la-gestion-des-dechets-enjeu-des-municipales-a-nantes/?

[303] Nantes Metropole, (2018). https://metropole.nantes.fr/files/pdf/dechet-proprete/tri-collecte/RAPPORT-NM-2018-A4paysage-BAT.pdf

current system towards a financing approach that drives behaviour change towards correct sorting and waste reduction. The design and adoption of the TEOM dates long time back and has not been reassessed. However, the interviewee stressed that such projects take time and there are no concrete measures undertaken currently to rethink the waste financing approach.

Greater Nantes has various facilities to optimise waste management, including four recycling stations, eleven waste dumps, two treatment and valorisation centres, open to the public (Alcéa and Arc-en-Ciel), and a composting platform Arc-en-Ciel (Figure 62).

Figure 62. Waste management facilities in greater Nantes. Source: Nantes Métropole.

Sorting, pre-collection

The sorting system distinguishes between two types of waste, separated into blue and yellow bags (Table 62). With regard to specific waste, households are asked to bring their glass waste to collective containers and for bulky waste, citizens use the recycling stations. Nantes Métropole further encourages to bring goods that are still in good conditions to so-called resource centres and textiles to dedicated recycling facilities.

Table 62. Blue and yellow bags for sorting. Source: Nantes Métropole.

Blue bags/bins (residual waste)	• polystyrene • empty engine oil can • CD / DVD / K7 • shoes (if in good condition and in pairs, think of textile terminals!) • Sanitary waste (baby diaper, tube of toothpaste, disposable razors, beauty products) • disposable plastic dishes (cutlery, plates, glasses) • frying oil (in a plastic bottle) • animal litter • aluminium foil • wallpaper and gift wrap • pencil • Bio-waste
Yellow bags/bins (recyclable material)	• plastic bottles • aluminium tray, tin cans • cardboard • books • cardboard boxes • paper

The city of Nantes almost fully operates on TRI'SAC using bags instead of containers, whereas outside Nantes and 20% of the inner-city households still use the traditional bins.[304] The main difference here is that the blue and yellow bins are emptied in separate loads, while the blue and yellow TRI'SAC bags are collected together (Figure 63). It is therefore necessary to separate the bags in a dedicated factory, on a conveyor belt, via optical detection. Introduced gradually from 2006 onwards, this collection scheme was extended in 2013 to all tower block districts in Nantes. The scheme aims to resolve spatial constraints at the same time encouraging selective sorting of the main types of domestic waste. TRI'SAC is inspired by Swedish and Norwegian systems that run on a limited number of colour-coded waste categories. Annually, 630,000 bags are distributed free of charge imposing a cost of EUR 1.2 million on public budgets. The system has been criticised for working poorly, as cleaning companies have used the yellow bags for unsorted waste for being free of charge. In addition, yellow bags are damaged in the collection and transport process ending up with the non-recyclable waste incinerated. To counteract this problem, the compaction rate in trucks has been reduced and the bag size has been decreased.[305]

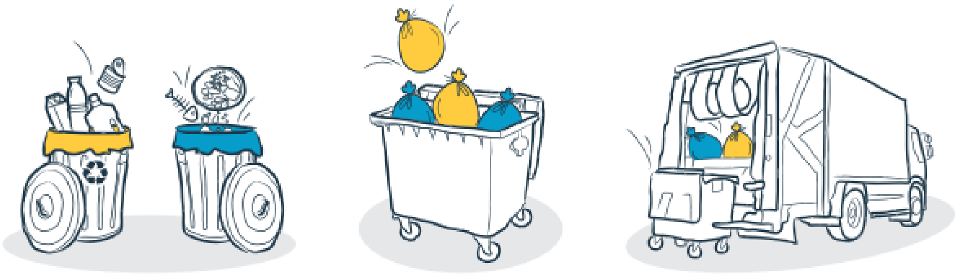

Figure 63. The TRI'SAC sorting system. Source: Nantes Métropole (2019). Annual Report on Waste.

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[304] For some households outside Nantes, yellow bins are replaced by transparent bags.

[305] Dumas, T., (2020). https://www.mediacites.fr/enquete/nantes/2020/01/30/rates-de-trisac-et-du-recyclage-la-gestion-des-dechets-enjeu-des-municipales-a-nantes/?

Collection and Transport

Door-to-door collection of unsorted and recyclable waste occurs once a week in the areas outside Nantes city, whereas the citizens of Nantes have a pick-up twice a week, those living in the city centre even thrice a week. The operators and their division of labour is summarised in the figure below.

Table 63. Summary of public and private waste operators. Source: Nantes Métropole (2019). Annual Report on Waste.

	Operator	Information
Public	JANVRAIE	• 70 staff and 29 vehicles • Sector: Nantes West and Nantes North • Activities: Collection of waste delivered to voluntary collection points for recyclable materials and glass, as well as maintenance of the collection points • Covered 145,451 km in 2018
	GRANDE BRETAGNE	• 68 staff and 23 vehicles • Sector: Nantes North and Nantes East • Activities: Collection of illegal dumped bulky waste, management of large containers for events and demonstrations • Covered 100,355 in 2018
	ÉTIER	• 121 staff and 43 vehicles • Sector: Nantes Centre and Nantes South • Activities: Collection from volontary TRI'SAC waste drop-off points, management of recycling stations and waste treatment facilitiescollection of specific waste in the city centre • Covered 248,112 km in 2018
	RÉGIE DU SUD OUEST	• 14 staff and 8 vehicles • Sector: Saint-Jean-de-Boisseau, Le Pellerin, La Montagne • Management of the containers • Covered 77,576 km in 2018
Private, covered 831,660 km in 2018	VÉOLIA	• Collection of unsorted waste and recyclables in Couëron, Indre, Saint-Herblain • Collection of bulky waste outside Nantes
	SUEZ RV OUEST	• Collection of unsorted waste and recyclables in Basse Goulain, Saint-Sébastien-sur-Loire, Vertou, Rezé, Les Sorinières, Bouguenais, Saint-Aignan-de-Grand-Lieu, Bouaye, Brains, Saint-Léger-les-Vignes • Collection of glass outside of Nantes
	URBASER ENVIRONMENT	• Collection of unsorted waste and recyclables in Sautron, Orvault, La Chappelle-sur-Erdre, Thouaré-sur-Loire, Mauves-sur-Loire, Sainte-Luce-sur-Loire and Carquefou

In addition to door-to-door services, inhabitants can voluntarily use containers to dispose glas, unsorted waste, and recyclable material. There are several types of (household) waste that are not collected door-to-door and can be disposed free of charge on landfills:

- rubble,
- green waste,
- wood,
- paper and cardboard,
- scrap metal,
- waste electrical and electronic equipment (WEEE), and
- hazardous waste.

The landfills are managed by Coved (2)[306], Nantes Métropole (1), Paprec (5), and Suez (3). Nantes Métropole additionally manages four recycling stations.

The transport of wastewater sludge to the storage platform (during non-spreading phases) is provided by the subcontractor ABLO as part of the contract that Nantes Métropole has until the end of 2020 with SUEZ ORGANIQUE. The transport from the platform to the agricultural fields (see section 8.2.2 for more information) is handled by the sub-contractor Boumard Cussoneau being equipped with the necessary gear.

Parts of the vehicle fleet are already fuelled with natural gas. In addition, Nantes Métropole is commissioning studies to look into alternative fuels, e.g. a hydrogen/solar solution and the production of biogas from bio-waste.

Currently, household bio-waste is not separately collected and accounts for 27% of the unsorted waste. Households are encouraged to bring their bio-waste (peels/left-overs, lawn and garden waste) to composting facilities. The Climate Plan includes a feasibility study for door-to-door collection of bio-waste and a pilot implementation. In December 2019, Nantes Métropole launched this 6-months pilot in Nantes Nord to develop a tailored solution for the entire metropolitan area. More precisely, the 1,600 households received kraft paper bags and bio-waste containers. In addition, 13 collective composters have been installed in the neighbourhood for individual drop-off and 200 residential houses had a door-to-door pick-up services for their bio-waste.[307]

This pilot is provisionally implemented in cooperation with the association compost in situ (see section 8.2.2 for further information). Currently, the collection is integrated in the regular collection schemes commissioned by Nantes Métropole. The collected bio-waste is transported to compost in situ's platform. The association takes care of the transportation to the composters that are adjacent to agricultural land against a fee. In the medium and long-run, a dedicated composting platform will be established, and the collection of bio-waste will be conducted independently from TRI'SAC. Nantes Métropole considers the possibility of selling abonnements for regular compost supply in this context, in case economically feasible. For awareness raising, education and training, Nantes Métropole considers involving the association compostri.

The general public is supportive of this management change, showing in the petition signed by more than 10,000 inhabitants asking for immediate implementation. The door-to-door collection of bio-waste is promised by almost all candidates for the major poste.[308] Nantes Métropole is equally satisfied with the effort and mentioned a number of learnings from this pilot:

- There is no one-fits-all solution for bio-waste separation and collection, as citizens have different interests, needs and levels of awareness which directly translates to willingness of separate their bio-waste and bring it to containers, or collective composters. In the city centre, households do not make use of compost, thus door-to-door collection of voluntary drop-off to containers is most appropriate.

- Since bio-waste has to be taken out on a regular basis on small quantities, the door-to-door collection system is more costly than the voluntary drop- off container approach. Nantes Métropole envisions a dense infra structure of containers.

- It is important to accompany the citizens in this transition to raise awareness and teach about correct separation.

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[306] Numbers in brackets indicate the number of landfills managed by the entity.

[307] Metropole, (2020). https://metropole.nantes.fr/actualites/2020/dechets-proprete-eau-energie/collecte-dechets-nord

[308] Dumas, T., (2020). https://www.mediacites.fr/enquete/nantes/2020/01/30/rates-de-trisac-et-du-recyclage-la-gestion-des-dechets-enjeu-des-municipales-a-nantes/?

Sorting, post-collection and destination

The waste directorate of Nantes Métropole organises the treatment and valorisation of unsorted household waste, as well as recyclable material are treated in the two waste treatment facilities Arc-en-Ciel (including composting platform), run by Véolia and Alcéa, run by Séché Enviornnement under contracts of Public Service (DSP). Other fluxes mostly from landfills are received and treated by provate operators in the context of regulated markets. As concerns bio-waste, Paprec Grand Ouest deals with wood and Ecosys with green waste.

In Nantes, there is a low level of automatisation in the process of composting and shredding. With regards to sorting of waste, automatisation is more advanced, however still involved manual actions. How automatisation will progress in future depends on the technology pathways that is chosen. In case, composting will kick-in in larger scale, Nantes Métropole will need to pilot some processes with regards to temperature control of the digester, etc.

The staff involved in collection and transport is split per company in Table 63. As concerns waste treatment, 40 employees work at Alcéa and 130 functionaries are employed at Arc-en-Ciel.[309]

8.2.2 *Description of currently used and potentially available (ready to implement) technologies*

This sub-chapter distinguishes three streams of bio-valorisation waste and their respective valorisation pathways;

1. Separated bio-waste from recycle centres, parks and gardens;
2. Bio-waste from households that are voluntarily separating bio-waste for compost; and
3. Bio-waste from commercial sources, public institutions, and door-to-door collected bio-waste in pilot region.

The flow chart below shows the trajectory of separated bio-waste, i.e. from recycle centres or park and garden waste, including wood. Woody material that has been disposed to the recycling station can be recovered to a large extent. Green waste from gardens and parks is transported to the composting platforms Saint-Herblain operated by Véolia (G-VAL) and Ecosys. Here, valorisation pathways include combustion, composting, shredding and wood energy. Smaller parts form diverse intakes and bulky waste is also valorised. The shredded garden waste is provided to farmers for free to complement their compost and for application to their fields. The compost that is produced on those platforms is commercialised by the operators, so is the wood energy pathway. Nantes Métropole does not benefit financially from any of those valorisations.

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[309] Nantes Metropole, (2018). https://metropole.nantes.fr/files/pdf/dechet-proprete/tri-collecte/RAPPORT-NM-2018-A4paysage-BAT.pdf

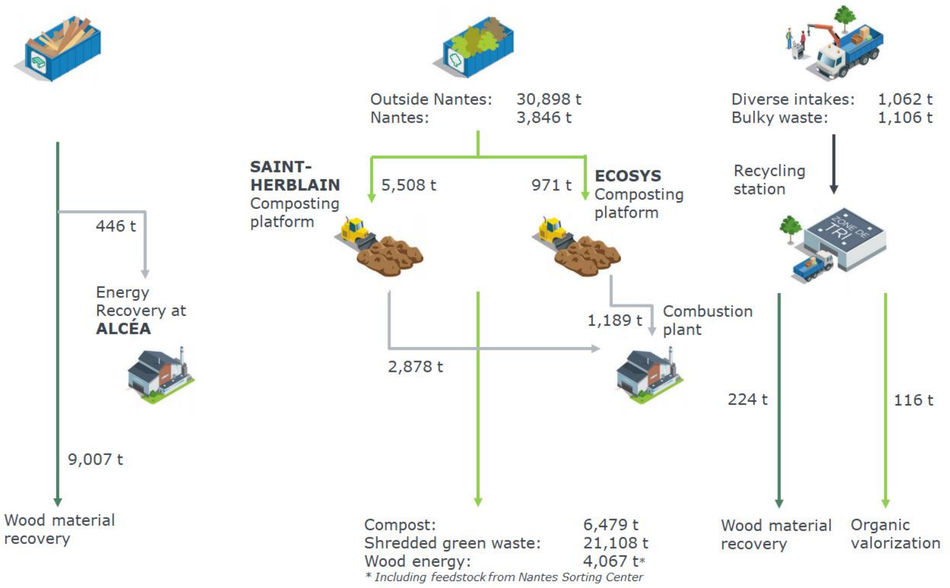

Figure 64. Bio-waste seperation and valorisation (including wood). Source: Nantes Métropole (2019). Annual Report on Waste.

In 2017, energy has been recovered from 3,000 t of bio-waste in the combustion plant Malakoff, located in the east of Nantes. The plant has been established in 2016 as a result of Nantes' climate plan und in partnership with ADEME, the French Agency for Ecologic Transition. The 150 MW plant is operated by Erena, a subsidiary of Engie and provides 12,000 homes and 180 tertiary establishments with energy. The plant is mainly fired by wood chips with 20% of the feedstock being bio-waste. The bio-waste comes from two facilities located 10km and 20km from the plant and operated by Ecosys and Veolia respectively. The procurement of bio-waste is approximately 10-15% cheaper than wood chips, yet of worse quality for combustion.[310]

The sorting facility Le Relais Atlantquie specialised on textiles and ensure the supply of raw material for the manufacture of cellulose wadding and for the manufacture of insulation wools in cotton fibres, e.g. the facility provides the company Métisse® with feedstock to produced bio-based thermic and acoustic insolation for buildings.

In Nantes Métropole, two major initiatives support composting in a complimentary manner; compostri is engaging households in composting practices and compost in situ is involved in bio-waste produced in larger scales, i.e. from public institutions or private companies. Nantes Métropole is not driven by the long-term economic viability of projects, their approach is guided by the motivation to return carbon to the soils, thus, closing the input-output loop of biomass between city and periphery. The following composting measures are undertaken in Greater Nantes.

- Individual Composting (16,057 households, or 13% of single-family houses, yielding on average 42 kg/person);
- Collective composting (225 shared composters, amongst 49 on school ground, 1,820 households, yielding on average 90-110 kg/person);
- Composting on farmers' markets;
- Education on composting and the formation of groups

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[310] l-ADEME, (2018). https://www.bioenergie-promotion.fr/wp-content/uploads/2018/09/ademewebalternativesdechetsverts010418.pdf

- Pre-composting system with regard to large-scale producers.[311]

In 2018, 155 m^3 of garden waste has been shredded in 12 operations. In addition, 1,750 Christmas trees have been collected, amounting to 220 m^3.

Since there is currently no separation of bio-waste on household-level in the absence of a collection system, the only valorisation pathway of voluntarily separated bio-waste is composting, encouraged by Nantes Métropole in cooperation with compostri.

The association compostri has been created in 2007 with the objective of promoting and developing shared composting facilities, as well as the valorisation of composting in general and in an urban setting. Today, the association builds his work on voluntary work and additionally employs nine staff. The managing board consists of nine members and takes all investment decisions placing a strong focus of the associative nature of the institution, as well as its core values.

In close collaboration with Nantes Métropole, compostri is implementing shared composters (neighbourhoods, condominiums, group of buildings and schools) accompanying the citizens of Nantes trainings and events. In the beginning their cooperation was based on subventions and grant-based support by Nantes Métropole as well as ADEME. In 2018, their contractual relationship changed as Nantes Métropole commissioned the installation of 40 new composting facilities per year until 2021, including services related to maintenance and training. Compostri has already reach this objective and is currently negotiating a new agreement with Nantes Métropole. Their current capacity allows an installation of 50 composters per year.

Currently, compostri manages 3,000 t of compost per year and constantly evaluates how and where to strategically expand their composter network. For this, compostri maps the household demand for composting and if more than five households are interested, compostri is installing a composter tailored to the expected demand.

A composting facility consists of three repositories; for input, maturation and for a stocking carbon rich material. Once established the composting facilities are managed by its users with little involvement from compostri in the medium- to long-run. Immediately after establishing a composter, compostri remains rather active in accompanying the users. After structures are established with appointed site managers, compostri reduces the frequency to yearly visits. The users are managing the composting facility, including supply of carbon rich materials, mixing the surface and taking care of the repository cycle. The only bottleneck that composters might encounter in the absence of compostri is the sufficient supply with carbon rich materials, such as dry leaves, woody plant trimmings and sawdust to provide energy for microorganisms while breaking down organic matter, however compostri is confident that households have been briefed sufficiently thereto.

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[311] Collectiveite De Martinique, (2019). https://www.collectivitedemartinique.mq/wp-content/uploads/2019/05/etude-technico-economique-cs-biodechets-201801-rapport.pdf, number of collective composters has been adjusted based on Annual waste report 2018.

With their current mission of proliferating composting techniques, compostri is working to capacity, nevertheless, the association is exploring vermicomposting which involves various species of worms in the decomposition process.

Compost in situ is an association that has evolved from compostri to focus on other sources of bio-waste. Compost in situ valorises bio-waste by composting it in direct proximity to agricultural lands for later application. In this manner, local farmers that are engaged in sustainable agriculture can return organic content to their soils. Farmers receive the compost free of charge in exchange providing space adjacent to their farming land for the composting platform.[312]

Compost in situ provides four solutions for composting presented in the table below.

Figure 65. Compost in-situ's circular bioeconomy model.

Table 64. Composting solutions suggested by compost in situ. Source: Compost in situ website

Solution	Bio-waste capacity	User groups
Composting in silos	5 to 25 t per year	private or public canteens (connected to schools, hospitals, or businesses), merchants' association, local composting, etc.
Composting on micro platforms	50 to 200 t per year	for local authorities, medical and social institutions
Adjacent to farmland	50 to 600 t per year	food waste producers near the composting platform
In cooperation with a farmer's network	1,200 to 2,500 t per year	food waste producers near the composting platform

In order to facilitate these solutions, compost in situ provides a range of services:

- **Collection** – During the collection process, attention is given to the quality of the sorting, as well as documentation and traceability. Latter is important since the bio-waste remains property of the producer, with compost in situ resuming responsibility. While large production sites are handled by compost in situ directly, services are complemented by local collectors. In addition, producers can directly deposit their bio-waste at mass collectors or depots.
- **One-off events** – Compost in situ offers collection and treatment of bio-waste on on-off or seasonal events, such as camping, tourist sites, festivals, etc.). The collected materials include food scraps, compostable dishes and dry toilets.
- **Composting** – Outside of collection commitments, compost in situ offers the installation of composting sites, start-up support and follow-ups, mechanised reversal nearby composting sites, and screening of compost.

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[312] Compost In Situ | Compost In Situ, la solution pour diminuer vos déchets à la source, tout en nourrissant le sol!

- **Raising awareness and accompanying projects** – Before starting a project, compost in situ pays particular attention to awareness raising and capacity building of involved stakeholders.

- **Selling equipment**

According to the annual water report, 100% of the produced wastewater sludge have been valorised, either for agricultural application or composting. 70% of the sludge has been used in agriculture, thus counteracting soil impoverishment and contributing to a good level of humidity and lime, if treated. The wastewater sludge of Nantes Métropole undergoes two types of processing; composting and applying lime for hygienisation. Far less wastewater sludge is composted as compared to liming. Composting of sludge goes hand in hand with mixing green waste and elevating the temperature for hygienisation. The following processing steps are undertaken to transform sludge into agricultural spreading:

1. Sludge production: Sludge is produced in a purification plant, dehydrated and whitewashed or dried;[313]

2. Sludge storage: Outside agricultural spreading periods, it is stored on the site of the treatment plants;

3. Spreading planning: Based on soil and sludge analyses, a provisional spreading plan is established;

4. Spreading: Sludge is spread over agricultural plots. A spreading register is kept, and soil analyses are carried out.

The traceability of sludge is guaranteed throughout this process. For the Tougas and Petite Californie resorts, certification of the sector according to the standard SYPREA (Union of Agricultural Recycling Professionals) was renewed in 2018.[314]

For farmers, the spreading of processed sludge and included processes/services is free of charge, i.e. transport, spreading, agronomic monitoring, advice etc. This further includes the planting of nitrate-fixing crops, and liming of the plot if the soil pH is too low.

Nantes Métropole has been interested in this type of valorisation as they consider it financially most interesting while working towards sustainable resource management. However, the development of regulating the management of wastewater sludge is uncertain and studies on alternative scenarios have been initiated. An alternative valorisation pathway constitutes energy recovery. This would reduce the amount of sludge spread on agricultural fields, thus leaving space for a more organic agriculture with application of compost from bio-waste.

With regards to emerging technologies and approaches towards bio-waste valorisation, Nantes Métropole considers adopting new approaches but so far has not formulated specific plans. The Territorial Climate Air Energy Plan lists two future energy production pathways linked to bio-waste, presented in the table below and studies further.

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[313] Lime is considered one of the most universal alteration compounds for stabilisation of sewage sludge, as it plays a critical role in decreasing the pathogenic content of sludge, accessibility of heavy metals, and the relevant environmental risks, as well as enhancing its agricultural benefits.

[314] Nantes Metropole, (2018). https://metropole.nantes.fr/files/pdf/eau-assainissement/Rapport_annuel_eau_2018_WEB.pdf

Table 65. Potential of developing different sources of energy based on bio-waste, identified in the Territorial Climate Air Energy Plan.

Energy Source	Estimated potential
Bio-waste to energy	The organic waste deposits from effluents and bio-waste from Nantes Métropole are estimated at around 70,000 t organic waste/year, which represents around 30 GWh/year of production potential in the form of biogas. A study of the bio-waste deposit confirmed the capacity to accommodate one or two territorial units in the city.
Agricultural biomass	Nantes Métropole is conducive to the installation of anaerobic digestion units due to the presence of livestock farming operations producing effluents (slurry, manure, manure) that can be used in this way. The potential for heat production is 18 GWh / year in the form of gas.

Due to the political objective to return carbon back to the agricultural soils, Nantes Métropole has no current or near-future ambitions with regards to facilitating the production of bio-plastics. The interviewee raised the concern that there is not enough evidence on the decomposition process and impact once returned to the soil.

8.2.3 Existing support from research organisations and other stakeholders

Nantes Métropole supports a number of local initiatives financially or in the frame of purchase agreements.

- Compostri and compost in situ (see section 8.2.2 for more information);
- The tricyclerie is an association that collects organic waste from restaurants and other private companies in order to produce compost;
    - The forward-looking "My City Tomorrow" initiative involved 300 stakeholders in local life, 22,000 people and 1,500 contributions to develop the conurbation's project for 2030;

Nantes Métropole works closely with ADEME (French Agency of ecologic transition) and the region Pays de la Loire in order to create synergies between public investment and implementing joint projects. Nantes Métropole is additionally engaging in the European RUE programme (rapproachment universities and enterprises) which is promoting innovation and start-ups in the southern region of Europe, in collaboration with public laboratories.

In addition, Nantes Métropole collaborates with the Crafts and Artisans Chamber and the Chamber of Commerce and Industry, mostly in relation to supporting professionals with their waste reduction ambitions. In addition, there are associations and initiatives that draft and implement action plans to reduce food waste.

Nantes Métropole does not have any formalised exchange with universities, is, however, building a connection with Nantes University at the moment that Nantes Métropole would like to intensify.

8.2.4 Legal environment, enablers & barriers

Nantes' policies are integrated in the regional policy schemes, e.g. the regional scheme for waste reduction and management. In addition, the region provides a waste management plan that Nantes Métropole has align its practices to. In this set-up, Nantes Métropole works with the Regional Direction of the Environment, Planning and Housing (DREAL).

In 2007, Nantes Métropole launched their first Climate Plan, pioneering climate action in France and Europe. The plan has been revised in 2017 ("**Territorial Climate Air Energy**

Plan").[315] One of the three strategic orientation of the plan is 100% valorising resources of greater Nantes, materialising in a zero waste target by 2025 with solutions for sorting and recycling bio-waste as well as composters as close as possible to residents. Nantes Métropole envisions a 20% reduction of unsorted waste by 2030 and would like to valorise 65% of their waste by 2030 (currently 37%).[316] The following sub-objectives are relevant in terms of bio-waste valorisation:

- 100% of the inhabitants have a sorting solution for their bio-waste readily available (Engagement #17)
- Establishment of 25-40 new collective composters per year, with the final goal of having 500 stations available by 2025, one composter per 1,200 inhabitants in 500m proximity.
- EUR 30 premium for the purchase of an individual composter, EUR 40 premium for an integrated worm compost system. These premiums constitute a 50% increase to the previous fee level.
- At least one Garden waste shredding facility per municipality in connection with awareness raising for gardening technique. Financial perpetuation of EUR 3,000 for the zero waste programme
- Feasibility study on the collection of household bio-waste (door-to-door, voluntary use of collective composters) in 2018
- Recover renewable energy from waste (Engagement #19)
- Study on the utilisation of biogas stemming from water treatment plants (for transports, heating, etc.)
- Ensure complementarity between the treatment methods for bio-waste: recovery agronomic by composting, in conjunction with farmers, energy recovery by methanisation
- Support methanisation projects carried out by private project developers

In addition to these sub-objectives, the Climate Plan stresses the importance of including the citizens in their actions and encourages the formation of partnerships, thus contributing to an innovative business environment.

