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REDII Ports | Interreg North Sea

Analysing (Waste) Material Flows in Port Areas

REDII PORTS | WP1 - PART 1

April 2024

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Metabolic

Colophon

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The research documented in this report was part of workpackage 1 of the REDII Ports project. This workpackage was conducted by VIVES and nice°. Metabolic Consulting was subcontracted for the first part of this workpackage for their expertise in material flow analysis.

This report forms the first part of the deliverable of this workpackage. The second part of the deliverable will be produced by nice° and VIVES at a later stage in 2024. For questions about workpackage 1 in general, please reach out to Michiel de Meyere (*michiel.demeyere@vives.be*) and Fenna den Hartog (*fennadenhartog@wearenice.org*).

For questions on the material flow analysis and/or data analysis done by Metabolic for this research, please reach out to Guillermo Corella Dekker (*guillermodekker@metabolic.nl*) and Rianne Stelwagen (*rianne.stelwagen@metabolic.nl*).

Executive summary

The REDII Ports project focuses on enhancing sustainability in port areas. In this report, we delve into the research done for the first part of workpackage 1. This involves a comprehensive Material Flow Analysis (MFA) within three case study ports.

Circular potential of ports

Ports can play a key role in the transition to a more sustainable global system. They are crucial to our economy, as they handle the majority of traded materials and serve as critical nodes for material and energy flows. As the world faces the urgent need for a sustainability transition to meet basic socio-economic needs while respecting planetary boundaries, ports emerge as potential catalysts for change. By embracing circular principles, ports can become facilitators and drivers of sustainable value chains.

The larger REDII Ports project

The REDII Ports (Renewable Energy Development and Intelligent Implementation in Ports) project operates under the broader European Interreg North-Sea Region program. The project focuses on the generation, storage, and consumption of cleaner energy and fuels in ways that are technically feasible and economically affordable. One of its primary objectives is to analyse excess materials in port areas and identify opportunities for more sustainable usage and potential as biofuel feedstock.

This research looks at circular opportunities for excess materials

The focus of the research in this report is specifically on analyzing excess materials in port areas and their industrial hinterlands. Initially, the scope was focused on materials that might serve as feedstock for biofuel production. However, this scope was broadened to address the needs of the overarching sustainability transition and recognize the interdependence between materials and energy. The two are deeply linked in our economy, necessitating a holistic approach to succeed in both material and energy transition goals and avoid unintended consequences.

Three case study ports

Three North-Sea port regions were used as case studies for this research; Port of Eigersund (NO), Port of Skagen (DK), and Port of Zwolle (NL). All three are partners in the larger REDII Ports project.

Method and frameworks used

For the three case studies, Material Flow Analysis (MFA) was used to analyse excess materials in the port regions and their industrial hinterlands. The MFA provides insights in inefficiencies and opportunities for more sustainable material usage. Besides looking at the mass of different material flows, this research also looked at the indirect or embedded impacts of different materials in terms of land-use, CO_2-eq. emissions and water usage. The material usage hierarchy frameworks of Lansink and Moermans were used to prioritize different ways of utilizing the excess materials to retain most value.

Each port showed various opportunities for more circular material usage

By minimizing waste and extending material lifetimes, ports can contribute significantly to sustainability goals. For each port, various opportunities were identified. For example, in Skagen, mineral waste streams could be deconstructed for reuse, Eigersund could recycle food waste into fertilizing products like compost, and Zwolle could reuse or recycle wood from and for construction projects. If recycling of organic materials is not possible, they could alternatively be used as biofuel feedstock.

MFA is only the first step: what is next?

Material flow analysis is only the first step, both in the REDII Ports project, as well as in practice. The transition has strategic implications and provides ports with a new role as facilitators and drivers