Besides the Climate Plan, the Territorial Food and Nutrition Plan touches upon the valorisation of bio-waste, as food waste reduction and organic agriculture are related topics that offer synergies. The Metropolitan Roadmap for Energy Transition was adopted in 2018 and five out of the 33 action points concern waste. Finally the Local Plan for Metropolitan Urbanism provides a frame for city planning, thus becomes relevant when installing green spaces, but also recycling infra structure and shared composters.

Due to the municipal election in March 2020, the municipality refrained from formulating new objectives towards 2030 until now.

The French norm on organic amendments U 44-95 from 2002 (implemented since 2004) impedes the commercialisation or even distribution of non-normed compost. According to compostri, norming compost requires rather expensive analyses. Therefore, only the

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[315] Metropole: https://metropole.nantes.fr/territoire-institutions/nantes-metropole/competences/climat

[316] Nantes Metropole, (2018). https://metropole.nantes.fr/files/pdf/environnement/Nantes_Metropole_PCAET_2018_12_07.pdf

feedstock providers are allowed to reuse the compost. Overall, most shared composting facilities achieve a balance between in- and outputs, however, oversupply of compost can occur.

The agricultural spreading of treated wastewater sludge is limited in accordance with municipal Land Application Plans. Therefore, there is a surplus of processed sludge which is currently transported to the Bretagne which increases the environmental footprint of this valorisation pathway.

According to the interviewee from Nantes Métropole, there is a trend of converting conventional agriculture into organic farming. Therefore, the demand for certified, good quality compost raises as opposed to the agricultural spreading produced from treated wastewater sludge.

From interviews with compostri and Nantes Métropole, it became evident that shared composting can only be effectively implemented, if accompanied by awareness raising, campaigning and training. Both representatives stressed the importance of engaging citizens. Once, convinced to using the composters, users are likely to continue providing their bio-waste. The composting facilities have specific opening hours which renders them a place of encounter and encourages dialogue between fellow composters, thus supporting the community aspect.

In Nantes, composting is voluntary which is another enabler according to the interviewees. There is no one-fits-all solution, as citizens need to make the choice that convenes them best. According to Mme Canonne, a combination of providing a network of shared composters and supporting individual composters is ideal for citizens interested in this practice. However, there will be always citizens that cannot be incentivised to do composting as there is a lack of interest or use for them. This has been an important learning leading to the pilot of the door-to-door collection in Nantes Nord.

Table 66 below lists some of the constraints for bio-waste valorisation in Greater Nantes, including mitigation measures.

Table 66. Overview of constraints and mitigation measures for bio-waste valorisation in Nantes.

Constraint	**Mitigation measure**
The architecture of historical centres with inflexible spatial planning and historic preservation imposes constraints with regards to instalment of collective bio-waste containers and composters. In addition, architects and city planners are opposed to include composters for not being aesthetic.	• Potential door-to-door selection system • Close cooperation with city planners and architects • Installation of shared composters in public green spaces, such as parcs
The composting sites in the city centre produce a surplus of compost whose distribution is constraint by norm U44-95	• Surplus compost is taken up by compostri associates. • Urban farming is taking up, in the medium-term, compost can be utilised by urban producers
Composters can attract rats and if not managed properly cause bad smell	• Proper management • Capacity building and training • Raising awareness that rats are already there and were not attracted by the composters • Installing grids and traps

9 Case study of the city of Oslo

Oslo is the capital of Norway and is both a county and municipality. It is located in the south-eastern part of Norway and as the governmental centre of Norway is key for industry and trade with the rest of Europe, especially in the maritime industries. It sits on the innermost part of the 100-kilometre-long Oslofjord, which hosts around 40 islands. In 2012, Oslo was ranked number one in quality of life among European large cities in a report by fDi magazine in 2012. Monocle magazine named it the 24th most liveable city in the world for 2019.

Part of Oslo's identity as a Scandinavian capital is its dedication to environmental initiatives. Part of the city's goals for the coming decade include a target to become climate neutral by 2050 compared to 1990. While Norway is not in the EU, this target is parallel to the EU's own goal of climate neutrality within the same time period. Integrated waste management is important for this transition and Oslo specifically has put in place a "recycle and reuse" society alongside a dedicated production of biogas for district energy production. The city already has two waste-to-energy plants to incinerate household waste from the city. In 2011, only 6% of the city's household waste went to landfill.[317] Oslo has a more rigorous plan set in place for the years 2015-2025 with a closer link to the circular economy.

Table 67. General information on the city of Oslo.

City	Oslo
Country	Norway
Geographical location	Østlandet Region, Oslo County
Population	1,027,000
Population density (inhabitants per km²)	1,400 (city proper) 3,300 (urban area)
GDP (EUR)	EUR 33.876 billion [A]
GDP per capita (EUR)	EUR 49,465
Green urban areas (%, Area)	20.49% [B]
Number of operating research centres promoting the bioeconomy	
University of Oslo Mathematics and Natural Science • Biodiversity and Systematics • Bioscience • Geosciences • Renewable Energy Systems	
Sources:[318] [A] Oslo Economy; [B] Index of Green Cities 2018	

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[317] https://www.c40.org/case_studies/c40-good-practice-guides-oslo-waste-management-strategy

[318] https://www.oslo.com/v/economy/; TravelBird, (2018). https://travelbird.no/gronne-byer-indeks-2018/

9.1 Analysis of the municipal waste generation scheme, trends, and future milestones

This chapter contains information on Oslo's waste sources with emphasis on municipal bio-waste and wastewater sludge.

9.1.1 Availability of municipal bio-waste as feedstock

Waste data in Table 68 and Figure 66 from the city of Oslo waste reports is thorough and transparent and shows that organic waste has been rising each year. Garden waste saw a very sharp drop between 2014 and 2018, but this can potentially be attributed to an extension of the categories for waste and therefore a further differentiation between tonne amounts.

Table 68.Municipal bio-share collected in 2010, 2014, and 2018 for 10 residential areas comprising the city of Oslo. Source: Avfallsanalyse 2018.

Year	**2010**	**2014**	**2018**
Organic waste	48,944	53,741	57,945
Garden waste	3,228	3,073	263
Wood waste	1,174	848	521
Total	**53,345**	**57,662**	**58,729**

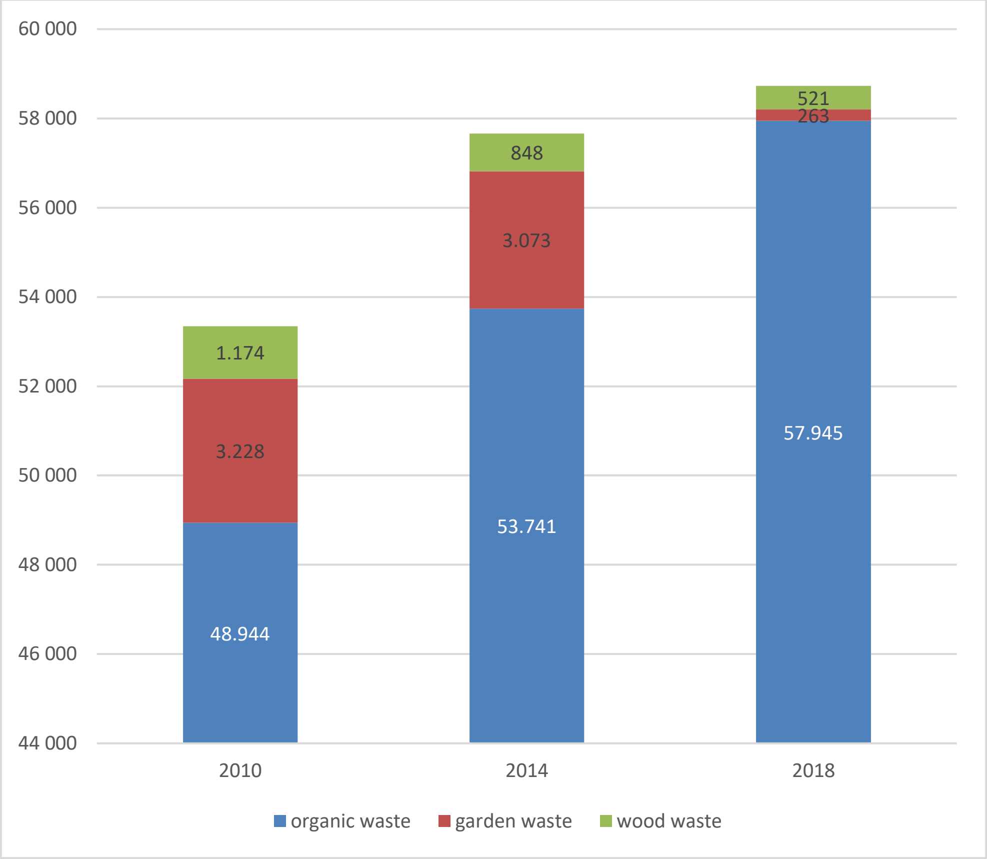

Figure 66. Year perspective for Oslo for bio-share of municipal waste between 2010 and 2018. Source: Avfallsanalyse 2018.

9.1.2 Availability of municipal wastewater sludge as feedstock

Eurostat has no data on wastewater sludge for Norway, but there is a report produced by the European Commission which reports the value for 2015 sludge in Oslo. The sludge in tonnes for 2015 in Oslo was 47,959.

9.2 Valorisation of Biological resources

9.2.1 Background information on the local waste management system

The Renovation and Recycling Agency of the municipality of Oslo is responsible for the collection and treatment of household waste. This includes waste incineration, district heating, composting facilities and the operation of the local biogas plant, as well as recycling stations. All recyclable fractions, with the exception of bio-waste, are delivered to private recycling operators. The household collection was initially sub-contracted, with the collector going bankrupt, leading Oslo municipality to take over the role as waste.

All other waste streams (e.g. public schools and businesses) are collected and treated by private enterprises.

The waste collection is financed through an annual waste collection fee that modulates based on the size of the container, beginning at about EUR 450 per year.[319] The fee is capped to the level that is needed to recover the cost of waste operation (as regulated by the Norwegian cost recovery regulation). Any revenues that arise as part of the waste operation are therefore used to reduce the waste collection fee. The wastewater collection is financed by the same principle but is separated from the solid waste collection with a separate fee.

Households are obliged to sort into four waste fractions. The fractions subject to regular collection are plastic packaging, bio-waste, residual waste and paper/cardboard/cartons. The first three are collected in the same container but are separated in the form of coloured bags (blue for plastic packaging and green for bio-waste). Furthermore, glass/metal, textiles, reusable items, gardening waste, waste electronics and electronic equipment (WEEE), dangerous waste, and bulky waste need to be delivered to various types of stations, e.g. neighbourhood containers, drop-off stations, or stores.[320]

Oslo municipality spends reportedly a lot of its effort on educating households in conducting better source separation. This is in the form of e.g. site visits as part of the school curriculum, and individual consultation of households to educate about source separation.

The collection trucks are fuelled by compressed gas, which is principally based on biomethane produced from biogas.[321]

The bio-waste is either composted or digested into biogas. The biogas is upgraded into biomethane, which is used as fuel for the public bus transport and waste collection in Oslo. The resulting digestate is sold as bio-fertiliser to farms.

With respect to wastewater sludge, the sludge is turned into biogas as well, of which some part is used for electricity and heat production, and some for transport fuel. Oslo municipality is currently in the process of upgrading its wastewater biogas plants to enable the production of biomethane for transport fuels.

The resulting biomethane is sold to gas distributors at the highest bidding price, which is determined as part of a renewable agreement. The production of biogas is not profitable so far, but the obtained revenues help recovering parts of the waste collection and treatment costs. The initial plan was that the biogas production from bio-waste would

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[319] Oslo Kommune, https://www.oslo.kommune.no/getfile.php/134409-1579085296/Tjenester%20og%20tilbud/Avfall%20og%20gjenvinning/Renovasjonsgebyr/Priser_renovasjon_private.pdf

[320] Oslo, Kommune, https://www.oslo.kommune.no/getfile.php/134759-1571397674/Tjenester%20og%20tilbud/Politikk%20og%20administrasjon/Etater%2C%20foretak%20og%20ombud/Renovasjons-%20og%20gjenvinningsetaten/Dokumenter%20Renovasjonsetaten/Sorteringsguide_visuell.pdf

[321] Seen from a mass-balance perspective. Biomethane is supplied to a gas provider, and the collection trucks use Natural gas (which principally also entaile biomethane)

achieve break-even or profitability, but due to several start-up issues with both the sorting and biogas plant, this has not been achieved so far. Reasons are, among others, an initially high degree of contamination of the bio-waste and higher maintenance requirements of the processing units than expected (e.g. for the pre-treatment, upgrading, and compression/cooling of biogas).

The waste separation of the bio-waste, plastic packaging, and residual waste is fully automated, based on the colouring the bags.[322] Also for the biogas installation, all processes are automated.

The main need for manual labour is for the transport and maintenance of processing units in the waste treatment (e.g. due to contamination of the fractions).

9.2.2 *Description of currently used and potentially available (ready to implement) technologies*

Oslo operates one biogas plant, Romerike biogassanlegg (RBA), which processes all of Oslo’s household bio-waste, and has a capacity of processing 50,000 t bio-waste per year.[323] Through fermentation into biogas, 135 local busses and 100 medium-sized farms can be supplied with biogas and bio fertiliser.[324]

The biogas plant pre-treats the raw material through mechanical separation of metals, plastics, and other undesired materials, and a reduction of the particle size down to 10 mm. Further, thermal hydrolysis (THP) is used as pre-treatment for its solid waste fractions. The THP consists of three steps. The first step pre-heats the substrate to 80-100°C. The second step boils the substrate at high temperature (130°C) and high pressure (4-5 bar) for 30 minutes, which is finally followed by a rapid decompression in the third stage. This process has been developed by a local company, Campi, and reportedly leads to a higher biogas yield than other pre-treatment methods.[325]

The THP pre-treatment further sterilises the material and increases its biodegradability.[326, 327] As a result, the resulting digestate is more suitable to be used as a bio-fertiliser (owing to the absence of e.g. pathogens and fungi). THP further alters the rheology, so that the loading rates of biogas plants (i.e. the anaerobic digester) can be doubled (as compared to other pre-treatments) and the digestate more easily dewatered.

The resulting biogas is upgraded to 99% biomethane, which is used as fuel for the busses of the public transport system. The resulting digestate is produced in three different forms (liquid, solid, and concentrated) of bio-fertiliser. The RBA biogas plant produced 25,000 m^3 of compressed biogas and 1,200 t of bio-fertiliser out of 7,300 t of bio-waste in 2013.[328] The biogas facility has encountered production issues with the gas upgrading technology,

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[322] Oslo Kommune, https://www.oslo.kommune.no/avfall-og-gjenvinning/hvorfor-kildesortere/nar-blir-noe-til-avfall/

[323] Oslo Kommune, https://www.oslo.kommune.no/getfile.php/134928-1421877643/Tjenester%20og%20tilbud/Avfall%20og%20gjenvinning/Behandlingsanlegg%20for%20avfall/Faktaark-Biologisk_behandling_av_matavfall.pdf

[324] Oslo Kommune, https://www.oslo.kommune.no/getfile.php/134922-1421877638/Tjenester%20og%20tilbud/Avfall%20og%20gjenvinning/Behandlingsanlegg%20for%20avfall/Faktaark-Biogass_og_biogj%C3%B8dsel.pdf

[325] ENS, (2012). http://ens-newswire.com/2012/03/23/food-waste-to-fuel-oslos-city-buses/

[326] Waterworld: https://www.waterworld.com/international/wastewater/article/16201472/thermal-hydrolysis-the-missing-ingredient-for-better-biosolids

[327] Oslo Kommune, https://www.oslo.kommune.no/getfile.php/134928-1421877643/Tjenester%20og%20tilbud/Avfall%20og%20gjenvinning/Behandlingsanlegg%20for%20avfall/Faktaark-Biologisk_behandling_av_matavfall.pdf

[328] Oslo Kommune, https://www.oslo.kommune.no/getfile.php/134922-1421877638/Tjenester%20og%20tilbud/Avfall%20og%20gjenvinning/Behandlingsanlegg%20for%20avfall/Faktaark-Biogass_og_biogj%C3%B8dsel.pdf

leading to about 20% of the produced biogas being flared, as opposed to the foreseen 5%.[329] This has led some municipalities to divert their bio-waste to other biogas facilities.

As of 2020, the RBA is processing 17,000 t of bio-waste – which is still below the minimum load of 30,000 t needed to ensure stable operations. This reduces the production of biogas and increases the need for co-substrate.[330] The co-substrates are provided by the private sector, and entail primarily food and feed wastes. However, no virgin materials (e.g. energy crops) nor residues that can be better valorised (e.g. as animal feed) are used.

Next to the savings in GHG emissions, the use of biomethane as a transport fuel has the side effect of producing significantly less NO_x and particulate matter in the exhaust, leading to a better ambient air quality.

With respect to the application of the digestate as bio-fertiliser, the use of bio-waste supports the recovery of phosphorus, which is a finite resource for crop production. Gardening waste is subject to composting, and the resulting compost is sold in different qualities.[331]

Oslo utilises the wastewater sludge to produce biogas. There are currently two installations, Bekkelaget renseanlegg (VAV) and Vestfjorden avløpsselskap (VEAS) which have respectively been operating since the 1960s and 1990s. The former provides biogas that is upgraded to sufficient transport quality, while the latter was in the process of upgrading as of 2017.[332] The VAV plant produced 1.7 mill. Nm^3 biogas that is nearly exclusively used for transport fuels and 21,000 t bio-fertiliser in 2016. The VEAS facility produced 8.5 mill. Nm^3 biogas for electricity and heat production (of which only 52% could be utilised) and 38,000 t bio-fertiliser.

The motivation behind upgrading both installations to provide biomethane is that owing to the abundance of hydropower in the Norwegian electricity supply, the use of biomethane to displace fossil transport fuels leads to higher GHG savings than using it to cover the facilities' own energy consumption.

The digestate resulting from the digestion process is used as bio-fertiliser. The use of wastewater sludge as fertiliser is precisely regulated and limited to specific agricultural crops and uses. The uses are determined through the testing for specific pollutants. The regulatory framework is expected to be updated in the near future, as it is outdated; it is however uncertain which changes and therewith implications can be expected. Any changes that would require the incineration of sludge, is reportedly anticipated to entail issues with respect to capacity and costs.

Owing to the restrictions associated with the use of wastewater sludge and the better quality of bio-waste as a fertiliser, wastewater and bio-waste are being kept separated in the respective biogas facilities.

9.2.3 Existing support from research organisations and other stakeholders

The biogas operators cooperate with a range of other producers and waste processors, universities, research institutes, and technical consultant firms. With respect to the latter three, these provide mainly analytical works.

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[329] Avfallsbransjen, (2020). https://avfallsbransjen.no/2020/01/13/skal-drofte-frakting-av-matavfall/

[330] Avfallsbransjen, (2020). https://avfallsbransjen.no/2020/01/20/framtiden-til-bioanlegget-pa-nes-og-haraldrudanlegget-skal-utredes/

[331] Oslo Kommune, https://www.oslo.kommune.no/avfall-og-gjenvinning/kjop-oslokompost/

[332] Oslo Kommune https://www.oslo.kommune.no/getfile.php/13243221-1505392314/Tjenester%20og%20tilbud/Politikk%20og%20administrasjon/Etater%2C%20foretak%20og%20ombud/Energigjenvinningsetaten/Dokumenter%20Energigjenvinningsetaten/2017.05.12.%20Faglig%20redegj%C3%B8relse%20om%20biogass%20i%20Oslo%20kommune%20v1.3.pdf

On the political domain, there is no network of stakeholders that gathers the whole value chain, which might be an issue for the future development of Oslo's climate strategy.

9.2.4 Legal environment, enablers & barriers

The basis for Oslo's bio-waste valorisation is the city's climate strategy, which foresees a reduction of GHG emissions by 50% until 2020 and 95% until 2030.[333] Oslo municipality initiated a set of actions to operationalise the strategy, including action on achieving zero discharges from the energy recovery of residual waste by increasing recycling.

The strategy further acknowledges the importance of alternative fuels for transport and the public bus transport as an important market for the local biogas producers.[334] According to the Norwegian waste processors association (Afvall Norge) however, high uncertainty remains with regards to ensuring a long-term demand for biogas-based transport fuels. One of the reasons is for example that the local public bus operator (Ruter) recently procured buses that run on imported biodiesel rather than biomethane.[335] The origin of this decision are the comparably higher costs, as there is e.g. a higher need for investments into infrastructure for biomethane. Furthermore, owing to preceding issues with air quality and the 'Dieselgate' revelations, there is a strong political intent to move to zero tailpipe emissions from busses, i.e. busses run on electric powertrains, instead of zero GHG emissions on the municipal level. Biofuels are therefore only seen as an intermediary step. The investment into biogas infrastructure for buses can in this light thus be seen as a redundant investment.

The GHG reduction potential from Norwegian biogas has been identified to be more favourable than the EU default values applied in the EU's Renewable Energy Directive (RED II, Directive 2018/2001). Buyers of biogas reportedly rely on these default values, which constitutes a barrier as the comparative GHG advantage is less evident.[336, 337]

To address this issue, several producers commonly developed a GHG savings tool to document the better savings potential. The GHG savings are reportedly at least 90%, with a potential well-above 100% when the biogas digestate is used as bio-fertiliser. The calculation is based on the RED II, but is adjusted for the use of waste feedstocks. In comparison, the default GHG savings of the RED II for biomethane for transport from bio-waste have a range of 20% – 80%.

The draft of the Norwegian climate action plan foresees a major role of biogas in the country's ambitions to reduce its GHG emissions by 95% until 2050.[338] The reasons provided for its high importance are two-fold: The road transport accounts for 30% of

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[333] Oslo Kommune https://www.oslo.kommune.no/getfile.php/13174213-1480690015/Tjenester%20og%20tilbud/Politikk%20og%20administrasjon/Etater%2C%20foretak%20og%20ombud/Klimaetaten/Dokumenter%20og%20rapporter/Climate%20and%20Energy%20Strategy%20for%20Oslo%20ENG.pdf

[334] Oslo Kommune, https://www.oslo.kommune.no/getfile.php/13320491-1554793018/Tjenester%20og%20tilbud/Politikk%20og%20administrasjon/Etater%2C%20foretak%20og%20ombud/Klimaetaten/H%C3%B8ringsinnspill%20til%20faggrunnlaget/Avfall%20norge%20-%20h%C3%B8ringsinnspill%20til%20faggrunnlag.pdf

[335] Budstikka, https://www.budstikka.no/nyheter/ruter-refs-vraket-lokal-biogass-vil-heller-importere-biodiesel/1917!/

[336] https://www.oslo.kommune.no/getfile.php/13261623-1513171475/Tjenester%20og%20tilbud/Politikk%20og%20administrasjon/Etater%2C%20foretak%20og%20ombud/Energigjenvinningsetaten/Dokumenter%20Energigjenvinningsetaten/Baerekraft-og-klimanytte-for-norskprodusert-biogass-2017.pdf

[337] https://www.oslo.kommune.no/getfile.php/13243221-1505392314/Tjenester%20og%20tilbud/Politikk%20og%20administrasjon/Etater%2C%20foretak%20og%20ombud/Energigjenvinningsetaten/Dokumenter%20Energigjenvinningsetaten/2017.05.12.%20Faglig%20redegj%C3%B8relse%20om%20biogass%20i%20Oslo%20kommune%20v1.3.pdf

[338] https://avfallsbransjen.no/2020/01/29/vil-ha-forutsigbarhet-for-biogass/

Norway's GHG emissions, for which biomethane can serve as an alternative fuel for heavy transport. In addition, biogas is perceived as a building stone for additional products, such as biopolymers and bio-char. Until the Norwegian climate action plan is final however, stakeholders express uncertainty to which extent biogas is expected to be part of the circular economy or mere as a bridging technology – constituting a (temporary) barrier.

According to Oslo's renovation and recycling agency however, the outlook for biomethane in heavy transport is positive. The road tolls in Oslo were recently reduced for biomethane-fuelled vehicle[339]. This led to reportedly positive feedback by stakeholders as it makes the investment into biogas fuelled vehicles more feasible and contributes to the EU Waste Framework Directive's (WFD) recycling target of 65%. Biodiesel is excluded from the reduced toll, as it does not contribute to the recycling target.

A further local barrier is the current regulation on how waste treatment can be financed.[340] The Norwegian 'selvkostregelverket' puts an upper limit on the total fees that municipalities can collect from citizens and it further regulates, which costs may be covered with it. As a result, not all investments and cost for raw materials (e.g. livestock manure), can be covered through waste handling fees.

An analysis of the residual waste fraction in 2019 has shown that bio-waste still exhibits a large share of the residual waste: about half (55%) of the bio-waste is still disposed as residual waste, with the remainder being sorted as bio-waste.[341] There is thus still a significantly untapped potential of bio-waste supply.

9.3 Valorisation of Biological resources in 2030

9.3.1 Future management of the waste streams in 2030

There are no specific changes foreseen in terms of the waste management. The political focus lies on compliance with the EU WFD and minimising the cost base. The WFD's material recycling target of 65% reportedly requires Oslo to introduce further measures. Next to the reduced road toll for biogas in heavy transport referred to above, Oslo municipality is evaluating different options, which includes a second sorting stage of the residual waste fraction and scaling up existing composting plants.

There are further on-going considerations of introducing different waste separation systems across the city, as different areas perform differently in waste separation. Introducing different systems is seen as an option to further utilise the untapped potential of increased bio-waste separation (as referred to above). The municipality is therefore currently testing the effectiveness of providing separate bio-waste containers.

Finally, additional changes in the waste management may result from a currently on-going evaluation of the local incineration- and biogas plants, reconsidering the current business model and the extent to which the Norwegian cost recovery regulation imposes barriers.

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[339] https://www.aftenposten.no/norge/i/GGOdxB/biler-med-biogass-kan-faa-bompengerabatt?

[340] Regjeringen, https://www.regjeringen.no/contentassets/6a5da53b1ba243eb86a4e2314abe96a4/husdyrgjodsel-til-biogass---gjennomgang-av-virkemidler-for-okt-utnyttelse-av-husdyrgjodsel- til-biogassproduksjon.pdf

[341] https://www.oslo.kommune.no/getfile.php/13352467-1575467207/Tjenester%20og%20tilbud/Avfall%20og%20gjenvinning/Avfallsanalysen/Avfallsanalyse%202019.pdf

9.3.2 *Future available methods/technologies for processing methods for managing separated bio-waste streams in 2030.*

Neither are chances foreseen in terms of the existing business model, nor in terms of increasing the level of automatisation and digitisation.

9.3.3 *Description of future technological potential available (ready to implement) for bio-waste processing)*

Oslo's renovation and recycling agency does not expect that any novel technologies will be market ready within this decade.

9.3.4 *Future legal environment, enablers & barriers*

Oslo's climate strategy and the Norwegian climate action plan are the two primary strategic documents, which will give rise to measures to stimulate the local bioeconomy.

According to Oslo's renovation and recycling agency, the framework of the RED II constitutes a barrier for the city's ambitions of promoting biomethane as an alternative fuel. The reason being that the Directive does not properly account for the overall life-cycle emissions. For example, the default values for electric powertrains entail zero GHG emissions, not accounting for emissions resulting from the required electricity production. Similarly, the GHG savings from using the biogas digestate as fertiliser are not accounted for; although they can lead to GHG savings of more than 100% in the context of Oslo. If no credit is given to these additional savings, there are reportedly also no incentives to obtain these savings. In conclusion, Oslo's renovation and recycling agency proposes to review the approach to identifying the GHG emission savings in the RED II, taking account for all life-cycle stages.

10 Case study of the city of Rotterdam

Rotterdam is a city located in the South Holland province and is the second largest city in the Netherlands. Alongside The Hague metropolitan area, the city is the 13th most populous area in the European Union. Rotterdam is Europe's largest seaport and an epicentre of trade and logistics. Rotterdam is known for its university, modern architecture and dedication to green spaces. In 2018, the city invested EUR 233 million in seven different projects dedicated to greenspace and social housing; they are projected to finish in the next 10 years. With this, there are multiple educational institutions and programmes that are devoted to sustainable architecture and green cities.

A key feature of a highly sustainable city is its waste management practices. Rotterdam does not fail in this regard and has a dedicated recycling programme as well as a recently developed plan for a waste-to-chemistry plant. More specifically, the plant will convert around 360,000 tonnes of plastic and mixed waste into 220,000 tonnes of new raw materials for the chemical industry. Waste collection in Rotterdam makes use of Enevo, a company specialising in innovative wate management through data analytics and route planning. The company is extending a project with the city to improve the overall efficiency of the current waste disposal plan.[342]

Table 69. General information on the city of Rotterdam.

City	Rotterdam
Country	The Netherlands

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[342] https://cities-today.com/rotterdam-increases-efficiency-of-waste-collection/

Geographical location	South Holland province
Population	644,618 inhabitants
Population density (inhabitants per km²)	1,979
GDP (EUR)	EUR 62.01 billion[A]
GDP per capita (EUR)	EUR 40,237[B]
Green urban areas (%, Area)	30-40% [C]
Number of operating research centres promoting the bioeconomy	
• Rotterdam University of Applied Sciences • Business Booster – Value Creation in the Next Economy • Creating Resilient Cities • River Delta Development Erasmus University Rotterdam • Urban Economic Development and Resilience track • Urban Environment, Sustainability & Climate Change • Urban Land Governance for Sustainable Development	
Sources:[343] [A] Arcadis, n.d.; [B] Teleport, 2020; [C] Fuller & Gaston, 2009	

10.1 *Analysis of the municipal waste generation scheme, trends, and future milestones*

10.1.1 *Availability of municipal bio-waste as feedstock*

Rotterdam has seen a major spike in the bio-share of municipal solid waste, namely in organic waste. The city's waste policy was recently overhauled and for 2015 set a goal of 83% recycling of all waste, which has helped in national separation targets as well. The major increase between 2014 and 2018 could be attributed to this 2015 target as the amount of organic waste became over 10 times higher across the 8 year timespan.[344]

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[343] Arcadis, n.d. https://www.arcadis.com/media/4/8/3/%7B483A4E62-BBD5-4328-9877-3A1113FB28BD%7DRotterdam%20City%20Focus.pdf; Teleport, 2020 http://teleport.org/cities/rotterdam/; Fuller, R. A., & Gaston, K. J. (2009). The scaling of green space coverage in European cities. *Biology letters*, *5*(3), 352–355. https://doi.org/10.1098/rsbl.2009.0010

[344] https://rotterdamcirculair.nl/

Table 70. Bio-share of municipal waste generated in Rotterdam for 2010, 2014, and 2018. Source: https://rotterdamcirculair.nl/

Year	2010	2014	2018
Organic Waste	794	1,160	8,912
Wood Waste	10,254	7,569	8,179
Total	**11,048**	**8,729**	**17,091**

10.1.2 Availability of municipal wastewater sludge as feedstock

The most recently available data for wastewater sludge for Rotterdam is taken from Eurostat. Data past 2016 was not available and the closest estimate for sludge is reported based on kilograms per capita and then multiplied by the population for the relevant year. The data is presented below for Rotterdam.

Table 71. Wastewater sludge data for 2010, 2014 and 2016.[345]

Year	2010	2014	2016
Wastewater Sludge (dry matter, t)	12,560	12,676	12,888

10.2 Valorisation of Biological resources

10.2.1 Background information on the local waste management system

The collection of household waste is the municipalities' responsibility. The responsible authority in Rotterdam is 'Schone Stad.' Households must pay an annual flat fee for waste collection, which is modulated based on the number of persons in a household. In 2020, the fee ranged from about EUR 285 to EUR 370, for single-family houses with households of respectively one and three or more persons.[346] The fee modulates in a similar dimension for multi-residential homes.

The regular waste collection consist of paper- and cardboard, glass, textiles, organic household waste (kitchen and small gardening waste), and residual waste.[347] There are further fractions that, depending on the individual fraction, can be collected free-of-charge, delivered to recycling stations, thrift shops, or places of purchase. These consist of usable large items, small chemical waste, used fats and oils, WEEE and larger residual waste.

The waste is collected in individual household containers for low-rise buildings and collective neighbourhood containers, which are underground or semi-deepened, for high-rise buildings.

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[345] Eurostat, 2020 https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_ww_spd&lang=en

[346] https://rotterdambis.notubiz.nl/document/8305519/1/Verordening%20afvalstoffenheffing%202020

[347] https://www.rotterdam.nl/wonen-leven/afval/afvalwijzer-online.pdf

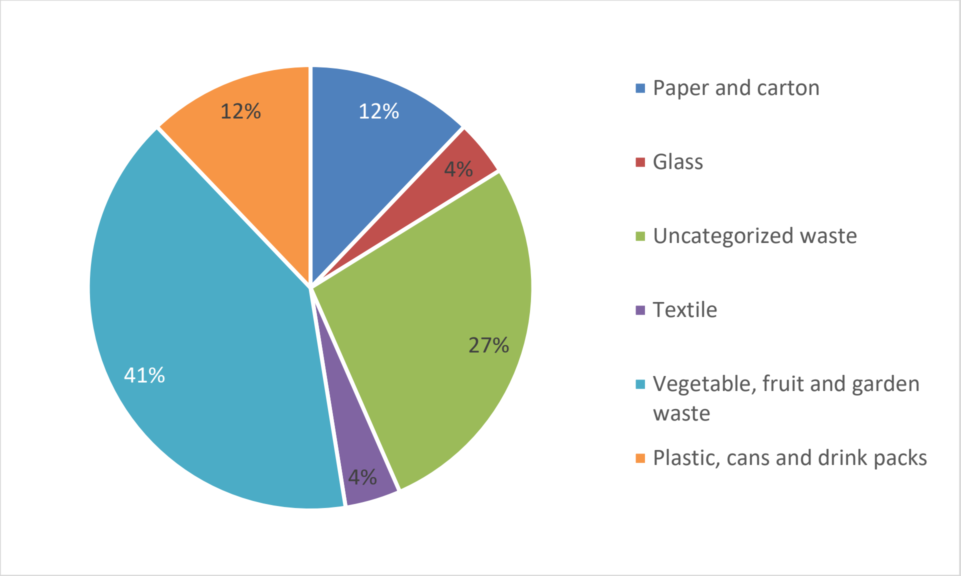

Figure 67. Makeup of household waste in Rotterdam. Adapted from source: https://www.rotterdam.nl/wonen-leven/afval/afvalwijzer-online.pdf

An assessment by the municipality has identified that about 40% of the mass of household waste is composed of organic household waste. The collection of organic household waste was introduced in 2014, and its roll-out is expected to be complete by 2023. Between 2014 and 2018, the amount of organic household waste collected increased more than ten-fold to 15 kg per capita.

Organic waste is collected at least on a fortnightly basis from currently 60,000 homes in low-rise buildings. The organic waste is currently processed by two companies (Indaver and Attero) into biogas and/or compost.[348, 349] About 11,000 tons of organic waste were collected in 2019, resulting in 4,000 tons of compost.[350]

Rotterdam is characterised by a limited availability of open space, leading to a high share of stacked and high-rise buildings (accounting for 75% of the population), coupled to limited public space. The collection of organic waste from high-rise buildings on a large scale has therefore been challenging in the past. To overcome this challenge, which generally applies in the Dutch context, a comprehensive study in multiple Dutch cities investigated and tested therefore incentive mechanisms to increase organic waste separation in high-rise buildings.

The study identified a basic package that is required to ensure effective organic waste separation, consisting of an organic waste container, communication materials, and a kitchen tray.[351] Building on these results, Rotterdam will commission organic waste separation in high-rise buildings from 2021 on, targeting 100% coverage by 2023. The organic waste will be collected with small rolling containers in a casing.[352]

Rotterdam is currently testing collection trucks that are fuelled by 'green energy' (more specific information could not be identified), as part of the municipality's efforts of making the collection fleet more sustainable.

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[348] https://www.indaver.com/nl-en/in-the-netherlands/
[349] https://www.attero.nl/en/
[350] https://www.rotterdam.nl/wonen-leven/gft/gft-infographic-2020.pdf
[351] https://www.vang-hha.nl/nieuws-achtergronden/2020/verbetering-afvalscheiding-hoogbouw/
[352] https://www.rotterdam.nl/nieuws/hoogbouw-gfe/

There are no changes foreseen regarding the overall waste management in Rotterdam towards 2030. Rotterdam has however set to medium-term target of halving its use of raw materials through increased reuse and recycling.

10.2.2 Description of currently used and potentially available (ready to implement) technologies

The collected organic waste is either composted or fermented. Alternatives are restricted by law or technically not yet possible.

The processing of wastewater sludge currently plays no central part in Rotterdam's circular economy programme (which forms the basis for Rotterdam's bio-waste ambitions, and is further presented below). Wastewater treatment is conducted by private service providers. The resulting wastewater sludge is processed into biogas.[353] At the port of Rotterdam, the digestate is further dried into granulate to fuel power stations.[354]

The municipality of Rotterdam and its partners are researching alternative technologies to biogas and compost, without any tangible results so far. According to the municipality, many technologies are not sufficiently ready yet for the application on the larger scale, whereas those technologies that are ready, the legal provisions prohibit such. The local legislation prohibits for example the production of fuel from bio-waste.

10.2.3 Existing support from research organisations and other stakeholders

Rotterdam's Circular Economy programme focuses on four sectors: agri-food and green flows, construction, consumer goods, and healthcare. These sectors were identified as part of a comprehensive stakeholder engagement process.[355] For each of these sectors, stakeholders took part in identifying and assessing relevant actions for each sector. In each sector, the municipality cooperates with a range of different types of stakeholders (i.e. enterprises, civil society, and institutions).

The Port of Rotterdam is also home to the world's largest bio-industrial cluster. The port acts as a location for the supply of bio-based feedstocks and contains five biofuel plants and biochemical plants.

10.2.4 Legal environment, enablers & barriers

The basis for Rotterdam's ambitions is the programme 'Circular Rotterdam', which defines the city's vision that households do not produce any residual materials by 2050.[356] As part of this programme, the municipality elaborated a set of measures that have been and will be enforced (referred to as the 'Raw Materials Note' – or 'Grondstoffennota'). [357]

An intermediate target is reducing the amount of residual waste from 296 kg per capita in 2018 down to 249 kg per capita in 2022 (i.e. a reduction of 16%), through a reduction in waste production and improved waste separation.

The progress of the 'Raw Materials Note' is subject to an annual implementation review by the 'BWB' (Building, Living and Outdoor Space) committee, which has however not yet been conducted as of 2020.

The 'Circular Rotterdam' programme for 2019-2023 has set the target to increase the share of energy that is produced from organic household waste, coupled to a reduction in food

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[353] https://www.wshd.nl/slibverwerking
[354] https://centraleslibverwerkingrotterdam.wordpress.com/over-csr/
[355] https://www.metabolic.nl/publications/circular-rotterdam/
[356] https://www.rotterdam.nl/wonen-leven/dat-doe-je-goed/
[357] https://rotterdam.notubiz.nl/document/7668776/1/s19bb016192_3_48473_tds

waste, and better separation of the residual and organic household waste.[358] There is still a large part of the organic waste being lost in incineration with energy recovery as it is either not separated from residual waste or contaminated with other waste fractions (rendering it unusable for e.g. biogas).

The national government is further currently finalising its National Waste Management Plan, which incorporates the new guidelines from the EU Waste Framework Directive and is expected to provide further legitimisation for Rotterdam's circular economy efforts.

A Dutch taskforce on existing barriers, has identified several barriers that impede the circularity.[359] With respect to bio-waste, the most important ones are as follows: the REACH regulation poses stricter requirements to secondary- than primary raw materials.[360] Risks, for example with regard to ecotoxicity (e.g. cadmium in phosphate fertiliser from phosphate rock), are accepted in primary substances, and the regular risk assessment and registration according to the REACH is sufficient. For secondary raw materials however, additional risk assessments are requested, such as regarding drug residues and pathogens that are covered by the REACH or POP Regulations.

A further barrier identified, is the lower price of primary raw materials compared to secondary raw materials – where measures are needed to stimulate the demand for secondary raw materials.

The pollution of organic waste is an issue for Rotterdam's waste processors. In order to mitigate the risk of pollution in high-rise buildings, the municipality is conducting an extra communication effort to facilitate and inform residents on proper separation and costs of contamination.

According to the municipality of Rotterdam, further pursuing source separation will be the most viable strategy in improving bio-waste valorisation, by securing sufficient supply.

11 Case study of the city of Turku

The city is located on the Baltic Sea coast and its economy is centred around the Port of Turku. In addition to its industry being closely linked to the maritime sector and trade, the city is a hub for learning and research with such institutions like Turku Science Park, University of Turku, Åbo Akademi and Turku University of Applied Science.

In 2019, the City of Turku signed a Sustainable Development Partnership Agreement with the Finnish Innovation Fund Sitra (hereafter Sitra)[361] on becoming carbon neutral by 2029 (on city's 800th anniversary) and climate positive hereafter.[362] To achieve this ambitious goal, the city will combine climate mitigation and adaptation measures with circular solutions.[363] The circular economy is thus pivotal to the city's climate neutrality. As a part of Circular Turku project[364], the city is currently working on an inclusive and systemic circular economy action plan for the Turku region.

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[358] https://rotterdam.raadsinformatie.nl/document/7381743/1/s19bb012023_4_50688_tds

[359] https://www.rijksoverheid.nl/documenten/rapporten/2019/10/10/adviesrapport-taskforce-herijking-afvalstoffen

[360] Primary raw materials are from virgin origin, whereas secondary raw materials are from recycled origin. https://ec.europa.eu/environment/green-growth/raw-materials/index_en.htm

[361] SITRA is a Finish Innovation Fund that collaborates with partners from different sectors to research, trial and implement new ideas, https://www.sitra.fi/en/

[362] https://www.turku.fi/uutinen/2019-02-01_sitra-ja-turku-tekevat-ilmastopositiivista-kaupunkia

[363] City of Turku, ICLEI (2020). Circular Turku: Regional Collaboration for resource wisdom. Bonn, February 2020.

[364] It is a project between ICLEI and city of Turku, aiming to design a regional roadmap to operationalize circularity in the Turku region: https://www.iclei.org/en/Circular_Turku.html

Table 72. General information on Turku. Sources: turku.fi, teleport.org, https://www.ymparisto.fi/en-US/Maps_and_statistics/The_state_of_the_environment_indicators/Communities_and_transport/Plenty_of_urban_green_in_Finnish_cities(28895)

City	Turku
Country	Finland
Geographical location	60o27.1'N, 22o16.2'E
Population	191,331 (2018)
Population density (inhabitants per km²)	779
GDP (EUR)	7,031,414,250
GDP per capita (EUR)	36,750
Green urban areas (%, Urban Area)	Around 32% (2013)
Operating research centres promoting the bioeconomy	
Turku Science Park University of Turku Åbo Akademi Turku University of Applied Science Novia University of Applied Sciences	

11.1 Analysis of the municipal waste generation scheme, trends, and future milestones

11.1.1 Availability of municipal biodegradable waste as feedstock

Table 73 presents the data on waste sources by treatment in Finland in 2018. The data for the Southwest region is presented below.

Table 73. Municipal waste by treatment method in Finland in 2018. Source: Waste statistics 2018, Statistics Finland

	Total	Material recovery, without aerobic and anaerobic digestion	Aerobic and anaerobic digestion	Energy recovery	Incineration without energy recovery	Landfilling and other disposal
Mixed waste	1,465,449	12,724	14,467	1,424,399	0	13,860
Separately collected waste total	1,431,111	863,473	378,731	183,225	953	4,729
Separately collected paper & cardboard waste	490,418	455,628	0	34,790	0	0
Separately collected biodegradable waste	**424,793**	**13,406**	**367,511**	**41,993**	**63**	**1,820**
Separately collected glass waste	89,985	79,831	0	10,044	50	60

Separately collected metal waste	154,465	154,464	0	0	1	0
Separately collected wood waste	**115,746**	**56,988**	**168**	**58,590**	**0**	**0**
Separately collected plastic waste	67,145	42,377	0	24,204	5	559
Separately collected electrical and electronic waste	57,477	57,476	0	0	1	0
Other separately collected fractions	31,082	3,303	11,052	13,604	833	2,290
Other and unspecified waste	144,522	9,775	6,541	124,827	19	3,360
Total waste	**3,041,082**	**885,972**	**399,739**	**1,732,451**	**972**	**21,949**

The share of biodegradable waste out of total municipal waste in 2018 is 14% (i.e. 424,793 tonnes). 87% of biodegradable waste is treated by aerobic and anaerobic digestion, 10% by energy recovery and 3% by material recovery (see Figure 68). Another important source of bio-resource is wood waste, which accounts for 3,8% of total municipal waste in 2018. Wood waste is primarily used for energy recovery (51%) and material recovery (49%).

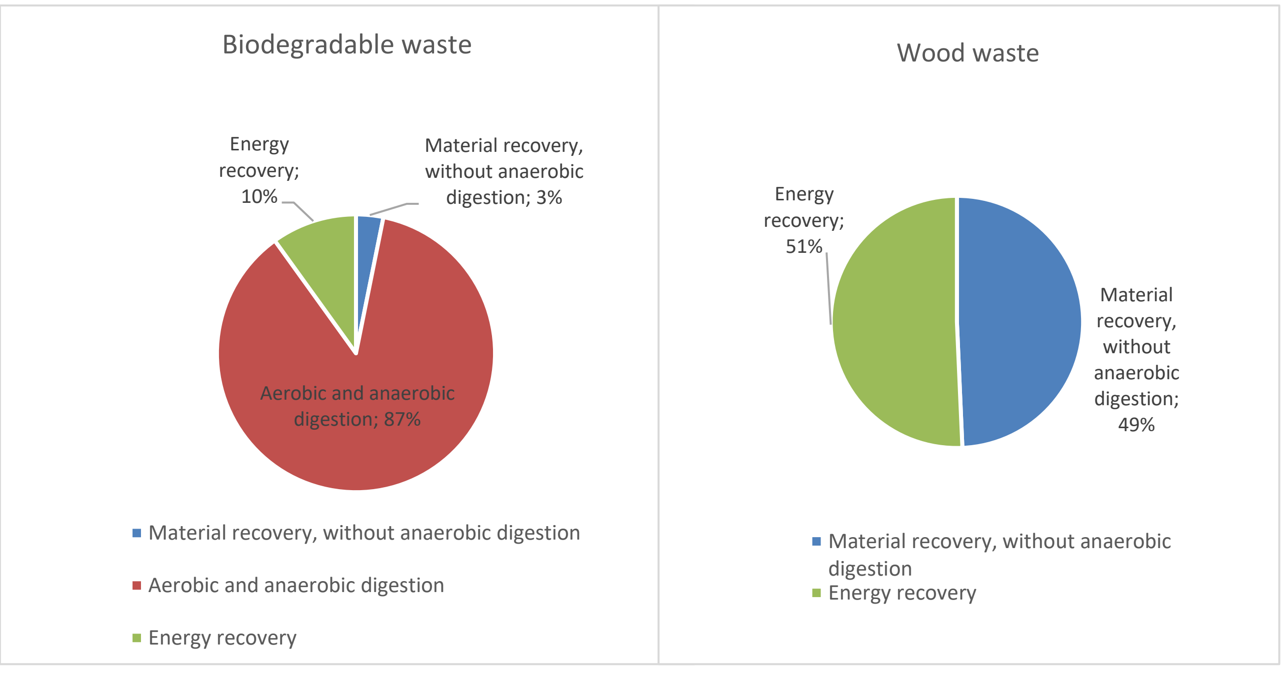

Figure 68. Treatment of biodegradable and wood waste in 2018. Source: Waste statistics 2018, Statistics Finland.

Municipal waste in the city of Turku is managed by Lounais-Suomen Jätehuolto Oy (LSJH), which is owned by 17 municipalities in the Southwest Finland. LSJH collects mixed and recyclable waste from the municipalities, including bio-waste. Table 73 presents the quantities of bio-waste collected by LSHJ for the 17 municipalities. No specific data for the city of Turku was identified. According the LSJH annual report 2019, the company collected 8,600 tonnes of bio-waste in the region.[365]

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[365] LSJH Annual Report 2019, available: https://vuosikatsaus.lsjh.fi/2019/ymparistoa-suojellen/

Table 74. Bio-waste collected in 2019 in Southwest region, Finland. Source: Calculated based on the information provided in the LSJH Annual Reports for 2016, 2017, 2018, 2019 available at: https://www.lsjh.fi/fi/

Year	**2016**	**2017**	**2018**	**2019**
Separately collected bio-waste (tonnes)	7,500	7,500	N/A	8,600

11.1.2 *Availability of municipal wastewater sludge as feedstock*

The wastewater sludge data for the city of Turku is calculated using data from Eurostat on urban wastewater sludge totals from treatment plans in each country within the case study. The values for kilograms per capita for the years 2008, 2010, 2012 and 2014, are reported and then multiplied by the population for each city or region for the corresponding year to get a rough estimate. This estimate can be assumed to be close to the value for the case studies in question.

Table 75. Wastewater sludge data for Turku for the years 2008, 2010, 2012 and 2014. Source: Eurostat, 2020 https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_ww_spd&lang=en

Year	**2008**	**2010**	**2012**	**2014**
Wastewater Sludge (dry matter, t)	4,773.6	4,728.3	4,690.2	3,882.2

The sludge produced by Kakolanmäki Wastewater Treatment Plants (WWTP) is treated by Gasum Oy, which owns a biogas plant at the Topinoja waste treatment centre in Turku. The plant processes around 50,000 tons of sludge from Kakolanmäki WWTP per year, producing 30 GWh / year used for various transport needs.[366] Digestate from sludge is used as fertilisers in agriculture (1/3) and in landscaping (2/3).

11.2 *Valorisation of Biological resources*

11.2.1 *Background information on the local waste management system*

Waste management in the city of Turku is organised by LSJH. The city of Turku owns 27% of LSJH and is the biggest shareholder. The company is responsible for collection and treatment of waste for more than 400,000 residents in the region. LSJH manages four waste treatment centres and eight sorting stations.

LSJH is financed through service fees rather than receiving direct funding from the municipalities. There are three main ways in which the waste management is financed:

- Fees for dropping off different types of waste at local recycling centres in each area, prices vary according to type of waste and by amount;
- The collection and transportation of waste products for companies and individuals;
- A yearly fee which is charged to property residents for handling their household waste and providing other services.

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[366] Operationalizing Regional Circularity, Best Practices From Turku,
From Extraction to Resource Recovery, A Systemic Water
Concept in Turku: https://www.turku.fi/sites/default/files/atoms/files//circular_turku_-_case_study_3.pdf

- The primary goal of the waste management is to recycle as much of the waste as possible. The unrecycled waste is primarily used as energy.

Sorting, pre-collection

Household waste is sorted into the following fractions: bio-waste, carton, glass, metal, paper, plastic packaging, electrical devices, hazardous waste and burnable waste.[367] Bio-waste consist of food scraps, fruits and vegetables peels, coffee and tea grounds, paper towels, spoiled groceries, fish bones and small bones, flowers and plant parts. Bio waste can be placed in composter or bio-waste container. If those two options are not available, the bio-waste can be put in the container for burnable waste (i.e. mixed waste container). According to a household waste sorting survey conducted by the LSJH, mixed waste still contained about 32% bio-waste in 2016.

In Turku every property must have a waste container for burnable waste and pay the service fee to LSJH. Any properties which are deemed to not be properly connected to waste management or which do not have proper containers to collect recyclables will be reported to the environmental protection unit, which can give out fines to both corporations and private individuals.

Collection, transportation & destination

The collection and transportation of waste is organised around three types of collection points:

1 Residential containers: every household has two containers, one for burnable/mixed waste the other for bio waste. These containers are emptied by LSJH and transported to their destination. The burnable waste is driven to the municipal waste incineration plant, while the bio waste is taken to be transformed into biogas or fertiliser.

2 Recycling points or containers for recyclables: these are containers for metal, glass, paper and cardboard. Large apartment buildings and houses may have their own containers for recyclables. These containers are emptied by LSJH and then brought to manufacturers who reuse the materials in their production.

3 Collection points: these are for large items, electrical devices, construction/garden waste, hazardous waste, plastic containers and end of life textiles. Individuals or companies must drive these items or pay to have LSJH transport their waste to large collection points. Electrical and hazardous devices are safely disposed of. Large items and construction waste are recycled for the materials or used for energy production. Plastics and textiles are reused in manufacturing or used in energy production.

According to the company emissions from transportation are notably lower than emissions from its treatment. Only about 1.5% of the waste recovered ended up not being used at all.

There are future plans to make local trucks transporting bio-waste run on biogas rather than the current diesel-powered trucks. This would make the transportation of waste more sustainable in the long-term.[368]

Sorting, post-collection

After collection of recyclable waste, LSJH sends recyclables to different companies or

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[367] https://www.lsjh.fi/en/jatelaji/bio-waste/
[368] https://www.gasum.com/en/About-gasum/for-the-media/News/2017/turku_en/

treatment facilities who can use them. For example, wood, paper, cardboard resources are sent to companies like Kompotek that uses these resources to replace plastic parts in different industries.[369]

By producing energy and products from waste instead of disposing of it, the system encourages the valorisation of waste. LSJH has also worked with local companies to understand what types of waste they can best use in their operations. This has simplified companies getting these materials and thereby increased their value.

Both bio-waste from LSJH and from Kakolanmäki WWTP are sent for treatment to the biogas plant at the Topinoja waste treatment centre, owned by Gasum Oy. Bio-waste is also used as fertiliser through composting.

No information on how labour intensive is collection and processing of biodegradable waste was identified.

11.2.2 Description of currently used and potentially available (ready to implement) technologies

Currently, the bio-waste collected as part of the municipal waste collection is used for production of biogas and biofertilisers. Bio-waste is delivered to Biolinja Oy's biogas plant, where energy and nutrients are produced from it.[370] Biolinja Oy's uses anaerobic digestion to produce biogas.

Similar to the waste management system in Turku, the project to transform the regions wastewater management system began with a collaboration between 14 municipalities to maximise the nutrient capture. Together the municipalities formed Turku Region Water Ltd. (Turun Seudun Vesi Oy) and Turku Region Wastewater Treatment Plant Ltd. (Turun seudun puhdistamo Oy).[371] The latter is responsible for operation of Kakolanmäki Wastewater Treatment Plant (WWTP) that treats most of the wastewater from the Turku region. Kakolanmäki WWTP uses mechanical, chemical and biological treatment processes to ensure efficient purification process. These processes can reach up to 99% of removal of organic matter and phosphorous and 80% removal of nitrogen.[372]

Wastewater sludge is transported from Kakolanmäki WWTP to Gasum Oy to recover the nutrients and produce biogas. Gasum Oy is a state-owned company that owns a biogas plant at Topinoja waste treatment centre in Turku. The plant produces around 30GWh of biogas per year from around 50,000 tons of sludge. The biogas produced there is used for the regional transportation needs. In addition, the nutrients form digestate are recovered as either fertilisers or landscaping, whereas the nitrogen products from the sludge are sold to chemical companies. In 2018, Gasum Oy entered into collaboration with Algol Chemicals to supply recycled nutrients (i.e. ammonia water).[373]

Kakolanmäki WTTP also supports energy recovery from the wastewater. It has a heat pump station, which Turku Energy Ltd utilises to extract heat from wastewater. Approximately 160 GWh of thermal energy per year are produced for district heating purposes and 30 GWh per year for district cooling. The heath recovery system is considered very efficient,

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[369] http://www.kompotek.fi/in-english/

[370] LSJH Annual Report 2017, available: https://lsjh.e-julkaisu.fi/vuosikatsaus2017/

[371] From Extraction To Resource Recovery, A Systemic Water Concept In Turku, Case Study https://www.turku.fi/sites/default/files/atoms/files/circular_turku_-_case_study_3.pdf

[372] Ibid.

[373] https://bioenergyinternational.com/biogas/recovered-nutrients-from-gasum-turku-biogas-plant-to-be-recycled-for-industry

with one unit of electrical energy used at the station producing three units for district heating and two units for district cooling.[374]

11.2.3 Existing support from research organisations and other stakeholders

Since 2015 when the city set the target of implementing the principles of resource wisdom[375] by 2040, the priority of the city has been to acknowledge and build on these existing strengths through direct collaboration with regional, national and international stakeholders.

Regional collaboration around the circular economy has enabled the city of Turku to design innovative projects at an appropriate scale and to mitigate the risks and burden of related upfront investments. In addition, cooperation across different levels of government (regional councils, national bodies, European institutions) has created a momentum around circular economy efforts in Turku.[376]

As such, the city of Turku is actively collaborating with regional and national actors to operationalise the circular economy. The key actors include:

- On the **international level**, the city of Turku is collaborating with the Green Circular Cities Coalition managed by ICLEI – Local Governments for Sustainability[377] to learn from best practices on circularity at a city level.

- On the **national level,** Turku engages with stakeholders such as the Ministry of Environment and Sitra. Exchanges with research institutions that develop tools for operationalising circular economy, such as the Finnish Environment Institute, are also central partners for Turku in widening the knowledge base and outlining key actions. For example, the city collaborates with Sitra on the Circular Turku project.

- On the **regional level,** public collaborators include for example the Service Centre for Sustainable Development and Energy of Southwest Finland (Valonia), the Regional Council of Southwest Finland and the Centre for Economic Development, Transport and the Environment of Southwest Finland (ELY Centre). Furthermore, municipality networks in Finland, such as the Finnish Sustainable Communities (FISU) network, are an important source of inspiration and peer-to-peer knowledge exchange.

- On the **local level**, the city is involving local businesses as well as regional and local waste, energy and water companies in its circular economy strategy by collecting their inputs and incentivising them to include circular economy principles into their work. Here, industrial symbiosis play an important role to facilitate circularity.

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[374] From Extraction To Resource Recovery, A Systemic Water Concept In Turku, Case Study https://www.turku.fi/sites/default/files/atoms/files/circular_turku_-_case_study_3.pdf

[375] The term ‘resource wisdom’ refers to an operating model developed by Sitra through which cities and municipalities can promote carbon neutral and waste free activities, while using resources within the ecosystem boundaries by 2050, see more: https://www.sitra.fi/en/topics/resource-wisdom/#what-is-it-about

[376] City of Turku, ICLEI (2020). Circular Turku: Regional Collaboration for resource wisdom http://e-lib.iclei.org/publications/Turku-report-web.pdf

[377] ICLEI – Local Governments for Sustainability is an international network consisting of over 1500 cities and sub-regional units that have committed to sustainability: http://eastasia.iclei.org/work/featured_activities/450.html

The feasibility study to Build an Active Network of Circular Economy Actors in the Turku region identified approximately 700 experts working within circular economy, of which approx. 270 businesses.[378] The key actors include among others:

- **The City of Turku**, Valonia, the Regional Council of Southwest Finland, LSJH, Topinpuisto, Smart Chemistry Park, Union of the Baltic Cities and the ELY Centre for Southwest Finland;
- **University of Turku**, focusing on the research in the field of biochemistry, biotechnology, food chemistry and food development as well as molecular plant biology;
- **Åbo Akademi**, Process Chemistry Centre;
- **Novia University of Applied Sciences** (Raasepori and Vaasa units) focusing on bio-economy and sustainable energy economy;
- **Turku University of Applied Science,** focusing on circular economy business models, platforms of value creation, built environment, product processes, new energy and water technology and environmental technology;
- **Turku Science Park Oy**, focusing on industrial symbioses in the Turku region.

11.2.4 Legal environment, enablers & barriers

The city's focus on circular economy and achieving climate neutrality by 2029 is grounded in the EU, national and local goals. At the EU level, the city's ambition on low carbon economy is in line with the EU's Green Deal, the Action Plan on the Circular Economy and the Plastics Strategy. At the national level, a strategic programme on circular economy is currently being developed to define the actions needed to promote circularity. This programme builds on the Finland's 2016-2025 circular economy roadmap.[379]

At the local level, the city of Turku is part of Circular Turku Project (together with Sitra and ICLEI), which supports the development of a regional roadmap that will operationalise circularity in the Turku region. Currently, five value chain priorities have been selected as part of the project, namely: food value chain and nutrient cycling, energy systems, buildings and construction, transport and logistics, and water cycles.

Local and regional governments can act as enablers and platforms for new circular economy solutions and can accelerate their adoption by effectively connecting businesses, universities and residents. The city of Turku aims to speed up the circular transition in the region though continuously strengthening multi-stakeholder collaboration.

Other enabling factors identified by the interviewees were the strong leadership and commitment of the city as well as engaged stakeholders. The Turku City Council decided unanimously on the ambitious 2029 climate target, which signalled the city's commitment to climate objectives. There are also many actors in Turku working on circular economy (around 700), e.g. the Turku University of Applied Science was mentioned as an active stakeholder in supporting and developing circular initiatives.

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[378] ICLEI GREEN CIRCULAR CITIES COALITION, Feasibility Study to Build an Active Network of Circular Economy Actors in the Turku Region, Finland Futures Research Centre, University of Turku (2019): https://www.utupub.fi/handle/10024/148291

[379] Leading the cycle – Finnish road map to a circular economy 2016–2025 (2016): https://media.sitra.fi/2017/02/28142644/Selvityksia121.pdf

11.3 Valorisation of Biological resources in 2030

11.3.1 Future management of the waste streams in 2030

The development of the waste sector and specifically biodegradable waste in the Southwest region and the city of Turku is guided by the National Waste Plan to 2023[380]. The Waste Plan sets the targets for 2030 in waste management and highlights the importance of high standards in waste management for achieving circular economy. The Waste Plan identifies the biodegradable waste as one of the key areas and sets specific targets for 2030:

- Halving food waste by 2030,
- Recycling 60% of the bio-waste included in all municipal waste generated,
- Increasing the use of fertiliser products made from recycled raw materials and those are used to replace fertilisers made from virgin raw materials.

To achieve this, the plan identified the needs to introduce advanced bio-waste treatment processes, advanced treatment facilities in areas with food industry and agriculture as well as to increase advanced bio-waste and municipal sewage sludge treatment capacity. The plan also proposed a number of measures to address the identified needs including: laying provisions of separate bio-waste collection, assessing the status quo, organising a national bio-waste campaign, increasing research funding for recycled fertiliser products and the reclamation, developing and introducing instruments in agriculture to encourage the use of recycled nutrients for field crops of nutrients from waste.

In addition, the Circular Economy Action Plan, which is currently being developed by the city of Turku as part of Circular Turku project will play a key role in further supporting the sustainable use of resources, including biodegradable waste.

11.3.2 Future available methods/technologies for processing methods for managing separated biodegradable waste streams in 2030.

In line with the National Waste Plan, the strong focus is on recycling of the bio-waste and increasing the use of fertiliser products made from recycled raw materials. There is also strong focus on research, innovation and collaboration. For example, to support research and innovation in the utilisation of material, water and energy flows, the Topinpuisto circular economy hub was created in Turku.[381] Topinpuisto brings together different actors to further operationalise circular economy as well as pilot new business operations and models. For example, the Topinpuisto introduced an initiative for recycling of end of life textiles. [382]

The interviewees mentioned that there is an increasing focus on digitalisation and automatisation, which can further support the achievement of circular economy and prevention of waste in general.

11.3.3 Description of future technological potential available (ready to implement) for biodegradable waste processing)

According to the interviewees, the valorisation of bio-resources is an important element in achieving the resource wisdom by 2050. One of the key aspects mentioned was that bio-resources should be upcycled, i.e. used to produce products of higher value.

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[380] National Waste Plan to 2023, available: https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/160889/SY_01en_18_WEB.pdf?sequence=1

[381] Topinpuisto circular economy hub, https://www.topinpuisto.fi/en/info-2/

[382] End of life textile recycling project, https://telaketju.turkuamk.fi/telaketju-2/

11.3.4 Future legal environment, enablers & barriers

The National Waste Plan to 2023 specifically targets the biodegradable waste and as such further supports bioeconomy. Currently, the Turku Circular Economy Action Plan as well as Biodiversity Plan are being developed for the city of Turku. Those two action plans will support further initiatives within bioeconomy.

Further collaboration on research and innovation for the use of bio-waste and its upcycling could stimulate the circular economy and bioeconomy of the city of Turku. However, it should also be noted that there are many circular initiatives already being implemented at the city level.

12 Recommendations and Conclusions

This report provides a synthesis of the work undertaken in work package 4 of the project *Studies on support to R&I policy in the area of bio-based products and services, Lot 1 Carbon Economy.* The project team reviewed and analysed ten different cities and regions within the EU as a means to understand how the bioeconomy can be prioritised and shaped across different geographies within the EU. More specifically, it was researched how the availability and management of biological resources can lead to stronger circular economy strategies at a local level.

The case studies for the cities and regions presented in this report are categorised by highly different levels of waste separation, systems of waste management and pathways for valorisation. In some cases, bio-waste is not part of the separation process, while in others bio-waste makes up a significant portion of total waste collected. Several key conclusions can be pulled from these case studies with regards to upscaling and promoting the bioeconomy as well as the circular economy.

A broad comparison of each city's bio-waste per capita (excluding wood waste) is presented in Figure 69 below. For each case study, bio-waste separation rates and values were extracted from municipal and regional reports. It is important to note that while the kilograms per capita for Cluj-Napoca and Nantes are relatively high, neither currently separate their bio-waste from household waste. Wastewater sludge per city and region is also presented yet is only the most recent data provided by Eurostat on a country-wide basis. It is then converted into per capita data in order to provide a comparable data point.

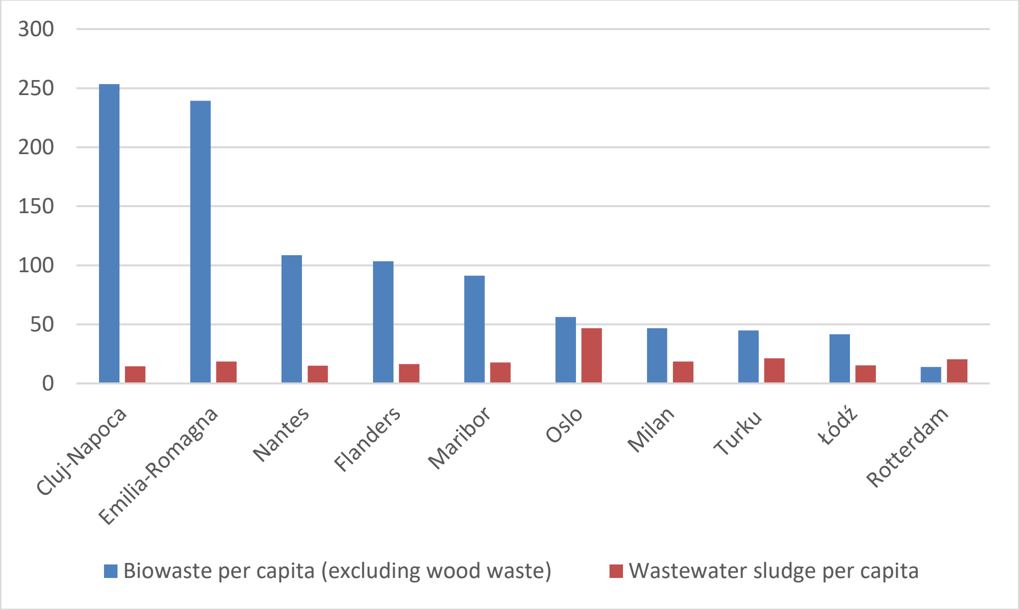


Figure 69. Bio-waste per capita excluding wood waste for cities and regions for 2018 cross-compared with wastewater sludge per capita. Data for Turku is for 2019.

Each city and region shed light on how different barriers might hamper the transition to a bio- and circular economy concept. These barriers will be discussed in turn in the sections below with general conclusions or possible solutions pulled from each. The barriers were identified by investigating waste management systems and initiatives throughout the different case studies through desk research, data mining, and interviews with key stakeholders. The key barriers are shown in the figure below and will be addressed one by one.

Figure 70. Barriers to scaling the bioeconomy based on the case studies.

12.1 *Robust data and reporting*

The bio-waste per capita presented in Figure 69 is classified as organic waste, biodegradable waste (in some cases) as well as vegetable and oils and canteen waste. The data presented for each case studies contains wood waste as well. In many cities, food waste is labelled as 'wet' waste and garden or wood fractions are classified under 'dry' waste, which also includes paper and plastic recycling. The divide between these categories differs across the EU member states. The way the waste is separated and further classified determines its potential end-use and in turn factors in investment potential and feasibility for upscaling of technologies. As the categories across the regions and cities vary, the identification of bio-waste differs and sometimes is not monitored at all. Clear instructions on the way that bio-waste is identified can further promote proper sorting and monitoring of waste, as well as the identification of potential valorisation pathways.

In addition, an important interpretation of the waste data is that lower bio-waste per capita may also be a product of waste reduction campaigns. While bio-waste availability in a region is important in terms of the availability for its further utilisation, its final use or destination post-processing can further characterise its necessity. Milan provides an interesting example of this. As a region with a strict campaign surrounding waste reduction, there is a parallel push for 100% valorisation of the waste that is left over. The stages beyond separation and then valorisation and more advanced end-uses are not necessarily reflected in the data reported for bio-waste.

Wastewater sludge data has also proven to be difficult to track down and only a few regions have their own reporting. Much of the wastewater data presented in this report is from Eurostat, signalling that there are not any concrete national requirements for wastewater sludge reporting. Also, wastewater plants often do not have tangible output data as the regulations on wastewater sludge used for bio-based fertiliser, for example, are very strict. Yet, biorefineries have the capacity to produce volatile fatty acids (VFAs) for both food waste and sewage sludge and exact data is necessary to provide reliable input costs and cost-benefit evaluation of the output.

Proper estimation and monitoring of the entire waste stream from collection costs to pre-treatment, treatment and finally valorisation and market demand is essential for a cost-effective bio-waste system. This encompasses both wastewater sludge as well as waste and separation of it by households. Using an EU-wide tool with consistent data such as waste quantity, type of collection, number of collection points, cost of fuel, etc. can highlight the benefits for upscaling the bioeconomy.

12.2 Collection and fine system

The collection system and its costs further determine a municipality's capacity to properly finance the entire collection, transport and delivery costs. Pick-up costs grow much higher if a collection system is door-to-door versus having drop-off points where citizens can deliver their separated waste fractions. Most cities have a combination of both. Collection fees that are based on the polluter pays principle are useful in the fact that they reduce waste and this principle is also embodied within the Waste Framework Directive. Yet it is important to note that as residents begin to reduce waste, the fees go down, which may result in a loss of income for the municipality. This loss of income from collection costs can be directly offset by post-delivery valorisation.

Fines are also used in Cluj-Napoca and Maribor to encourage proper sorting, but there are still low incentives to police or implement these fines. One of the key conclusions is that fines are used strictly to 'threaten' citizens but are rarely enforced. Partnered with a rigorous plan to spread awareness of the necessity to separate can result in a well-functioning collection system that does not have to rely on fines or policing in the first place. Oslo, for example, uses revenues from waste operations to reduce the waste collection fee. This acts opposite to a fine, rewarding rather than punishing households. In Cluj-Napoca, the fine system is not strictly enforced and often leaves the trash behind for residents to re-sort before the following week's pickup.

Milan is one successful example where environmentally conscious actions are directly rewarded. Milan encourages active reduction in waste through a reward system. Milanese institutions or businesses are eligible to receive tax breaks if they can show that they are redirecting their bio-waste, for example to charity organisations. Last year, the city's restaurants and other businesses received an 18% tax reduction; both the municipality and private companies then work together actively to reach a common goal.

12.3 Policy sphere

The legal framework across all of the cities and regions is broadly catalysed by the EU's Circular Economy Action Plan and Bioeconomy Strategy as well as the Waste Framework Directive and its most recent target for 2035 of a 65% recycling rate across MS. EU policy shapes the strategies that have emerged within the different case studies, yet there are different regulatory avenues that different countries or cities have undertaken. The EU strategies and binding documents generally stimulate and strengthen the development of the circular and bioeconomy at the regional and city level, however, further alliance between MS can help lessen competition. For example, CEE countries have high levels of biomass without sufficient sources of depository; only 20% of biorefineries in the EU are located in Central and Eastern European countries. There is also a lack within Central and Eastern European countries of action plans and development, which is detrimental to the reach and functioning of the EU strategies. In general, MS should be encouraged to develop their own action plans that boost the relationship between the public and private sector. Clusters or platforms that engage companies in research projects from universities or institutes can support uptake of new bio-waste strategies.

The Wcycle Institute in Maribor is a key example where the private and public sector developed a self-sustaining partnership through a circular economy action plan. The Wcycle Institute in Maribor is a product of five different public companies in the waste, utility, energy, water, and transport sectors. The Institute, most notably, introduced a circular economy plan for the city of Maribor and has also formed its own city holding, contributing to the governance structure. The circular economy plan highlights the necessity for the cooperative economy and ensuring that there are the right conditions for a bottom-up approach. As a consultancy, Wcycle forms a distinct bridge between being self-financed (private) and an active member of the municipality of Maribor.

As mentioned above, bio-clusters also play an important role in a number of the case studies and are typically comprised of both public and private stakeholders. A cluster is a natural platform where communication across different parts of the 'bioeconomy value chain' is facilitated. Governments should initiate and promote clusters. AgroTransilvania, a cluster from Cluj-Napoca, has 80 members including the municipality, private companies, food processors and producers, and financial institutions. Clusters are also trans-regional, meaning that there are members of cluster networks outside of their given municipality, which can foster the enabling environment for regions that have a higher capacity to use their bio-waste as a resource.

There is also a need to enforce the partnership between broader circular economy objectives and how they affect waste streams. This can in part be accomplished through regional directives as well as action plans, such as 'Circular Rotterdam,' which helps to lower contamination from bio-waste to render it usable for biogas. Local and regional action plans can act as enablers for circular economy transitions through engagement across stakeholder groups and different policy levels (local and international). Turku, for example, has adopted a focus on the circular economy on the international (e.g. Green Circular Cities), national (e.g. Ministry of Environment and Sitra), regional (e.g. Valonia) and local (e.g. utility and private companies) level.

Future developments in EU policies should also not be compromised by regulations that keep certain provisions not sufficiently aligned with the technological progress. For example, EU default values applied in the EU’s Renewable Energy Directive (RED II) are relied upon by buyers of biogas in terms of potential GHG reductions from its use. In Oslo, there has been evidence to show that electric powertrains are more beneficial than the biomethane powered bus system already in place. The default values within the RED II framework do not account for the required electricity generation for fuelling the powertrains. Streamlining the framework of RED II alongside the Bioeconomy Strategy is necessary such that as emerging technologies within the bioeconomy surface, they are adequately supported by parallel or coinciding sectors.

12.4 Education and perception

One of the driving conditions for a comprehensive waste strategy is whether the community is made aware of the benefits of, at the onset, waste separation and later on, the potentials for valorising and monetising waste streams. Tying education and awareness of waste into the policy sphere can be one way to promote self-sustaining waste prevention actions. In Italy, the National Programme for Waste Prevention focuses on sustainable production with changes in raw materials and technologies, green public procurement, re-use, research, and awareness raising and education on waste prevention. The city of Oslo has also put significant effort into educating households on waste through school curriculums (bringing students on site visits) as well as individual household consultations.

Changes to waste policies, as they are constantly adapting, must come with powerful campaigns to inform and change the behaviours of residents. Cluj-Napoca is a good example of this. Cluj-Napoca overhauled their waste separation system in 2019 and in the process also implemented a campaign to make sure that the residents were made aware of the changes. The city replaced all of the trash points in the city with bright coloured bins for clear separation. In terms of communication, the municipality also sent out flyers and provided free bins and clear bags for each household to ensure correct separation. Since the campaign, the private collection companies have left behind trash that has not been properly sorted as punishment, creating a stigma and strong attention to pure waste fractions.

Collaboration between research networks and platforms for dissemination are necessary to create an environment both in the rural and urban setting. Clusters are a valuable way to alter misconceptions of the bioeconomy and its added value to a community. Łodź, beyond also putting in significant effort into the educational aspect of separation, is home to an annual bioeconomy conference, the European Bioeconomy Congress.

12.5 Technologies/valorisation pathways

The technologies available for bio-waste processing are characterised by various stages of TRL due to the highly diverse economic starting points and bio-waste inputs potentials of the case studies. The necessary investment costs for the installation of brand-new technologies are split across countries with opposing enabling environments. Case study countries such as the Netherlands, Norway and Italy already have the infrastructure in place and political capacity to process their bio-waste, while some Central and Eastern European countries are still finding the economic feasibility of installing new technologies. The investment payoffs are not yet high enough if countries are required to finance the new technologies themselves.

All of the case studies presented in this report participate in conversion of bio-waste to compost. At the base level, the technology necessary to process bio-waste into compost involves a relatively simple fermentation process and implementation costs are not overtly high. Following conversion, compost can then easily be commercialised or distributed for free or with a reduced cost for farmers or citizens that are actively participating in separation or reducing their carbon footprint. Nantes, Maribor, Milan and Emilia-Romagna are focused on compost production for urban or rural distribution. Nantes processes bio-waste that is brought to a drop-off location and then community members can pick up the processed compost for free.

Biogas production is one of the most common end-uses for bio-waste and is the main pathway for Flanders as well as Emilia-Romagna. On the other hand, stakeholders from Cluj-Napoca cited biogas as too expensive or inefficient for the state of their enabling environment. This concern from the Cluj-Napoca is not unfounded in truth and there is evidence from Oslo to prove that investing in a biogas plant and further maintaining it with sufficient inputs of bio-waste is difficult as well as costly. Yet, Oslo still presents a success story of not only utilising bio-waste but very actively promoting the circular economy.

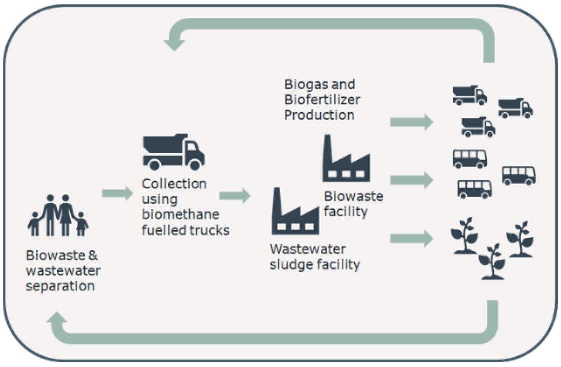


Figure 71. Circular economy system Oslo.

Oslo has a well-functioning circular economy system within its waste processing operations (see Figure 71). The bio-waste that is separated by citizens is collected by trucks that run on compressed gas which is produced from the household bio-waste. If the bio-waste is not digested into biogas and further biomethane for the public busses and collection trucks, it is turned into bio-fertiliser. The city has also overcome an initial cost roadblock by implementing thermal hydrolysis (THP) as pre-treatment; the pre-treatment can help account for impurities in the separated waste. The RBA biogas plant produced 25,000 m³ of compressed biogas and 1,200 tonnes of bio-fertiliser in 2013. Oslo also processes its wastewater sludge into biogas through two installations. Rotterdam as well as Turku have plans to turn their collection fleet into a 'green fleet,' through use of biofuel. Oslo's business model is one that can be duplicated across other geographies.

In general, support from research institutions and knowledge sharing between sectors is necessary to generate trust in biotechnology investments for example. In addition, transparency regarding TRL is necessary as it can act as an indicator for countries or regions that are lacking in higher-end uses or technologies (e.g. Central and Eastern European countries). Developing and enabling biotechnological innovation and further sharing this innovation across MS will also enable bio-based production at an industrial level. Larger companies that are active in the bio-based sector are necessary for significantly upscaling the bioeconomy framework. In Emilia-Romagna, HERAmbiente and Ca.Vi.Ro. are responsible for a wide breadth of research projects on the transformation of bio-waste in various stages of implementation (see Figure 49). HERAmbiente alone runs over twenty separation, bio-waste and processing facilities. Private investment is vital for the future of the bioeconomy and should be further stimulated by European funding sources such as the European Investment Bank or the European Fund for Strategic Investments. Pooling several sources of financing can ease the implementation and upscaling of biotechnology in regions that are lacking.

12.6 Separation, valorisation, reduction and high-end

A rigorous system for the separation of waste is the backbone to high recycling rates that are low in impurities, meaning contamination from other waste fractions. Cities that have focused much of their attention on separation have higher potential to reach comprehensive valorisation and high-end uses of the waste. High-end uses are classified within this analysis as uses that are beyond biogas production or compost. Experience from Oslo's biomethane production for the bus transport revealed that due to an initially high degree of contamination of the bio-waste, the processing costs were much higher than expected. The need for pre-treatment and upgrading resulted in a production of biogas that has yet to be profitable. This points to the overarching need for proper separation to be the core of a city's waste management system. Even so, Oslo has partially accounted for their lack of profitability through an auction system such that the biomethane is sold to the highest bidder.

The capacity for valorisation stems directly from the separation and its subsequent monitoring and value accuracy. The potential for a city or a region to be able to use their bio-waste is directly correlated with whether they are able to track it in the first place. As can be extracted from the barriers outlined above, the costs alone of collection and separation are covered by the community through fees. Yet, only a few cities that then valorise the waste put the value back into the community.

The circular economy framework is embedded in the value that waste can add to the economy as a whole. As citizens are the ones that are producing the waste, it comes without a question that they should be able to see the monetary benefits of valorising it. Or, in the case of Nantes, where they see the value by receiving free processed compost. It is at the point when valorisation has become a default when waste reduction can be the priority. Partnered with waste reduction is taking what is left and achieving a zero-landfill objective. This objective entails using whatever waste is left to meet market demand for waste.

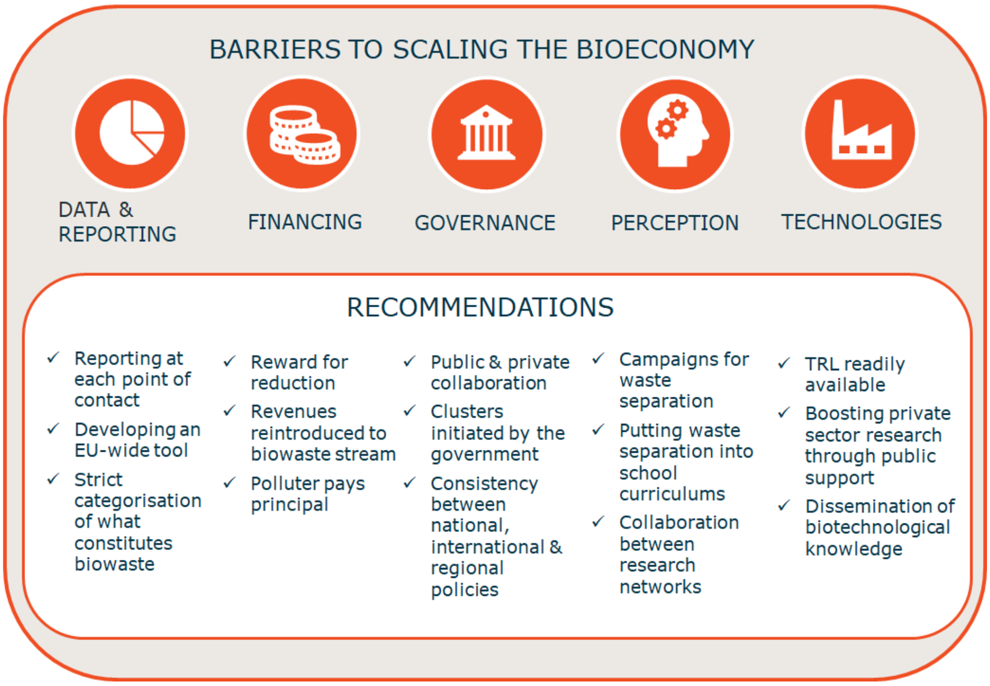
12.7 Towards 2030

The most recent updates to the Waste Framework Directive include a scaling up of recycling rates to 60% by 2030 and 65% by 2035. These changes have trickled down to many MS, but there is still a significant lack of attention taken to specifically bio-waste. Achieving a recycling rate that embodies both dry and wet waste of 65% is feasible, yet further scaling up the separation of bio-waste is not in the works for many countries. The Bioeconomy Strategy and Circular Economy Action Plan have helped facilitate the attention towards bio-waste, yet there is still evidence that local circular and bioeconomy action plans are lacking, especially in Central and East European countries.

While there are many cities and countries that have concrete and independent plans for the future, there are some that are heavily reliant on the EU's support if they hope to really scale up their bioeconomy. The large divide between the wages and investment capabilities between Central and Eastern European countries and other EU member states makes it difficult for a level playing field in the EU. Financing of biotechnologies can be much more prohibitive in countries where the investment costs do not justify the future profitability. Therefore, it is necessary to generate additional investment support from both private and public sources for Central and Eastern European countries over the next ten years.

Still, the case studies in this report have taken clear measures to improve the bio-based sector. Cluj-Napoca has not made plans to require separation of bio-waste, yet has put considerable effort into encouraging home-composting. As households become used to separating their bio-waste, further investment in valorisation and processing is the logical next step. The same is the case for Łódź. In both Emilia-Romagna and Milan, the path towards 2030 is embodied by wide-reaching research projects to expand existing technologies. In addition, Italy's most recent decree announcing the availability of subsidies for biomethane production will of course generate support from the bio-based sector. The involvement of the private sector in both Milan, through among others the fashion industry, as well as Emilia-Romagna in multiple bioproduction streams, is a major enabling factor as well. Turku has also introduced its own ambitious recycling target outside of the EU-wide target and has pulled in the private sector through small businesses as well as each level of government. The city of Turku also established a circular economy hub, called the Topippuisto aimed at supporting research and business development within the bio and circular economy.

Flanders has invested significant effort into possible alternatives to the recovery of wastewater sludge, a sector that is lacking across many of the other case studies. As mentioned before, improving existing technologies to include or incorporate food waste or wastewater sludge can be a resolution to combat feasibility or cost issues. Biorefineries, for example, often already have the capacity to process wastewater sludge. This is highly relevant for all of the case studies as well as the other MS.



BARRIERS TO SCALING THE BIOECONOMY

DATA & REPORTING
- ✓ Reporting at each point of contact
- ✓ Developing an EU-wide tool
- ✓ Strict categorisation of what constitutes biowaste

FINANCING
- ✓ Reward for reduction
- ✓ Revenues reintroduced to biowaste stream
- ✓ Polluter pays principal

GOVERNANCE
- ✓ Public & private collaboration
- ✓ Clusters initiated by the government
- ✓ Consistency between national, international & regional policies

PERCEPTION
- ✓ Campaigns for waste separation
- ✓ Putting waste separation into school curriculums
- ✓ Collaboration between research networks

TECHNOLOGIES
- ✓ TRL readily available
- ✓ Boosting private sector research through public support
- ✓ Dissemination of biotechnological knowledge

RECOMMENDATIONS

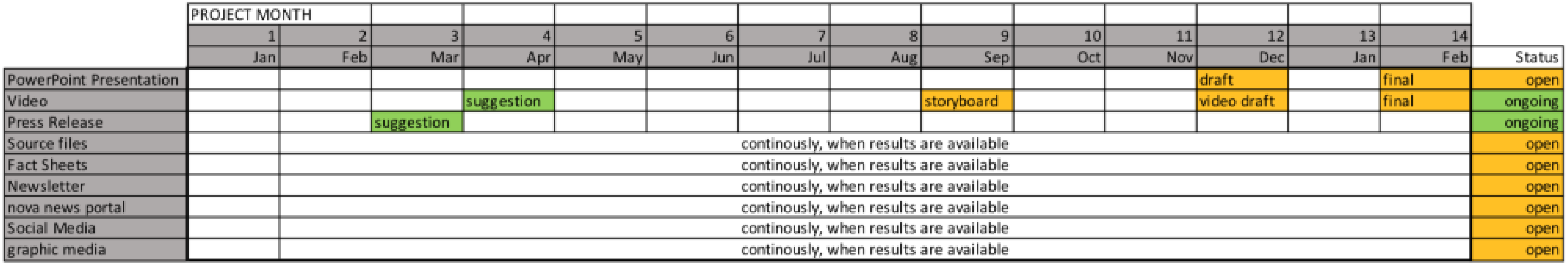
Figure 72. Recommendations to addressing identified barriers.

The main takeaway for the future of the bioeconomy is the need for interaction and collaboration at every governmental level. A barrier cited in several instances and in interviews with stakeholders, is the disconnect between cities that have bio-waste, but no place to put it and cities that have the technological capacity to process bio-waste, but not enough input. Enhancing cross-border alliances through cluster networks will result in a well-balanced bio-based sector with sufficient inputs and outputs.

WORK PACKAGE 5: COMMUNICATION ACTIVITIES

1 Timeline for the communication activities

The timeline of the communication activities is shown in Figure 73.



	PROJECT MONTH														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Status
PowerPoint Presentation												draft		final	open
Video				suggestion					storyboard			video draft		final	ongoing
Press Release			suggestion												ongoing
Source files		continously, when results are available													open
Fact Sheets		continously, when results are available													open
Newsletter		continously, when results are available													open
nova news portal		continously, when results are available													open
Social Media		continously, when results are available													open
graphic media		continously, when results are available													open

Figure 73. Timeline for the communication activities

2 Stakeholder and Channels

The project's dissemination activities are targeted at the overarching goal to bring the knowledge to the stakeholders. To achieve this, scientific results were communicated at the end of the project.

Relevant target groups were identified as decision-makers on political levels (cities and regions, furthermore on national and EU levels), general public and to a lesser extent industrial stakeholders and scientists.

Dissemination activities conducted in this project are following a logic of strategic communication to foster the success of the external communication. The identification of specific stakeholders (audience) allows for the determination of respective relevant contents (message) and the selection of appropriate communication vehicles (channel) to contribute to the broad dissemination of relevant outcomes (impact). The dissemination activities conducted that way are summarised in Table 76.

- Audience → Message → Channel → Impact

Table 76. Summary of communication strategy for each stakeholder group

STAKEHOLDER (AUDIENCE)	MESSAGE	COMMUNICATION VEHICLE (CHANNEL)	FREQUENCY	IMPACT / GOAL
Policy / Decision makers	Awareness of potentials, positive evaluation of circular economy, technology potentials and legislative enablers, best practice examples of case studies	Fact sheets, newsletter, Press Release, video	End of the project	Motivate them to perceive new findings, take action on barriers for sustainable development and preserve drivers
General Public	Explaining circular economy and carbon flows in an understandable way, importance of research in this field, positive evaluation of circular bioeconomy	Press Release, video, Fact sheets	End of the project	Education, knowledge, awareness of the issue and recognise opportunities for personal action
Industry	Awareness of potentials, Potential for research contracts, positive evaluation of	nova newsletter, nova news portal (news.bio-based.eu), nova business networks on Social Media: Twitter, LinkedIn	End of the project	Motivate them to make use of new information and convert company structures, invest in further research

	circular bioeconomy			
Scientists	Results, Outcomes, Significance of research in context of circular bioeconomy, Potential of results, high quality of conducted research	Science media, Science press (through Press Release), nova news portal (news.bio-based.eu), nova business networks on Social media: Twitter, LinkedIn, currently under review: Including outcomes on carbon flows in the JRC's Online Sankey Biomass Diagram	End of the project	Share results, start discussion on the future of the carbon economy, trigger further research

3 External Communication Tools

A mixture of strategically selected communication tools has been used (well-established dissemination tools from nova-Institute in combination with novel platforms) to reach the targeted audience. The communication tools used are described below.

3.1 Video

A video was produced to illustrate the flow of organic carbon caused by a human being. For this purpose, an animated cartoon with a specifically designed character was developed. This type of video was chosen because it is a modern and up-to-date solution which is able to communicate relatively abstract information in a digestible format. It is sent to the client by the end of the project and will be published on nova-Institute's YouTube Channel[383].

The video aims to address both target groups, general public and policy makers to show how daily human activities are linked to the utilisation and creation of flows of carbon and how they could be utilised. General public is addressed to raise knowledge about the topic. Decision-makers on political levels (cities and regions – with the support of national and EU levels) are addressed to motivate them to make use of the new information and knowledge about carbon flows, for example by implementing new procedures to optimise the use of carbon in waste streams and measures to foster circular bioeconomy in their city and region. Further relevant target groups are industry stakeholders and researchers. For the latter target groups, the video can help to propagate the publication of the study's outcomes.

A storyboard was suggested by the end of September 2020 and then modified with the goal to have a first video draft by the end of December 2020 which was fulfilled. Originally it was proposed that the video describes human-based carbon flows as an example for one selected city to make its impact visible. By following each flow in detail (hygiene, construction, household, vital processes). In an agreement with the client, it was decided

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[383] For nova-Institute's YouTube channel, visit https://www.youtube.com/channel/UC25_n9CmaaxfliTLbenoG_A

to not consider one specific city within the video and to keep it more general. The full script of the video including detailed sources of the included statements is provided in the annex.

3.2 Publishable Materials

Results are delivered in two formats: i) as complete scientific reports including an executive summary and ii) in more digestible, shorter formats (Fact sheets) which include the project's key messages.

In order to effectively communicate the results, the main chapters are summarised to condensed versions. Fact sheets are developed on the following topics:

- The current state of carbon flows,
- Future scenarios for European demand and supply of carbon,
- Research and Innovation for the use of carbon resources
- Case studies on the use of urban carbon flows.

They can be disseminated and made available to download, e.g. via nova channels to the public and other stakeholders.

3.3 Press release, newsletters and Social media

To effectively communicate the results of the project to a wider audience of stakeholders, nova-Institute offered and recommended using a selection of appropriate communication channels such as press release, news portal article, social media communication (Twitter, LinkedIn) and newsletter. These actions take place at the end of the project.

- A press release (see Annex) will be published at the end of the project and distributed to established industry magazines and trade journals by nova-Institute.
- An article on the nova news portal Bio-Based News (news.bio-based.eu) will be published. With over 4 million readers per year, this is one of the largest portals for industrial biotechnology and bio-based economy in Europe, with the addition of other sources of renewable carbon (carbon capture and utilisation as well as recycling).
- The article on Bio-Based News will be linked on Twitter and LinkedIn. The Twitter account[384] has about 3,300 followers.
- Almost all of nova-Institute's employees are active on LinkedIn and share news regularly. nova-Institute has about 1,700 followers on LinkedIn, CEO Michael Carus has 9,200.
- The article on Bio-Based News will be linked in nova-Institute's monthly newsletter. nova-Institute offers monthly newsletters to their contacts in the relevant topics. Subscribers (approximately 2,700 as of January 2021) who have expressed an interest in themes related to the project will be sent specific updates and news items every month.

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[384] For nova-Institute's twitter account, see https://twitter.com/Bio-based_News/

3.4 Slide presentation

A slide presentation covering the project background and research questions, the methodology and the final results including key findings was designed and provided to the client.

3.5 Source files

A source file, which contains all data on European carbon flows and future scenarios is compiled and shared with the client.

3.6 Graphic Media

A set of illustrations for the main outcomes is provided. The files are produced for specific needs such as printing, social media and animated slides and can be made available to download or for sharing in social and scientific media.

3.7 The Sankey Biomass Diagram

The results could be utilised in the JRC's online Sankey Biomass Diagram[385] to make the results available to even broader public.

3.8 Fact Sheet

See below for fact sheet in entirety.

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[385] For access to the online tool, visit https://datam.jrc.ec.europa.eu/datam/mashup/BIOMASS_FLOWS/index.html
For background information, see http://publications.jrc.ec.europa.eu/repository/handle/JRC108649

CARBON ECONOMY

STUDY BACKGROUND

The Carbon Economy study maps out the current pathways available for the transition towards a low fossil carbon economy as well as the barriers that hinder this transition. Based on the conclusions and key findings the scene is set for the future of the bio-based economy with a particular focus on case studies of regions and cities across the EU, an evaluation of promising innovations and novel technologies for the realisation of such an economy and a sweeping regulatory analysis on EU directives and regulations that pertain to the carbon economy. This attention to the local level as well as the broader policy sphere is supported by a scientific understanding of the carbon economy as well as potential future scenarios towards 2050.

STATUS QUO: UNDERSTANDING THE CARBON ECONOMY

Contrary to the energy sector, there are several sectors which cannot be decarbonised. These are the food and feed sectors as well as chemical and material sectors. Proteins, fats and carbohydrates contain carbon; organic chemistry is defined by the use of carbon and cannot be decarbonised; also, all usages of wood for example will always be based on carbon. In the context of the climate crisis, one needs to be more specific and say that fossil carbon is the problem.

Before the transition to a low fossil carbon economy can be realised, a broad understanding of the current situation regarding the use and sourcing of carbon has to be built. Therefore, carbon flows are examined on three different scopes. On a global level, the natural and anthropogenic carbon cycle is considered to determine organic carbon flows and stocks that are relevant for economic activities. The amount of carbon stocked and characteristics of several of the Earth's spheres are depicted including the atmosphere, the biosphere, the hydrosphere and the lithosphere. Furthermore, the technosphere is examined which includes carbon flows and stocks that are relevant for economic uses of organic carbon-based substances.

For the European level, a comprehensive picture of current carbon demand and the corresponding supply of various sectors is drawn. The sectors include energy, heat & fuels, food & feed and material use including chemicals & plastics, construction & furniture, pulp & paper, and textiles. For all material flows, the corresponding carbon content and the source of carbon (fossil, bio-based, recycling) is determined.

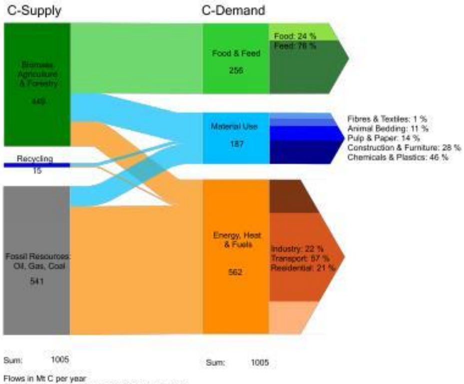
On the level of a single human, a novel bottom-up approach is introduced, that accounts all biogenic carbon flows caused by daily activities of an average adult. This model can be used to fill data gaps or assess existing data on usable carbon flows occurring in a city.

KEY FINDINGS

For the transformation from fossil resources to renewable resources, the consideration of carbon flows in addition to overall material flows is highly relevant due to diverging properties of alternative fuels (e.g. heating value) and materials (e.g. dry matter, carbon content).

The largest share of the EU-27's carbon demand used for energy, heat, and fuels (56%) with a fossil share of 85%, see Figure below. The second largest consumption of carbon resources is food and feed (23%) where only carbon from biomass is used. The third sector are chemicals and materials (17%) with a fossil share of 39%.

Carbon Flows in the EU-27 (2018)



Flows in Mt C per year
Only material and energetic recycling considered;
Biomass recycling neglected

CARBON ECONOMY

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FUTURE SCENARIOS FOR THE CARBON ECONOMY IN 2050

In previous work carried out in this study, relevant flows of materials containing organic carbon within the European economy are gathered. It is shown, that more than half (54%) of the carbon currently used in the EU-27 has fossil origin. In order to shape the transition to a more sustainable, low fossil carbon economy, future scenarios are developed and assessed regarding their sustainability potentials. For the energy sector, six scenarios for the EU's carbon demand and supply in 2050 are derived from a previous study. The scenarios include:

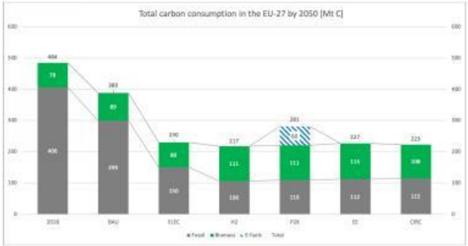
- Scenario 1: Business as Usual (BAU),
- Scenario 2: Electrification (ELEC),
- Scenario 3: Hydrogen (H2),
- Scenario 4: Power-to-X (P2X),
- Scenario 5: Energy Efficiency (EE), and
- Scenario 6: Circular Economy (CIRC)

Parallelly, for the sectors of food, feed and material use, a set of parameters is examined to derive two further scenarios. The material use includes chemicals & plastics, construction & furniture, pulp & paper, and textiles. The scenarios developed this way are:

- Scenario I: Sufficiency (sufficiency-oriented consumption patterns)
- Scenario II: Technology (strong technological improvements and acceptance)

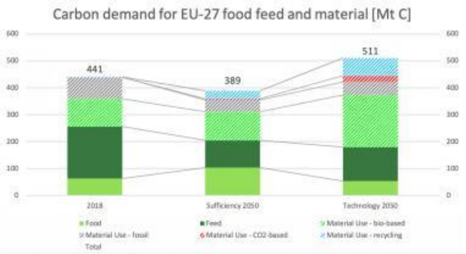
KEY FINDINGS

Six scenarios for the EU-27 energy sector in 2050 have been adopted to determine the carbon demand and supply, see figure below. All scenarios imply a reduction of the annual demand for fossil carbon from 406 Mt C (2018) to between 299 Mt C (in the business-as-usual scenario) and 106 Mt C (in the hydrogen scenario).



Annual carbon demand in the EU-27 energy sector by 2050 and 2018 for comparison, separated by carbon source. Carbon required to produce E-Fuels separately highlighted.

Two scenarios for the EU-27 food, feed and material sectors in 2050 have been developed to determine the corresponding carbon demand and supply, see figure below. For plastics and chemicals, the share of fossil supply decreases for both scenarios from 91% (2018) to between 50% (Sufficiency scenario) and 30% (Technology scenario).



Carbon demand for food, feed and material in EU-27 2018 and by 2050 for both scenarios

A sustainability assessment has been conducted, showing that the business-as-usual scenario lacks behind the other five scenarios for the 2050 energy sector. For food, feed and materials, the majority of sustainability indicators show positive trends compared to today for both of the examined 2050 scenarios.

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STUDIES ON SUPPORT TO R&I POLICY IN THE AREA OF BIO-BASED PRODUCTS AND SERVICES

CARBON ECONOMY

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The Carbon Economy study maps out the current pathways available for the transition towards a low fossil carbon economy as well as the barriers that hinder this transition. Based on the conclusions and key findings the scene is set for the future of the bio-based economy with a particular focus on case studies of regions and cities across the EU, an evaluation of promising innovations and novel technologies for the realisation of such an economy and a sweeping regulatory analysis on EU directives and regulations that pertain to the carbon economy. This attention to the local level as well as the broader policy sphere is supported by a scientific understanding of the carbon economy as well as potential future scenarios towards 2050.

REGULATORY ANALYSIS AND ASSESSMENT OF INNOVATIVE TECHNOLOGIES

A regulatory analysis is carried out, dedicated to the identification of regulatory drivers and obstacles for the production of bio-based products from urban bio-based sources (biowaste and wastewater sludge). The findings of a previous report are used to analyse relevant EU legislation amendments between 2018 and Q2 2020. The impacts of the amendments for the valorisation of urban bio-based waste streams are summarised. The amendments effect the following directives / regulations:

- Landfill Directive
- Nitrates Directive
- Fertilisers Regulation
- REACH Regulation
- Waste Framework Directive
- Sewage Sludge Directive
- Renewable Energy Directive
- Effort Sharing Decision & Regulation
- The Gas Directive
- The Plastics Regulation
- A European Strategy for Plastics in a Circular Economy
- Closing the loop – An EU action plan for the Circular Economy

Many of the directives had sweeping changes, while others have amendments expected in 2021 and have yet to be updated.

In a second step, the availability of technologies for the material use of carbon is assessed together with technological opportunities to boost resource-efficiency. Innovative technologies in different maturity levels are collected and analysed for their potential contribution to a low fossil carbon economy with the help of multiple indicators, including:

- technology readiness level (TRL)
- limitations and potentials
- research needs and supporting actions
- versatility
- climate effects
- retrofitting potential

The assessment has been conducted separately for five groups of products, which are:

- bulk chemicals & fuels
- polymers
- proteins for food & feed
- hydrogen
- fine chemicals

A comprehensive long-list of technologies is compiled to derive a short-list of promising technologies for the assessment. In a summary, beneficial uses for each technology are identified. Feedback of external experts is used to improve the results.

KEY FINDINGS

In order to assess existing barriers and drivers for the use of urban biogenic waste streams, current amendments to relevant pieces of EU legislation have been analysed. Effects on the use of waste streams for the production of bio-based products, have been summarised.

An evaluation of technologies for a transformation towards a low fossil carbon economy for the material use of carbon has been conducted. For each of six product groups promising technologies have been identified. Some findings are that electrochemistry is highly promising for polymers, fine chemicals and hydrogen production. Microbial systems have potential for bulk chemicals & fuels, proteins, polymers and fine chemicals.

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CASE STUDIES

Ten case studies of European regions and cities are conducted in order to provide a local perspective at the current state of biowaste and wastewater sludge utilisation rates. The availability of bioresources and their valorisation stage are determined, as well as the presence of the circular economy in local governance and existing technological approaches towards valorisation. The selection of cases is conducted in such a way that progressive initiatives could be highlighted with strong potential for value chains. The final selection centres on diversity (regionally and socio-economically), population size, technological innovation and institutional innovation. This results in eight cities and two regions for analysis:

- Cluj-Napoca (RO)
- Emilia-Romagna (IT)
- Flanders (BE)
- Łódź (PL)
- Maribor (SI)
- Milan (IT)
- Nantes (FR)
- Oslo (NO)
- Rotterdam (NL)
- Turku (FI)

Within each case study, wastewater and biowaste data are collected in order to provide a comparison point that can be evaluated across the EU. Stakeholders from clusters, municipal governments, NGOs, academic institutions and public authorities are interviewed in order to gain a closer focus on the goals and future of each region.

KEY FINDINGS

Case studies regarding the current state of biowaste and wastewater sludge utilisation in 10 European regions show, that each region has taken clear measures to improve the situation. The measures are manifold reaching from encouraging home-composting (Cluj-Napoca, RO, and Łódź, PL) to subsidies for biomethane production (Emilia-Romagna and Milan, IT) to ambitious recycling targets (Turku, FI).

In some of the examined regions, biowaste streams occur but aren't valorised while in others, the technological capacity to process biowaste exists, but there is not enough input. Enhancing cross-border alliances through cluster networks would result in a well-balanced bio-based sector with sufficient inputs and outputs

BARRIERS AND RECOMMENDATIONS BASED ON THE CASE STUDIES

Barrier	Recommendations
Data & Reporting	• Reporting at each point of contact • Developing an EU-wide tool • Strict categorisation of what constitutes biowaste
Financing	• Reward for reduction • Revenues reintroduced to biowaste streams • Polluter-pays principle
Governance	• Public & private collaboration • Clusters initiated by the government • Consistency between national, international & regional policies
Perception	• Campaigns for waste separation • Incorporating waste separation into school curriculums • Collaboration between research networks
Technologies	• Technological Readiness Level (TRL) transparency • Boosting private sector research through public support • Dissemination of biotechnological knowledge

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APPENDIX 1 – WP1 UNITS AND CONVERSION FACTORS

The data used in this report are derived from various sources of multiple scientific disciplines from geology to climate science to empirical economics. Each discipline uses its own terminology and units for mass, energy, flow rates or volume therefore, the units are converted to be comparable. The conversion methods and assumptions are described in this section. Furthermore, many information on carbon stocks and flows are derived from data on materials and products, not directly from data on carbon. The methods and underlying assumptions for the calculation of the carbon content are also explained in this section.

1.1. Prefixes and General Conversions

In this report the units used to express the stocks and flows of carbon through different subsystem of the planet are gigatons (Gt) of carbon or gigatons of carbon per year (Gt/y) respectively and therefore following the majority of studies in the realm of economics in this field, see for example BP (2019)*, Naims (2016)*. In contrast, a commonly used unit for carbon stocks and flows in climate sciences is petagrams (Pg). Fortunately, one Gt equals one Pg:

$$1\ \mathrm{Gt}\ = 10^{9}\ \mathrm{kg}$$

$$1\ \mathrm{Pg}\ =\ 10^{12}\ \mathrm{g}\ =\ 10^{12} * 10^{-3}\ \mathrm{kg}\ =\ 10^{9}\ \mathrm{kg}.$$

Other Prefixes used in this report and in the studies examined are shown in Table 1

Table 1. Relevant prefixes for carbon stocks and flows

Prefix	Factor		Prefix	Factor
E (exa)	10^{18}		G (giga)	10^{9}
P (peta)	10^{15}		M (mega)	10^{6}
T (tera)	10^{12}		k (kilo)	10^{3}

Conversion factors for energy units, not specific for any material group are listed in Table 2.

Table 2. Conversion factors for energy units (unspecific)

From	To	Conversion factor	Explanation	Source
toe	kWh	1,16E+04	toe = tons of oil equivalent	[1]
kg oe	J	41,868,000		[2]

Table 3 shows conversion factors for volumes used in this report.

Table 3. Conversion factors for volumes (unspecific)

From	To	Conversion factor	Source
Barrel (US, petroleum), bbl	m3	0.15899	[1]
US gallon	m3	0.0037854	[1]

1.2. Conversion factors for fossil fuels Petroleum

There is no universal standard for the report of petroleum production rates. The most commonly used unit is the U.S. barrel (bbl.) or (bl.), see Table 4. Beneath, several other volume units exist like the Imperial barrel (bl. Imp.) or (bbl. Imp.). Occasionally, barrel (bl. or bbl.) when used for several other liquids refers to different volumes [3].

Due to historical reasons, the abbreviation Mbl. or Mbbl. does not stand for Million barrel but for thousand barrels (m for mille). Hence, 1 million barrels is often abbreviated as MMbbl.

Table 4. Conversion factors crude oil

From	To	Conversion factor	Explanation	Source
t petroleum	t C	0.8549		[4]
Million barrel petroleum	Gt C	1.17E-04	1 barrel = 0.1364 metric tons; multiplied with crude oil carbon content	[4, 5]
Million barrel crude oil	Mt C	0.1166	see above	
m3 crude oil	kg	734.21	Density of "100% mineral petrol"	[1]
tonne crude oil	GJ	47.10	Gross caloric value of "100% mineral petrol"	[1]

Natural Gas

Natural gas (NG) or fossil gas consists mainly of several hydrocarbon gas compounds as well as a small fraction of non-hydrocarbons. To calculate the carbon content of natural gas, the carbon content of every major hydrocarbon gas compound is derived from the atomic weight and the weighted average is calculated by using the average proportion on natural gas of each compound according to [4] , see Table 5.

Table 5. Calculation of the carbon content of natural gas.

Compound	Average Proportion	C-Content (atomic weight)	Explanation
Methane	93.07%	74.87%	
Ethane	3.21%	79.89%	
Propane	0.59%	81.71%	
Higher Hydrocarbons	0.32%	83%	Assumption
Non-hydrocarbons	2.81%	0%	Assumption
Weighted Average		**72.99%**	

Liquefied natural gas (LNG) is an important derivate of natural gas (NG). It is generated by cooling down natural gas and thereby reduce its volume for benefits in transport and storage. Table 6 gives an overview of conversion factors for NG and LNG used in this report.

Table 6 Conversion factors for natural gas (NG) and liquefied natural gas (LPG)

Sector	From	To	Conversion factor	Explanation	Source
Natural Gas	Mtoe (LNG)	t C (LNG)	0.624	1 Mtoe = 0.855 Mt LNG; carbon content, see above	[5]
Natural Gas	m3 (NG)	kg (NG)	0.735	1 billion cubic metres NG = 0.735 million tonnes LNG	[5]

Natural Gas	billion m3 (NG)	Gt C	5.36E-04	carbon content, see above	
Natural Gas	m3	kg	0.80	Density	[1]
Natural Gas	tonne	GJ	49.78	Gross caloric value	[1]
Natural Gas	m3	kg	0.80	Density	[1]
Natural Gas	tonne	GJ	49.78	Gross caloric value	[1]
LPG	m3	kg	518.44	Density	[1]
LPG	tonne	GJ	49.30	Gross caloric value	[1]

Coal

Coal is a sedimentary rock formed by dead plant matter which is transformed under pressure over time. The coalification process forms biotic material from peat to lignite, or brown coal, to sub-bituminous coal, to bituminous coal and then to anthracite. Those coal types have different carbon contents, according to [6]. To extract information on carbon content from data on world coal production not disaggregated for different coal types, the average carbon content of worldwide produced coal is calculated. The average carbon content is weighted by the specific share on world coal production, see Table 7.

Table 7. Calculation of the carbon content of coal (unspecific), own calculation according to [6]

Coal Type	World production share 2010	Carbon Content
Lignite	6,7%	37,0%
Sub-bituminous	46,2%	49,9%
Bituminous	46,9%	68,3%
Anthracite	0,2%	74,8%
Weighted Average		**57,7%**

To gather information on carbon flow from sources that use energy units (Mtoe) to express coal production instead of mass units, those must be converted. Therefore, the Mtoe value is converted to J, see Table 2, then the average energy content of each coal type according to [6] is used to calculate the corresponding mass of the coal type and then the specific carbon content of each coal type, see Table 7, is used to calculate the mass of carbon in one Mtoe, see Table 8.

Table 8. Calculation of the carbon content of coal given in energy units (Mtoe), own calculation according to [6]

Coal Type	Energy content [GJ/t Coal]	Mass of coal [Mt] in 1 Mtoe	mass of carbon [Mt C] in 1 Mtoe
Lignite	11,9	3,52	1,30
Sub-bituminous	18,9	2,22	1,11
Bituminous	25,8	1,62	1,11
Anthracite	26,7	1,57	1,17
Weighted average by world production	21,7	1,93	1,11

1.3. Conversion factors for Biomass products

The amount of carbon in biomass can vary widely, as it depends on the carbon content of the biomass feedstock. This in turn is determined by the amount of carbon in constituents like protein, fat, cellulose or starch and sugar within a compound. To estimate the carbon content, the mass percentage of carbon in these components has to be calculated, see table 9, according to [7].

Table 9. Carbon content of different biomass constituents (in %)

Biomass Constituent	**Carbon content [%] in dry matter material**	**Source**
Cellulose	44,4%	[7]
Sugar (Sucrose)	42,12%	own calculation based on [8]
Starch	44,26%	[7]
Protein (estimated average value)	55,7%	[7]
Fat (estimated average values)	76%	[7]

In addition, various assumptions and values for the carbon content in biomass exist in the literature. For example, according to FAO [8], the carbon content of biomass in vegetation (e.g. trees, herbs, shrubs) is always between 45% and 50% (by oven-dry mass), see Table 10.

Table 10. Conversion factor of biomass (vegetation), according to [8]

From	To	Conversion factor	Source
kg Biomass (oven-dry)	kg C	47,5%	[9]

1.4. Conversion factors for synthetic fuels

Synthetic fuels that are produced from hydrogen and carbon dioxide (CO_2) using electricity are called e-fuels (electrofuels, electric fuels). This process is known as power-to-fuel and, depending on whether gaseous (e-gas) or liquid fuels (e-liquids) are synthesized, can be implemented using power-to-gas or power-to-liquid technology. Therefore, carbon content can vary between these two fuel groups.

In addition, the carbon content strongly depends on the origin of the electricity used. Electricity from renewable energy sources to e-fuels with a lower carbon shares than from fossil resources.

Table 11 shows the amount of CO_2 used for the synthesis of e-gas and e-liquids.

Table 11. Amount of CO2 used for PTG and PTL synthesis, according to [10]

Technology	**Fuel type**	**Amount of CO_2 used for synthesis**
Power-to-gas (PTG)	1 kg e-methane	3,0 kg
Power-to-liquids (PTL)	1 l e-diesel	3,8 kg

APPENDIX 2 – WP2 CARBON DEMAND DATABASE

Table 1. Total carbon consumption in the industry sector in the EU-27 by 2050 [Mt C]

	Today	Scenarios for 2050					
	2018	**BAU**	**ELEC**	**H2**	**P2X**	**EE**	**CIRC**
Fossil	97.5	55.6	22.7	11.8	14.9	20.4	16.9
Biomass	24.9	38.4	46.5	51.1	50.6	56.0	48.6
E-Fuels	0.0	0.0	0.0	0.0	21.3	0.0	0.0

Table 2. Total carbon consumption in the transport sector in the EU-27 by 2050 [Mt C]

	Today	Scenarios for 2050					
	2018	**BAU**	**ELEC**	**H2**	**P2X**	**EE**	**CIRC**
Fossil	210.1	154.0	74.0	73.2	72.0	73.5	71.9
Biomass	12.9	19.4	19.4	18.9	42.1	41.0	33.1
E-Fuels	0.0	0.0	0.0	0.0	14.0	0.0	0.0

Table 3. Total carbon consumption in the residential sector in the EU-27 by 2050 [Mt C]

	Today	Scenarios for 2050					
	2018	**BAU**	**ELEC**	**H2**	**P2X**	**EE**	**CIRC**
Fossil	98.1	89.8	53.0	21.2	22.7	17.9	25.9
Biomass	41.0	31.5	14.5	17.8	18.9	26.3	17.8
E-Fuels	0.0	0.0	0.0	0.0	25.1	0.0	0.0

Table 4. Total carbon consumption in the energy sector (industry, transport and residential) in the EU-27 by 2050 [Mt C]

	Today	Scenarios for 2050					
	2018	**BAU**	**ELEC**	**H2**	**P2X**	**EE**	**CIRC**
Fossil	405.7	299.4	149.7	106.3	109.7	111.8	114.7
Biomass	78.8	89.2	79.9	111.1	110.5	115.4	108.1
E-Fuels	0.0	0.0	0.0	0.0	60.4	0.0	0.0

Table 5. Total carbon consumption in the material sector in the EU-27 by 2050 [Mt C]

	Today	Scenarios for 2050	
	2018	**Sufficiency**	**Technology**
Fossil	79.0	44.0	48.0
Biomass	103.0	106.0	194.0
CO2	0.0	4.0	25.0
Recycling	3.0	30.0	65.0

APPENDIX 3 – WP2 COMMONLY USED INDICATORS FOR ENERGY SUSTAINABILITY

Table 1. Overview of the commonly used indicators for the assessment of the sustainability in the energy sector

Indicator	unit	Short description	Reference
RES share	%	The indicator refers to the share of renewable energy sources in the gross final energy consumption[386]	Eurostat: SDG7 Affordable and clean energy[387] EU Resource Efficiency Scoreboard, 2015, Carbon indicators[388] E. Penalvo-Lopez at al, 2017, A methodology for analysing sustainability in energy scenarios[389] IEA, EEA, Eurostat, UNDSA, IAEA, 2005, Energy indicators for sustainable development: guidelines and methodologies[390]
Primary energy consumption	TOE	Total energy needs[391]	Eurostat: SDG7 Affordable and clean energy[392] IEA, EEA, Eurostat, UNDSA, IAEA, 2005, Energy indicators for sustainable development: guidelines and methodologies[393]
Final energy consumption	TOE	Energy consumed by end users[394]	Eurostat: SDG7 Affordable and clean energy[395] EU Resource Efficiency Scoreboard, 2015, Carbon indicators[396] IEA, EEA, Eurostat, UNDSA, IAEA, 2005, Energy indicators for

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[386] Eurostat, Share of renewable energy in gross final energy consumption by sector, 2020, see: Statistics | Eurostat (europa.eu)

[387] Eurostat, Sustainable development indicators, SDG7 Affordable and clean energy, see: 7. Affordable and clean energy - Eurostat (europa.eu)

[388] European Commission, Resource Efficiency Scoreboard, 1015, Carbon indicators, see: RE scoreboard 2015 v24 (europa.eu)

[389] Peñalvo-López, E.; Cárcel-Carrasco, F.J.; Devece, C.; Morcillo, A.I. A Methodology for Analysing Sustainability in Energy Scenarios. *Sustainability* **2017**, *9*, 1590., see: Sustainability | Free Full-Text | A Methodology for Analysing Sustainability in Energy Scenarios (mdpi.com)

[390] International Atomic Energy Agency (IAEA),United Nations Department of Economic and Social Affairs (UNDSA), International Energy Agency (IEA), European Environment Agency (EEA), Eurostat, 2005, Energy indicators for sustainable development: guidelines and methodologies, see: STI/PUB/1222 (iaea.org)

[391] Eurostat, Primary energy, 2020, see: Statistics | Eurostat (europa.eu)

[392] Eurostat, Sustainable development indicators, SDG7 Affordable and clean energy, see: 7. Affordable and clean energy - Eurostat (europa.eu)

[393] International Atomic Energy Agency (IAEA),United Nations Department of Economic and Social Affairs (UNDSA), International Energy Agency (IEA), European Environment Agency (EEA), Eurostat, 2005, Energy indicators for sustainable development: guidelines and methodologies, see: STI/PUB/1222 (iaea.org)

[394] Eurostat, Final energy, 2020, see: Statistics | Eurostat (europa.eu)

[395] Eurostat, Sustainable development indicators, SDG7 Affordable and clean energy, see: 7. Affordable and clean energy - Eurostat (europa.eu)

[396] European Commission, Resource Efficiency Scoreboard, 1015, Improving buidings, see: RE scoreboard 2015_v24 (europa.eu)

			sustainable development: guidelines and methodologies[397]
Energy related GHG emissions[398]	Index 2000=100	Ratio between energy related GHG and gross inland consumption of energy[399]	Eurostat: SDG7 Affordable and clean energy[400] EU Resource Efficiency Scoreboard, 2015, Carbon indicators[401] E. Penalvo-Lopez at al, 2017, A methodology for analysing sustainability in energy scenarios[402] IEA, EEA, Eurostat, UNDSA, IAEA, 2005, Energy indicators for sustainable development: guidelines and methodologies[403]
Energy productivity	EUR/Mtoe	The indicator measures the amount of economic output that is produced per unit of gross available energy.	Eurostat: SDG7 Affordable and clean energy[404] EU Resource Efficiency Scoreboard, 2015, Carbon indicators[405] Other studies[406][407] refer to energy intensity instead. Both indicators are comparing the energy consumption in relation to the GDP[408].

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[397] International Atomic Energy Agency (IAEA),United Nations Department of Economic and Social Affairs (UNDSA), International Energy Agency (IEA), European Environment Agency (EEA), Eurostat, 2005, Energy indicators for sustainable development: guidelines and methodologies, see: STI/PUB/1222 (iaea.org)

[398] Please note that while all the above-mentioned publications make use of indicator on GHG emissions in energy sector, its definition slightly varies.

[399] Eurostat, Energy import dependency, 2020, see: Statistics | Eurostat (europa.eu)

[400] Eurostat, Sustainable development indicators, SDG7 Affordable and clean energy, see: 7. Affordable and clean energy - Eurostat (europa.eu)

[401] European Commission, Resource Efficiency Scoreboard, 1015, Carbon indicators, see: RE_scoreboard 2015_v24 (europa.eu)

[402] Peñalvo-López, E.; Cárcel-Carrasco, F.J.; Devece, C.; Morcillo, A.I. A Methodology for Analysing Sustainability in Energy Scenarios. *Sustainability* 2017, *9*, 1590., see: Sustainability | Free Full-Text | A Methodology for Analysing Sustainability in Energy Scenarios (mdpi.com)

[403] International Atomic Energy Agency (IAEA),United Nations Department of Economic and Social Affairs (UNDSA), International Energy Agency (IEA), European Environment Agency (EEA), Eurostat, 2005, Energy indicators for sustainable development: guidelines and methodologies, see: STI/PUB/1222 (iaea.org)

[404] Eurostat, Sustainable development indicators, SDG7 Affordable and clean energy, see: 7. Affordable and clean energy - Eurostat (europa.eu)

[405] European Commission, Resource Efficiency Scoreboard, 1015, Carbon indicators, see: RE_scoreboard 2015_v24 (europa.eu)

[406] Peñalvo-López, E.; Cárcel-Carrasco, F.J.; Devece, C.; Morcillo, A.I. A Methodology for Analysing Sustainability in Energy Scenarios. *Sustainability* **2017**, *9*, 1590., see: Sustainability | Free Full-Text | A Methodology for Analysing Sustainability in Energy Scenarios (mdpi.com)

[407] International Atomic Energy Agency (IAEA),United Nations Department of Economic and Social Affairs (UNDSA), International Energy Agency (IEA), European Environment Agency (EEA), Eurostat, 2005, Energy indicators for sustainable development: guidelines and methodologies, see: STI/PUB/1222 (iaea.org)

[408] Difference between the two indicators is that energy productivity is calculated as GDP divided by energy consumption, while energy intensity is calculated as energy consumption divided by GDP. KAPSARC, http://www.necst.eu/wp-content/uploads/PPT_Hobbs.pdf

APPENDIX 4 – WP3 LONG LIST OF TECHNOLOGIES

The long-list includes available technologies which are mainly listed according the addressed feedstock (CO_2, plastic waste, and biomass; indicated in squared brackets) and technology (chemical conversion, biotechnological conversion, and biochemical conversion). Additionally, the technologies for the production of green hydrogen as well as plant/prop modifications are listed below. Slight deviations of the TRL from the short list may occur since the long list is less product-specific and more general.

1.2 [CO_2] Carbon Capture and Utilisation (CCU)

Carbon capture

- Currently about 30 projects/companies listed for CO_2 capture from various sources: ambient air, pre combustion, oxyfuel combustion and post combustion
- Ranging from pilot, demonstration, pre-commercial to commercial scale

Carbon utilisation

- Currently over 100 projects/companies listed using or planning to use CO_2 for various applications
- Ranging from lab, pilot, demonstration over pre-commercial to commercial scale

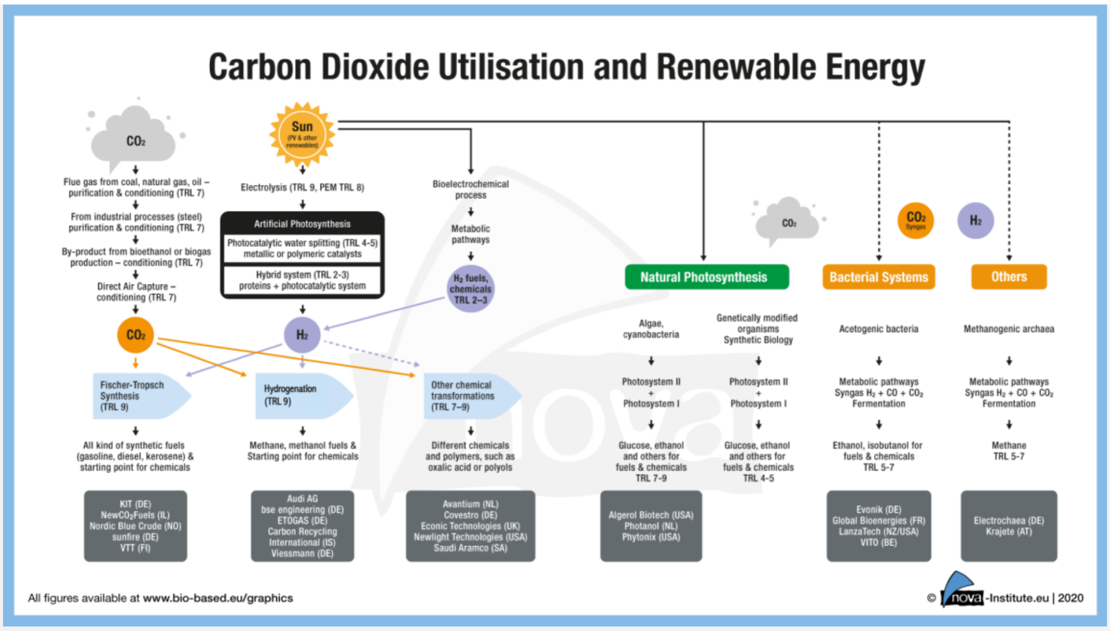

Figure 1: Carbon Dioxide Utilisation and Renewable Energy. Adapted from Raschka et al. (2019).

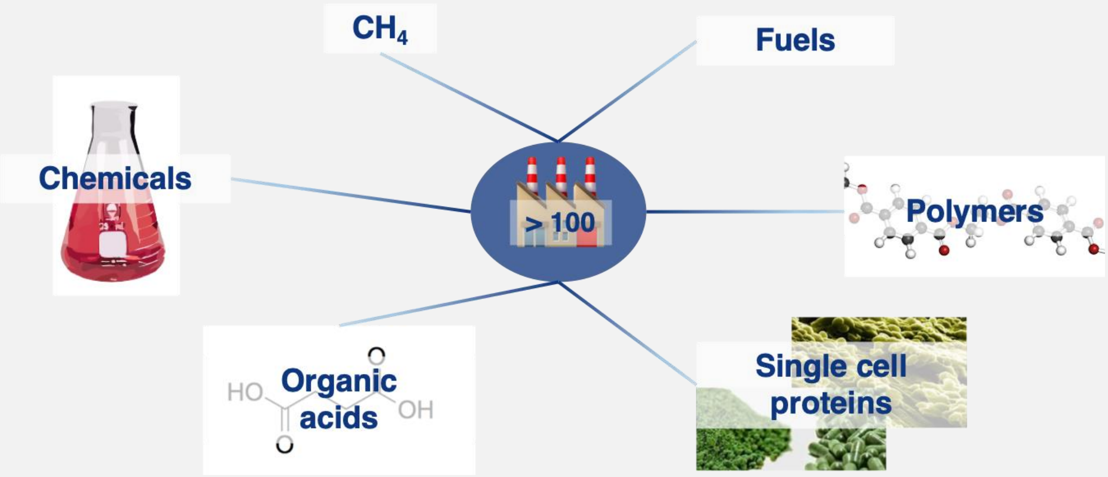

Figure 1. Product range that can be covered via carbon capture and utilisation. Adapted from nova-Institut GmbH.

1.2.1 [CO_2] Chemical conversion

Chemical conversion includes the use of conventional chemical reaction systems, catalysts and energy input to convert CO_2 (or other carbon-containing gases) into various products as e.g. chemicals, gases, polymers or synthetic fuels.

Electrochemical conversion is a special chemical conversion that uses electrical energy to reduce CO_2. Examples: formic acid, oxalic acid etc..

Table 1. Chemical conversion technologies based on CO_2 feedstocks.

Process/Technology		Description (specifically for CO_2 utilisation)	TRL	Products
Chemical conversion				
Power-to-X	Photochemistry (Artificial Photosynthesis)	CO_2, water and sunlight are photochemically converted into carbohydrates and oxygen.	3	Carbohydrates, chemicals, energy storage gas, synthetic fuels
	Electrochemistry	CO_2 is electrically reduced to CO in water as a solvent. The CO is subsequently further reduced to organic acids or ethylene.	3-5	Chemicals, synthetic fuels
	Fischer-Tropsch synthesis	Syngas that is further processed to hydrocarbons as synthetic fuels and waxes, as well as naphtha.	9	Synthetic fuels, synthetic waxes, Fischer-Tropsch (FT) naphtha
	Hydrogenation	Chemical reaction between CO_2 and hydrogen (H_2) to form methanol and water (H_2O). Specific catalysts are needed to drive the reaction.	9	Chemicals, energy storage gas, synthetic fuels
	Syngas production	Reduction of CO_2 to carbon monoxide (CO) by hydrogen addition and adjusting component (CO, CO_2, H_2 and H_2O) ratio by reverse water-gas shift reaction.	9	Chemicals, FT napththa, energy storage, polymers, synthetic fuels
Mineralisation		CO_2 is fixated in inorganic compound	9	Carbonates
Polymers and textiles	Polycarbonate synthesis	Chemical reaction between CO_2 and epoxides (ethylene oxide (EO) or propylene oxide (PO)) to form PEC or PPC. Specific catalysts are needed to drive the reaction.	9	Polycarbonates, polycarbonate polyols

	Polyolefin synthesis	CO_2 is hydrogenated or converted via Fischer-Tropsch into methanol or syngas. These intermediates are used as feedstocks for further polyolefin synthesis.	3	Polyethylene (PE), polypropylene (PP)
	Polyurethane and textile synthesis	Polycarbonate polyols are chemically reacted with isocyanate to form polyurethanes and further be processed into textiles.	9	Polyurethanes, textiles
	Others (e.g. polyacrylate, polyester, polyurea)	Chemical reaction between CO_2 and various other molecules.	3-4	Polyacrylate, polyester, polyurea

1.2.2 [CO_2] Biotechnological conversion

Biotechnological conversion includes the use of so called biocatalysts to convert CO_2 (or other carbon-containing gases) into various products as e.g. polymers, chemicals or gases.

- Biocatalysts = enzymes (non-living) or microorganisms (living)
- High selectivity, yield and reproducibility
- No addition of toxic chemicals for conversion

Table 2. Exemplary microorganisms that can be utilised for the biotechnological conversion of CO_2.

Acetogenic bacteria	Archaea	Cyanobacteria	Microalgae
e.g. *Clostridium ljungdahlii*	e.g. *Methanococcus spec.*	e.g. *Spirulina spec.*	e.g. *Pavlova spec.*
chemoautotrophics		photoautotrophics	
Syngas (H_2 + CO + CO_2) or CO_2	Syngas (H_2 + CO + CO_2) or CO_2	Syngas and CO_2 + H_2O + light	CO_2 + H_2O + light
Alcohols, organic acids	Gases	Sugars, lipids, organic acids, alcohols	

Table 3. Biotechnological conversion technologies based on CO_2 feedstocks.

Process/Technology	Description (specifically for CO_2 utilisation)	TRL	Products
Biotechnological conversion			
Acetogenic bacterial system	Fermentative conversion of syngas, CO or CO_2 into alcohols, chemicals and polymers.	9	Chemicals, polymers, proteins, synthetic fuels
Archaea-based system	Fermentative conversion of CO_2 into methane.	9	Energy storage gas, proteins
Cyanobacterial system	Natural photosynthesis for conversion of CO_2 into chemicals.	7	Carbohydrates, chemicals, proteins, synthetic fuels
Synthetic microbial systems (Synthetic Biology)	Engineered fermentative CO_2 conversion into chemicals, building blocks and polymers.	4	Chemicals, polymers, proteins
Plant system	Production of valuable compounds via plants.	6-9	Fine chemicals, pharmaceuticals

1.3 [Plastics & Polymers] Recycling

1.3.1 [Plastics & Polymers] System prerequisites for recycling

System prerequisites for recycling are:

- Waste collection
- Sorting and separation

Waste collection is needed to ensure that the potential feedstock can be directed to suitable processes which are ranked analogous to the waste hierarchy. During collection the waste can be pre-sorted which contributes to better yields in the following sorting and separation processes.

Sorting and separation are needed to obtain more homogeneous waste streams (e.g. PET bottles sorted by colour). The process contributes to higher yields and quality of recycled materials and decreases the complexity and requirements of all following recycling processes

Table 4. Waste collection systems as prerequisite for recycling technologies.

Process/Technology	Description	TRL	Products

Waste collection				
Collection system	Door-to-door (single fraction)	Waste is collected in separate bins.	-	Collected waste fractions separated into Paper, Glass, Plastic, Metal, and Bio-waste
	Door-to-door (Co-mingling of 2 fractions)	Plastic and metal is collected in one bin.	-	Waste fraction containing plastic and metal fraction
	Door-to-door (Co-mingling of 3 fractions)	Collection of three fractions together in one bin.	-	Collected waste fractions separated into paper, plastic, and metal, or plastic, metal, and glass fraction
	Door-to-door (Co-mingling of all fractions)	All fractions are collected in one bin.	-	Collected waste containing all fractions
	Bring points	Waste can be transported to bring-points which collect different waste fractions via separate containers.	-	Collected waste fractions separated into Paper, Glass, Plastic, Metal, and Bio-waste
	Civic amenity sites	Waste can be transported to amenity sites which collect different waste fractions.	-	Collected waste fractions separated into Paper, Glass, Plastic, Metal, and Bio-waste

Table 5. Waste sorting systems as prerequisite for recycling technologies.

Process/Technology		Description	TRL	Products
Sorting and separation				
Sorting & separation system	Air separator/wind shifter	Separation of lighter fractions (e.g. paper, foils/films, dust) from the waste.	8-9	Pre-sorted heavy and light fractions
	Magnet	Separation of magnetic metals (e.g. iron).	8-9	Waste fractions sorted by e.g. ferrous and non-ferrous material
	Sorting machine (NIR spectroscopy)	Identification of different polymers types.	8-9	Plastic waste fractions sorted by their polymer type

				(e.g. PP, PE, PVC, PET)
	Sorting machine (CCD)	Identification of different coloured plastics.	8-9	Plastic waste fractions sorted by their colour
	Shredder	Disruption of plastic waste into smaller flakes.	8-9	Plastic flakes
	Density fractionation	Fractionation of plastic waste in dependence of the density of contained polymers.	8-9	Plastic waste fractions sorted by their polymer type (e.g. PP, PE, PVC, PET)

1.3.2 *[Plastics & Polymers] Mechanical recycling*

Mechanical recycling is realised via extrusion in which plastics are melted and processed into pellets, or other shapes for further producing applications (e.g. injection moulding). Mechanical recycling can only be applied on thermoplastics, does not change the molecular structure of the polymer, and does not remove colours, hazardous substances, and additives from the plastic.

Product uses:

- **Plastic recyclate:** For the production of products via injection moulding

Table 6. Mechanical recycling technology based on plastics & polymers feedstocks.

Process/Technology		Description	TRL	Products
Mechanical recycling				
Extrusion	Screw-extrusion	Plastic is melted via heaters and mechanical energy generated by turning screws, the molten polymer exits the extruder through a formative opening where it is cooled down.	8-9	Plastic recyclate in form of pellets and other shapes

1.3.3 *[Plastics & Polymers] Chemical recycling*

Available technologies are divided into

- Thermochemical technologies
- Solvent-based technologies

- Biochemical technologies

Three basic mechanisms are part of different technologies:

- Depolymerisation (via thermochemical, solvent-based, and biochemical technologies)
- Purification (via solvent-based methods)
- Conversion (via thermochemical methods)

Thermochemical conversion includes the conversion of hydrocarbons in presence of heat into various products such as char, oil, syngas, and energy.

- Implementation of a wide range of up- and downstream processes
- Removal of colours, hazardous substances, and additives from the plastic

Thermochemical depolymerisation includes the depolymerisation of a polymer via heat to obtain their building blocks (e.g. monomers, dimers, oligomers) which can be used for the synthesis of new polymers.

- Limited to certain polymers (e.g. PS, PMMA)
- Removal of colours, hazardous substances, and additives from the plastic

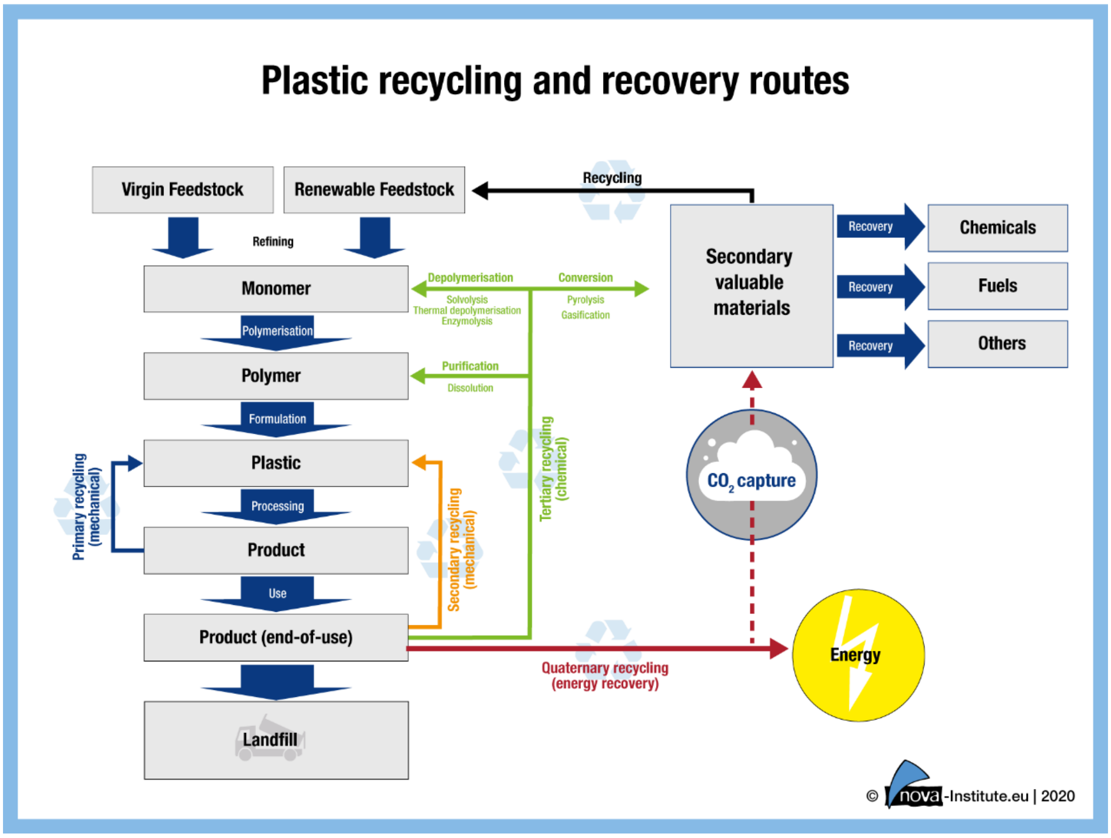

Figure 2. Plastic recycling and recovery routes.

Table 5. Thermochemical recycling technologies based on plastics & polymers feedstocks.

Process/Technology		Description	TRL	Products
Thermochemical conversion				
Pyrolysis	Thermal cracking	Under absence of O_2 hydrocarbons are thermochemically cracked into lower molecular weight hydrocarbons and gases.	7	Char, chemicals, synthetic fuels (gas, oil), synthetic waxes
	Catalytic cracking (one-step)	Under absence of O_2 and in presence of a catalyst hydrocarbons are thermochemically cracked into lower molecular weight hydrocarbons and gases whereby the product yield	6-7	Char, chemicals, synthetic fuels (gas, oil), synthetic waxes

		can be controlled by the catalyst.		
	Catalytic cracking (two-step)	In the first step hydrocarbons are thermochemically cracked under absence of O_2 before they are catalytically cracked in a second step into lower molecular weight hydrocarbons and gases.	6-7	Char, chemicals, synthetic fuels (gas, oil), synthetic waxes
	Hydrocracking	In presence of H_2 hydrocarbons are thermochemically cracked and hydrogenated into lighter saturated hydrocarbons and gases.	4	Char, chemicals, synthetic fuels (gas, oil), synthetic waxes
Gasifiction	Steam gasification	Indirect hydrogenation of hydrocarbons using heat and steam as hydrogen source in presence of air/O_2 to produce low/medium heating value gas.	7-8	Syngas (H_2, CO, N_2/ H_2, CO), Low/medium Btu
	Catalytic gasification	In a two-step-process the hydrocarbons are undergoing pyrolysis first before the pyrolysis followed by catalytic reforming of volatiles into high heating value gas.	4	Substitute natural gas (SNG) (CH_4)
	Hydrogasification	Direct hydrogenation in H_2 atmosphere at high pressures.	4	Syngas (H_2, CH_4, CO), High Btu
Incineration	Incineration	Combustion of hydrocarbons and production of energy in form of heat.	9	Energy (thermal or electrical), ash and CO_2, recovered solids (e.g. metals)
		Thermochemical depolymerisation		
Pyrolysis	Thermal depolymerisation	Under absence of O_2 certain polymers are thermochemically cracked into their building blocks (monomers) by end-chain scission.	7	Chemicals (polymer building blocks)

Solvent-based depolymerisation or solvolysis includes the depolymerisation of a polymer in a solvent to obtain their building blocks (e.g. monomers, dimers, oligomers) which can be used for the synthesis of new polymers.

- The processes can be very specific for targeted polymers
- Removal of colours, hazardous substances, and additives from the plastic

Solvent-based purification or dissolution includes the selective removal of a polymer from plastics. The molecular structure of target polymer remain unchanged which can directly be used for the plastic production.

- Processes can be very specific for targeted polymers
- Primarily applicable on thermoplastics
- Removal of colours, hazardous substances, and additives from the plastic

Table 7. Solvent-based recycling technologies based on plastics & polymers feedstocks.

Process/Technology		Description	TRL	Products (e.g. from PET as feedstock)
Solvent-based depolymerisation				
Solvolysis	Alcoholysis (Glycolysis)	Utilisation of glycols as solvent for the depolymerisation of e.g. PET, PUR, and PLA.	6-7	Bis(hydroxyethyl)terephthalate (BHET), polyols
	Alcoholysis (Methanolysis)	Utilisation of methanol as solvent for the depolymerisation of e.g. PET, PUR, and PLA.	6-7	Dimethyl terephthalate (DMT)
	Hydrolysis	Depolymerisation of polymers such as PET, PU, PA, POM, PC, CA, PBAT, PBS, PHA, and PLA in an aqueous environment under neutral, acidic, or basic conditions.	4-5	Terephthalic acid (TPA)
	Ammonolysis/Aminolysis	Utilisation of ammonia as solvent for the depolymerisation of e.g. PET, PUR,, and PA.	3	TPA Amide

Solvent-based purification				
Dissolution	Dissolution	Dissolution of a target polymer in a solvent followed by the removal of undissolved components such as other polymers, additives, and pigments and precipitation of the purified target polymer.	6-7	PET

Biochemical depolymerisation (Enzymolysis) includes the depolymerisation of a polymer into its building blocks (e.g. monomers, dimers, oligomers) via enzymes as so-called biocatalysts.

- Biocatalysts are very specific for targeted polymers
- Biocatalysts are produced by different organisms such as microorganisms and fungi.
- Biocatalysts can be harvested from their producing organism to be applied in the process of enzymolysis in their isolated form (without its producing organism), alternatively the organism can be utilised to produce the biocatalyst directly in the process of enzymolysis
- Removal of colours, hazardous substances, and additives from the plastic

Table 8. Biochemical recycling technologies based on plastics & polymers feedstocks.

Process/Technology		Description	TRL	Products
Biochemical – Enzymolysis				
Enzymolysis	Enzymolysis	Depolymerisation of polymers via biocatalysts.	3	Monomers, dimers, oligomers

1.4 [Biomass] Biomass utilisation

Biomass utilisation includes all technologies based on the use and conversion of biomass and biogenic streams. This includes fresh biomass from agriculture and forestry, biogenic side- and waste-streams as well as biogenic fractions in wastewater, waste gases, and other streams.

Available Technologies for biomass utilisation are divided into

- Mechanical and physical processes
- (Thermo)chemical technologies
- Electrochemical conversion
- Biotechnological conversion

Biogenic waste gases → CO_2

The mechanical and physical preparation of biomass includes all traditional treatment options without the use of chemical, thermochemical and biotechnological conversion. This includes separation technologies like **filtration**, **distillation** and **extraction**. Additionally **mechanical fragmentation** and crystallisation (incl. freezing) is included in these technologies. Most of the mechanical processes are used in the pre-treatment of biomass to make it suitable for further technological steps (upstream) or in the separation of products after a chemical or biotechnological production part (downstream).

1.4.1 [Biomass] Chemical conversion

Chemical conversion includes the use of conventional chemical reaction systems, catalysts and energy input to convert biomass into various products as e.g. chemicals, gases, polymers or synthetic fuels. Typical chemical processes use chemical reaction systems and chemicals together with catalysts for the conversion processes. This can be assisted by heat and pressure. The specific thermochemical processes (see later) use heat as energy source for the conversion processes.

Electrochemical conversion is a special chemical conversion that uses electrical energy to reduce biogenic resources.

Table 9. Chemical conversion technologies based on plastics & polymers feedstocks.

Process/Technology	Description	TRL	Products
Chemical conversion			
Pulping	Biomass, mainly wood (2G, straws, bamboo) is the chemical disintegration of plant material (lignocellulose) to cellulose fibres for paper and chemical pulp.	9	Chemical pulp, paper pulp; black liqueur, lignin, lignosulfonates
Oxidation	Biomolecule conversion via chemical oxidation processes, esp. sugars or lignin (alcohol -> aldehyde -> organic acids).	6-9	Chemicals (aldehydes, organic acids)
Hydrogenation	Biomass conversion via hydrogenation processes.	9	Chemicals
Hydrolysis	Biomass conversion via hydrolysis.	9	Chemicals

Hydrodeoxygenation	Biomass (waste fats and oils, oil plants) is hydrodeoxygenated to produce naphtha.	9	Chemicals, polymers, synthetic fuels
Extraction	Extraction of valuable molecules from biomass via gaseous of liquid solvents.	6-9	Fine chemicals, chemicals, protein
Esterification	Conversion of bio-based molecules via esterification. Especially the reaction of an organic acid with an alcohol or phenol as condensation.	6-9	Chemicals, oligomers, polymers, fibers
Etherification Etherification	Conversion of bio-based molecules to an ether via linkage of to functional building blocks via an ether bridge (O).	6-9	Chemicals
Isomerisation	A process in which a bio-based molecule or molecular fragment is transformed into an isomer with a different chemical structure.	6-9	Chemicals
Polymerisation	Polymerisation of biogenic building blocks to bio-based oligomers, polymers and co-polymers.	6-9	Chemicals, polymers, fibers, plastics
Electrochemistry	Biogenic molecules are electrically reduced to intermediates or final products.	4	Chemicals, fuels

1.4.2 [Biomass] (Thermo)chemical conversion

Thermochemical conversion includes the use of heat energy to convert biomass into various products as e.g. chemicals, gases, polymers or synthetic fuels. The conversion can be assisted by the use of catalysts.

Table 10. (Thermo)chemical conversion technologies based on biomass feedstocks.

Process/Technology	Description	TRL	Products
(Thermo)chemical conversion			
Gasification	Biomass (1G, 2G, municipal solid waste, organic waste) is gasified to produce syngas.	9	Chemicals, FT naphtha, energy storage, polymers, synthetic fuels
Hydrolysis and hydrogenation	Biomass (1G and 2G) is hydrolysed to sugars that can subsequently be hydrogenated to chemicals.	9	Chemicals

Incineration	Combustion of hydrocarbons and production of energy in form of heat.	9	Energy (thermal or electrical), ash and CO_2, recovered solids (e.g. metals)
Pyrolysis	Under absence of O_2 hydrocarbons are thermochemically converted into lower molecular weight hydrocarbons and gases.	7	Char, chemicals, synthetic fuels (gas, oil)

1.4.3 [Biomass] Biotechnological conversion

Biotechnological conversion includes the use of so called biocatalysts to convert biomass into various products as e.g. polymers, chemicals or gases.

- Biocatalysts = enzymes (non-living) or microorganisms (living)
- High selectivity, yield and reproducibility
- No addition of toxic chemicals for conversion

Table 11. Biotechnological conversion technologies based on biomass feedstocks.

Process/Technology	Description	TRL	Products
Biotechnological conversion			
Anaerobic digestion	Biomass (1G and 2G) is anaerobic digested to produce biogas.	9	Gaseous fuel, syngas (after reforming)
Gas fermentation	Fermentative conversion of syngas from biomass (1G, 2G, municipal solid waste, organic waste) to alcohols and chemicals.	6	Chemicals, proteins, synthetic fuels
Sugar fermentation	Fermentative conversion of hydrolysed biomass (1G and 2G) to alcohols and chemicals.	9	Chemicals, biofuels, proteins
Insects and other animals	e.g. conversion of biomass and biogenic wastes via insect feeding to insect biomass.	6-9	Chemicals (chitin, chitosan), proteins
Stem cells	Conversion of sugars and amino acids from biomass into pharmaceuticals and proteins.	4	Pharmaceuticals, proteins

1.5 Green hydrogen and renewable energy as enabling technology

Renewable energy, mostly in the form of green hydrogen is an indispensable enabler for carbon utilisation. Especially for direct CO_2 utilisation via CCU and Power-to-X technologies.

Principle: Hydrolysis of water into hydrogen and oxygen (electrolysis) powered by electricity from renewable energy.

Table 12. Enabling technologies for the production of green hydrogen via renewable energy.

Process/Technology	Description	TRL
Alkaline electrolysis	Electrolysis is performed with two electrodes that are operated in a liquid alkaline electrolyte solution of potassium hydroxide (KOH) or sodium hydroxide (NaOH) at 60–80 °C.	9
Battolyser (nickel-iron accumulator-based electrolysis)	Alkaline electrolysis is coupled with an integrated nickel-iron battery for energy storage.	4
High-temperature electrolysis	Electrolysis is performed at high temperatures between 100 and 850 °C.	9
Polymer electrolyte membrane (PEM) electrolysis	Electrolysis is performed in a cell with a solid polymer electrolyte at 50–80 °C.	7-9
Solid oxide electrolysis (SOEC) (High-temperature co-electrolysis; Cerium (IV) oxide–cerium (III) oxide cycle)	Electrolysis is performed in a cell with a solid oxide or ceramic electrolyte at 500–850 °C.	9

1.6 Plant/crop modification techniques

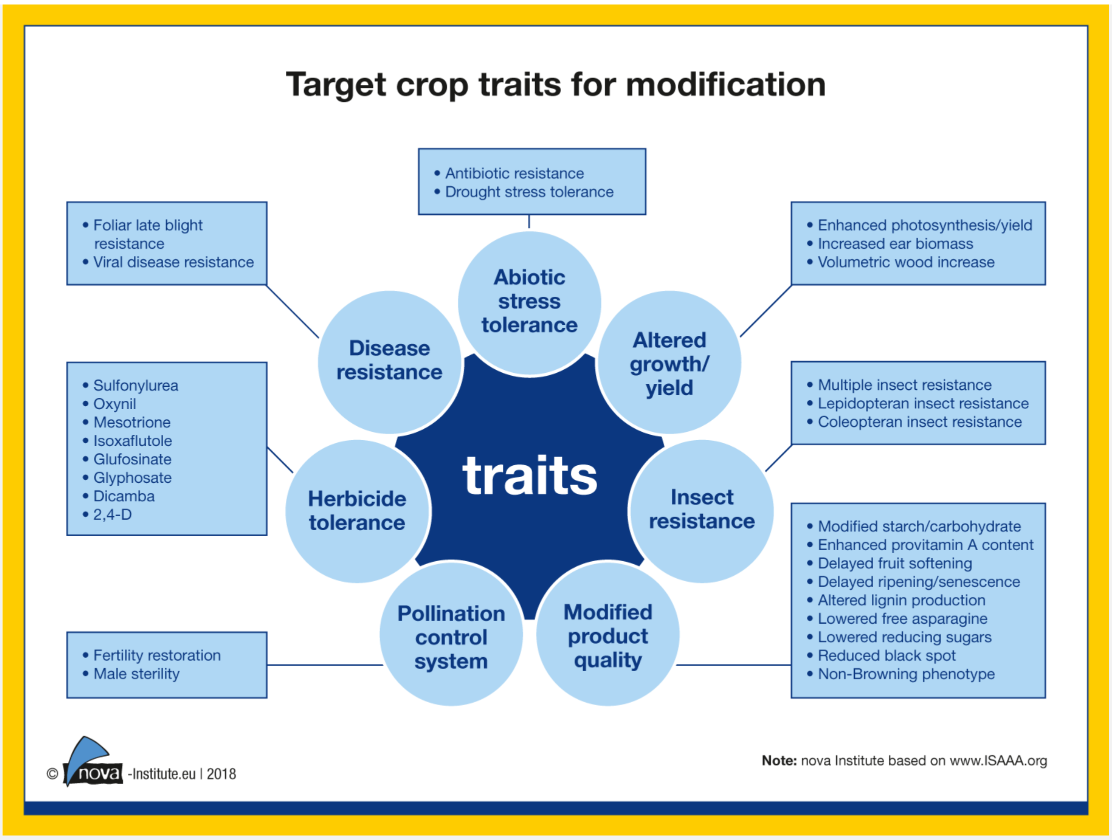

Figure 3. Target crop traits for modification. Adapted from nova-Institut GmbH.

Table 13. Techniques for trait modification.

Process/Technology	Description	Advantage	Disadvantage
Conventional breeding	Classical breeding Plant crossbreeding until desired trait Classical mutagenesis breeding Introduction of mutations via chemical or physical stress	Long-term established and accepted method	Classical breeding often backcrossing necessary → time-consuming Classical mutagenesis breeding unspecific introduction → high risk of unwanted, untargeted mutations (> 99.9 %)
Genetic engineering	Mainly insertion of foreign genes via transformation, transfection and transduction	More specific, reduced amount of unwanted, untargeted mutations	Unwanted, untargeted mutations still possible Transgenic crop generation

Genome editing	Deletion/Insertion, knock-out of genes, possibly without introduction of foreign genes, via CRISPR/Cas, TALEN and Zinc finger nucleases	Highly specific and fast, very low risk of unwanted, untargeted mutations (< 0.0000001 %)	Knowledge of genome required

1.6.1 *Regulation of modification techniques*

Process-based focus:

Regulation based on the process (transgenic / foreign DNA element or conventional breeding) that was used to introduce / induce the new trait.

Product-based focus:

Regulation based on the end-product constituting transgenic / foreign DNA element or not.

Table 14. Regulation of modification techniques across different regions.

Process/Technology	EU	Canada	China	USA
Conventional breeding	No GMO	GMO ➢ PNT* regulations (plants expressing novel traits) ➢ product based (case-by-case)	No GMO	No GMO
Genetic engineering	GMO	GMO/ PNT	GMO	GMO
Genome editing	GMO	GMO/ PNT	No clear regulation; massive investment in genome editing so regulation will not be restrictive	No GMO; ➢ product based (case-by-case)

*PNT definition: A plant with a novel trait (PNT) is a plant that contains a trait which is both new to the Canadian environment and has the potential to affect the specific use and safety of the plant with respect to the environment and human health. These traits can be introduced using biotechnology, mutagenesis, or conventional breeding techniques; http://www.inspection.gc.ca/plants/plants-with-novel-traits/eng/1300137887237/1300137939635

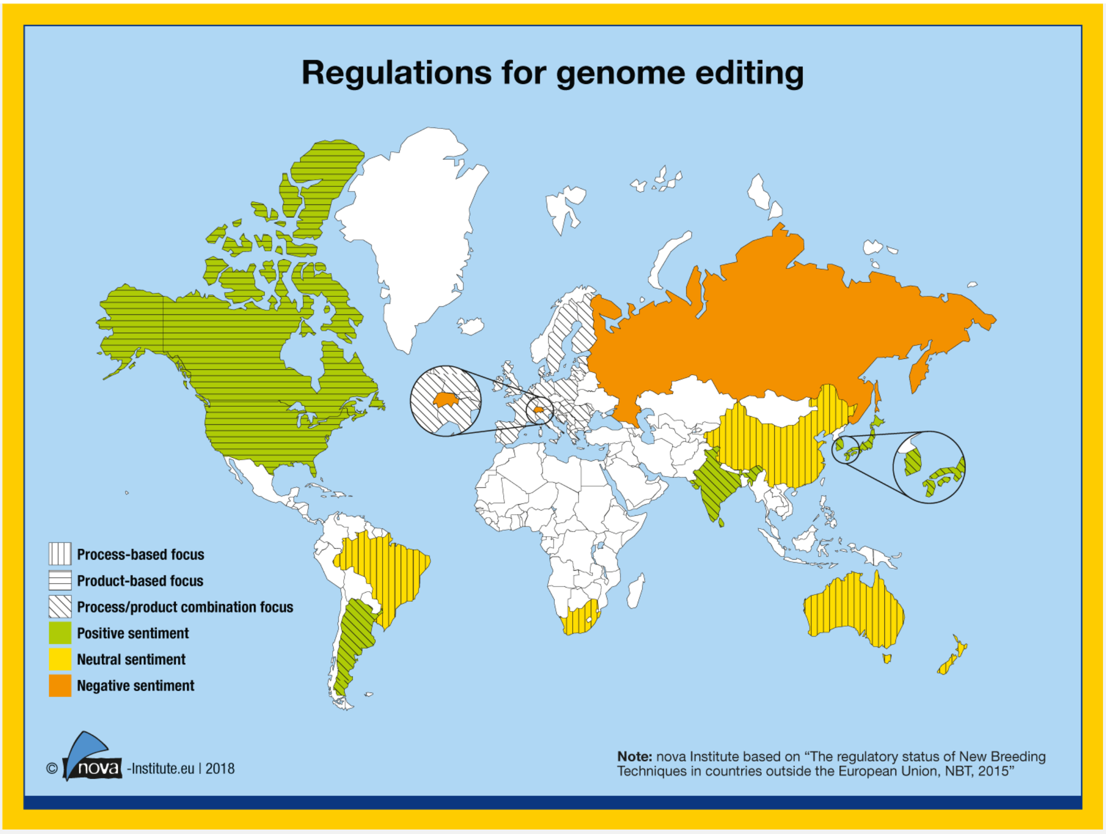

Figure 4. Regulations for genome editing. Adapted from nova-Institut GmbH.

APPENDIX 6 – WP4 CASE STUDY TEMPLATE FOR INTERVIEWS

General information

- Country / region / province.
- Population.
- Universities/ Research institutes on bioeconomy.

Biological resources availability (to the extent possible)

- Origin, amount (volume and weight) and technical characteristics (as potential feedstock for biorefining) of bio-waste.
- Origin, amount (volume and weight) and technical characteristics (as potential feedstock for biorefining) of wastewater sludge.
- Origin (urban versus rural, local versus imported), if available by amount (volume and weight) and technical characteristics (as potential feedstock for biorefining) of other local sources of biomass.

Biological resources valorisation TODAY

- Collection scheme (separate/ mixed together, direct delivery from small and medium size companies.
- Technical processes and technologies for valorisation per waste category.
- Bio-based products from urban bio-waste, wastewater sludge and other sources of biomass.
- Current business model, stage of digitalisation, jobs involved, skills and capacities required.
- EU, national, local regulatory drivers and obstacles supporting/limiting the current valorisation.
- Governance aspects, pricing, financing.
- Economic, social, environmental (and Climate) outcomes of the current valorisation.

Biological resources valorisation TOMORROW:

- Collection scheme – potentials for improvement.
- Technical processes and technologies for valorisation – potentials for technical and process improvements for innovative bio-based products.
- Current business model – potential for improvement.
- How to address regulatory obstacles and support regulatory drivers?

- What are the EU, national, local funds to finance innovative value chains for the valorisation of urban bio-waste, wastewater sludge and other sources of biomass through the production of innovative bio-based products?

- Expected economic, social, environmental (and climate) outcomes of the future innovative valorisation.

Circular economy, including circular bioeconomy TODAY

- Analysis of existing national / regional / urban circular economy strategies, projects and measures.

- Technical, economic, juridical, social, environmental (including and climate-related) aspects and outcomes.

- EU, national, regional, local financial schemes to draft, launch, implement and assess circular economy strategies, projects and measures.

- Current business models.

- EU, national, local regulatory drivers and obstacles supporting/limiting circular economy measures.

- Circular economy governance aspects.

- Specificities of circular bioeconomy as part of circular economy.

Circular economy, including circular bioeconomy TOMORROW

- How to improve / what are the potentials of existing national / regional / urban circular economy strategies, projects and measures (incl. digitalisation, platforms?

- How to improve / what are the potentials of technical, economic, juridical, social, environmental (and climate)-related aspects and outcomes?

- How to improve / what are the potentials of EU, national, regional, local financial schemes to draft, launch, implement and assess circular economy strategies, projects and measures?

- How to improve / what are the potentials of current business models?

- How to address regulatory obstacles and support regulatory drivers?

- How to improve / what are the potentials of circular economy governance aspects?

- How to improve / what are the potentials of circular bioeconomy as part of circular economy?

APPENDIX 7 – WP4 LIST OF ONGOING PROJECTS AVAILABLE ON CORDIS

Project	Name	Description	Status	Time Frame	Budget	Coordinator
HORIZON 2020	ULTIMATE	indUstry water-utiLiTy symbIosis for a sMarter wATer society	Ongoing	June 2020 - May 2024	€ 16 614 813.75	KWR WATER B.V. Netherlands
Horizon 2020	Zero Brine	Re-designing the value and supply chain of water and minerals: a circular economy approach for the recovery of resources from saline impaired effluent (brine).	Ongoing	June 2017 – May 2021	€ 11 078 222.69	TECHNISCHE UNIVERSITEIT DELFT Netherlands
Horizon 2020	nextGen	Towards a next generation of water systems and services for the circular economy	Ongoing	July 2020 – June 2022	€ 11 389 106.04	KWR WATER B.V. Netherlands
Horizon 2020	SCALIBUR	Scalable Technologies for Bio-urban waste recovery	Ongoing	November 2018 – October 2022	€ 11 728 483.61	INSTITUTO TECNOLOGICO DEL EMBALAJE, TRANSPORTE Y LOGISTICA, Spain
HORIZON 2020	SEArcularMINE	Three innovative technologies within a circular procedure that will target magnesium, lithium and other trace elements.	Ongoing	June 2020 - May 2024	€ 5 834 016.25	UNIVERSITA DEGLI STUDI DI PALERMO, Italy
HORIZON 2020	WaysTUP!	Aims to establish new value chains for urban bio-waste utilisation to produce higher value products, including food and feed ingredients through a multi-stakeholder approach.	Ongoing	September 2019 - February 2023	€ 11 670 317.81	SOCIEDAD ANONIMA AGRICULTORES DE LAVEGA DE VALENCIA, Spain
HORIZON 2020	YPACK	Pre-industrial validation of two food packaging solutions based on PHA. New	Ongoing	1 November 2017 - 30 April 2021	€ 7 277 671.25	AGENCIA ESTATAL CONSEJO SUPERIOR

		packaging will use food industry by-products in the frame of the EU Circular Economy strategy.				DEINVESTIGACIONES CIENTIFICAS, Spain
HORIZON 2020	URBIOFIN	Demonstration of an innovative biorefinery for the transformation of Municipal Solid Waste (MSW) into new Bio-Based products.	Ongoing	June 2017 - December 2021	€ 14 606 669.31	INDUSTRIAS MECANICAS ALCUDIA SL Spain
Horizon 2020	BIO-PLASTICS EUROPE	Connecting economic and environmental gains and will focus on sustainability strategies and solutions for bio-based products to support the Plastics Strategy.	Ongoing	October 2019 - September 2023	€ 8 503 592.50	HOCHSCHULE FUR ANGEWANDTE WISSENSCHAFTEN HAMBURG Germany
Horizon 2020	B-Ferst	Main objective to integrate the valorisation of bio-wastes in agriculture management plans for new bio-based value chains with interaction between farming and fertiliser sectors.	Ongoing	1 May 2019 - 30 April 2024	€ 10 016 296	FERTIBERIA SA Spain
Horizon 2020	NUTRIMAN	Nitrogen and Phosphorus network compiling knowledge “ready for practice” for such recovered product applications, practices for agricultural practitioners.	Ongoing	October 2018 - September 2021	€ 1 999 927.50	3R-BioPhosphate Ltd. Hungary
HORIZON 2020	NOMAD	Aims to develop a novel, small-scale tech solution that will recover fibre and specific nutrients from the digestate.	Ongoing	October 2019 - September 2022	€ 5 499 857.01	ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS Greece

HORIZON 2020	TO-SYN-FUEL	Demonstrate conversion of organic waste biomass (Sewage Sludge) into biofuels	Ongoing	May 2017 - September 2022	€ 14 196 108.72	FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V. Germany
HORIZON 2020	Bio4Products	Demonstrating a flexible value chain to utilise biomass functionalities in the processing industry	Ongoing	September 2016 - February 2021	€ 5 930 520	B.T.G. BIOMASS TECHNOLOGY GROUP BV Netherlands

APPENDIX 8 – WP5 VIDEO SCRIPT AND SOURCES

Carbon is an essential element for life on Earth. In cities, it comes from many sources and is contained in almost any product or material we use. After the lifetime of a product, the carbon can be re-used in many ways. Yet almost 46%[409] of the waste throughout Europe is disposed. That is a huge waste of resources and money and also a burden on the environment. Let's see what that means for each of us.

Every day, every human being uses and releases carbon. Most of the time we don't even realise it. A lot of our Carbon output comes from organic waste. Every European citizen produces 167 kilograms[410] of it every year. By separating our waste properly, we can keep it in the loop and make new useful things of it. Nowadays organic waste is turned into biogas or compost. But there are many innovative ways to recover carbon from it. Another big source of our carbon output is paper. In Europe the average Person produces 95 kilograms[411] of paper waste every year! We can put those billions of kilograms to use by recycling them. Or even better: by upcycling them! Let's talk about water! An average European uses up to 45,000 litres[412] of water every year for household activities alone. Together with water, excrements, detergents and body care products, an average of 38 kilograms[413] of carbon is flushed down the drain. We might not like the idea of re-using our sewage, but it can be utilised and turned into a lot of useful things. Like Fertiliser. And there are so many possibilities to explore yet! Pretty neat right? There is so much potential to valorise our daily carbon output. Awareness is only the first step to bring about change. We need more research, data and collaboration between the people involved. Waste is a resource! Let's use it!

In light of its Bioeconomy Strategy, the European Commission funded three studies to support research and innovation policies on bio-based products. This video presented the flow of organic carbon caused by a human being as part of the Carbon Economy study.

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[409] 45.8% of the waste treated in EU-27 Member States in 2018 was disposed (38.8% landfilled, 6.3% other disposal treatment and 0.7% incinerated without energy regeneration). 54.2% of the waste was recovered (38.1% recycled, 10.1% backfilled, 6.0% incinerated with energy recovery) according to Eurostat (2020), online data code: env_wastrt

[410] 492 kg municipal waste per capita per year in 2018 in the EU-27, 34% of municipal waste is bio-waste, according to Eurostat (2020), online data code: env_wasmun and European Compost Network (2019): "Bio-Waste in Europa", see https://www.compostnetwork.info/policy/bio-waste-in-europe/

[411] 95 kg of paper and carboard wastes per inhabitant in 2018 in the EU-27 according to Eurostat (2020), online data code online data code: ENV_WASGEN

[412] Water consumption of household from public water supply. Average for each EU-27 Member State with data available, weighed by population according to Eurostat (2020), online data code online data code: env_wat_cat and Eurostat (2020), online data code online data code: demo_pjan

[413] 27.9 kg excrements, toilet paper 7.5 kg, 0.5 kg shampoo & showering gel, 2.1 kg detergents = 38 kg, figures from various sources, see work package 1, "human carbon flow model"

APPENDIX 9 – WP5 PRESS RELEASE

The need for bio-based carbon in a sustainable future

EU funded "Carbon Economy" project illustrates current and future role of bioeconomy in a low carbon economy for Europe.

Carbon is the basis for a multitude of processes on our planet, many of them as parts of human economic activities. However, in a time when "decarbonisation" is on everybody's lips as the solution to the climate crisis, it seems almost ironical to run a project on "carbon economy". What were the reasons behind this focus and what are the objectives achieved?

Contrary to the energy sector, there are several sectors which cannot be decarbonised. These are the food and feed sectors as well as chemical and material sectors. Proteins, fats and carbohydrates contain carbon; organic chemistry is defined by the use of carbon and cannot be decarbonised; also, all usages of wood for example will always be based on carbon. In the context of the climate crisis, one needs to be more specific and say that *fossil* carbon is the problem. Bio-based carbon from plant and animal sources – constituting the bioeconomy – as well as other renewable carbon sources can constitute a viable alternative to fossil carbon.

COWI (DK) and nova-Institute (DE), supported by University of Utrecht (NL), have recently finished a study for the European Commission (DG RTD) that aimed at exploring the role and potential of renewable carbon in our economy towards mitigating climate change. The study addressed the question of how much carbon will be needed in Europe by 2050 and how it can be provided sustainably. For the first time, a comprehensive and holistic mapping of carbon flows on a global and European level has been conducted to create a solid knowledge base. Future scenarios for the European demand and supply have been explored, showing how carbon flows can be designed in a more sustainable and circular way, reducing the dependence on fossil carbon sources. Furthermore, current legislative drivers and barriers for the realisation of such an economy have been identified and promising innovations and novel technologies have been evaluated. Besides, hands-on case studies of ten cities and regions have been conducted to discover, how urban bio-waste and waste-water sludge can be utilised in a circular bioeconomy to make high-value products.

The results and the knowledge will be shared on various channels – for experts as well as general public. Key messages summarise the main outcomes of the study:

- For the transformation from fossil to renewable resources, the consideration of carbon flows in addition to overall material flows is highly relevant due to diverging properties of alternative fuels (e.g. by heating value) and materials (e.g. by dry matter or by carbon content).
- The largest share of the EU-27's carbon demand is used for energy, heat, and fuels (56%) with a fossil share of 85%, see figure 1. The second largest consumption of carbon resources is food and feed

(23%) where only carbon from biomass is used. The third sector are chemicals and materials (17%) with a fossil carbon share of 39%.

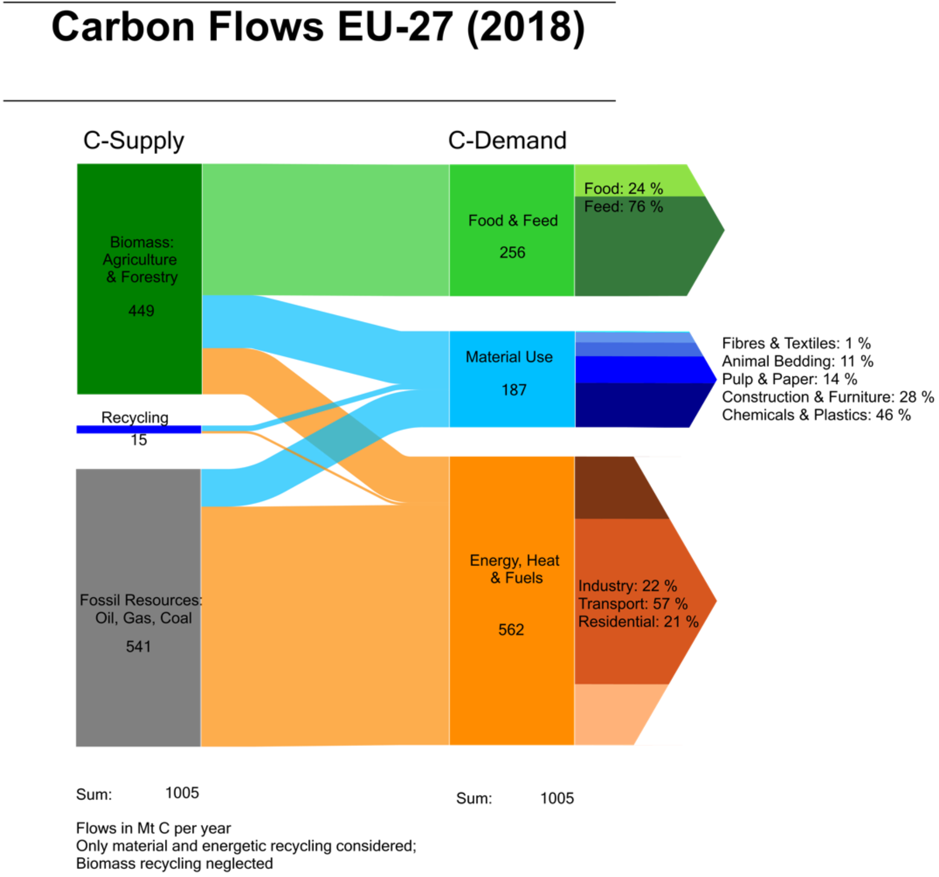

Figure 1: Flows of organic carbon within the EU-27 economy

- Six scenarios for the EU-27 energy sector in 2050 have been adopted to determine the carbon demand and supply, see figure 2. All scenarios imply a reduction of the annual demand for fossil carbon from 406 Mt C (2018) to between 299 Mt C (in the business-as-usual scenario) and 106 Mt C (in the hydrogen scenario).

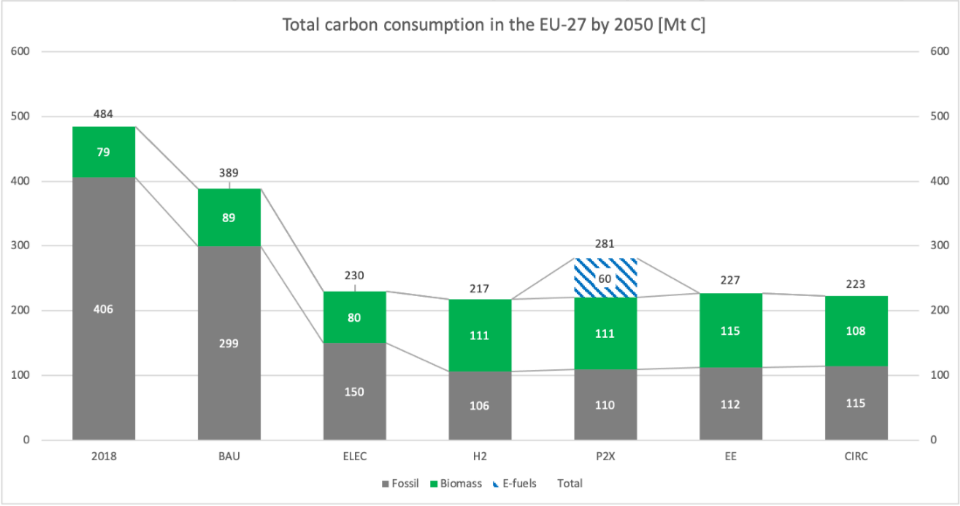

Figure 2: Annual carbon demand in the EU-27 energy sector by 2050 and 2018 for comparison, separated by carbon source. Carbon required to produce E-Fuels separately highlighted.

- Two scenarios for the EU-27 food, feed and material sectors in 2050 have been developed to determine the corresponding carbon demand

and supply, see figure 3. For plastics and chemicals, the share of fossil supply decreases for both scenarios from 91% (2018) to between 50% (Sufficiency scenario) and 30% (Technology scenario).

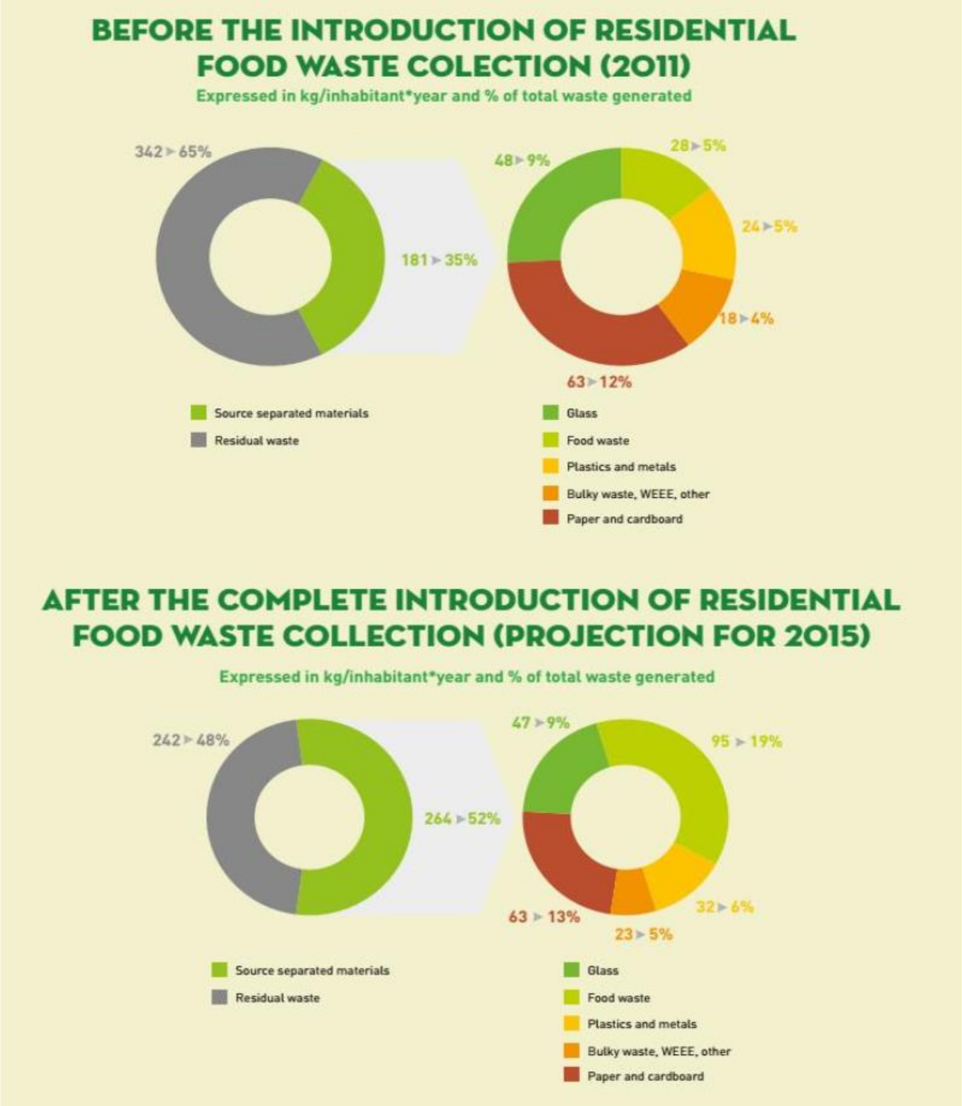

Figure 3: Carbon demand for food, feed and material in EU-27 2018 and by 2050 for both scenarios

- A sustainability assessment has been conducted, showing that the business-as-usual scenario lacks behind the other five scenarios for the 2050 energy sector. For food, feed and materials, the majority of sustainability indicators show positive trends compared to today for both of the examined 2050 scenarios.
- In order to assess existing barriers and drivers for the use of urban biogenic waste streams, current amendments to relevant pieces of EU legislation have been analysed. Effects on the use of waste streams for the production of bio-based products, have been summarised.
- An evaluation of technologies for a transformation towards a low carbon economy for the material use of carbon has been conducted. For each of six product groups promising technologies have been identified. Some findings are that electrochemistry is highly promising for polymers, fine chemicals and hydrogen production. Microbial systems have potential for bulk chemicals & fuels, proteins, polymers and fine chemicals.

- Case studies regarding the current state of bio-waste and wastewater sludge utilisation in 10 European regions show that each region has taken clear measures to improve the situation. The measures are manifold, reaching from encouraging home-composting (Cluj-Napoca, RO, and Łódź, PL) to subsidies for biomethane production (Emilia-Romagna and Milan, IT), to ambitious recycling targets (Turku, FI).
- In some of the examined regions, bio-waste streams occur but are not valorised while in others, the technological capacity to process bio-waste exists, but there is not enough input. Enhancing cross-border alliances through cluster networks would result in a well-balanced bio-based sector with sufficient inputs and outputs.

A short explanation video was produced, illustrating the flow of organic carbon caused by a human being (YouTube LINK)

For questions about the project, please contact the coordinator Mr Tomasz Kowalczewski at COWI (TOKL@cowi.com).

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The report herein contains five Work Packages (WPs) that embody the requirements set out in the European Commission's «Studies on support to R&I policy in the area of bio-based products and services - Carbon Economy (Lot 1).» The main aim of the project was to map out the current pathways available for the transition towards a low carbon economy as well as the barriers that hinder this transition. Based on the conclusions and key findings from the WPs, the authors set the scene for the future of the bio-based sector with a particular focus on ten case studies of regions and cities across the EU (WP4), an evaluation of promising innovations and novel technologies for the realisation of such an economy and a sweeping regulatory analysis containing Q1 2020 updates (WP3) on EU directives and regulations that pertain to the low carbon economy. This attention to the local level as well as the broader policy sphere is supported by a scientific understanding of the low carbon economy (WP1), potential future scenarios towards 2050 (WP2) as well as clear dissemination of the findings across the entire study (WP5). In the frame of the study an animated educational video was produced. The final study report contains an executive summary followed by each Work Package in its entirety, which can also be treated as stand-alone reports in their own right.

Le présent rapport contient cinq modules de travail qui reprennent les exigences énoncées dans le document de la Commission européenne intitulé «Études sur le soutien à la politique de recherche et d'innovation dans le domaine des bio-produits et des bio-services, Économie carbone (Lot 1)». L'objectif principal du projet était de tracer les voies actuelles disponibles pour la transition vers une économie à faibles émissions de carbone fossile ainsi que les obstacles qui entravent cette transition. Sur la base des conclusions et des principales constatations formulées dans les modules de travail, les auteurs ont dressé le tableau de l'avenir de la bioéconomie en se concentrant sur dix études de cas relatives à des régions et des villes de l'UE (module de travail 4), sur une évaluation des innovations prometteuses et des nouvelles technologies pour la mise en place d'une telle économie et sur une analyse réglementaire détaillée contenant les mises à jour des directives et règlements de l'UE relatifs à l'économie carbone selon l'état de la situation au premier trimestre 2020 (module de travail 3). Cette attention portée au niveau local ainsi qu'à la sphère politique plus large est soutenue par une compréhension scientifique de l'économie carbone (module de travail 1), des scénarios futurs potentiels à l'horizon 2050 (module de travail 2) ainsi qu'une diffusion claire des observations à travers toute l'étude (module de travail 5). Dans le cadre de cette étude, une vidéo éducative animée a été produite. Le rapport d'étude final contient une note de synthèse suivie par chaque module de travail dans son intégralité. Par ailleurs, ces modules peuvent également être traités comme des rapports autonomes à part entière

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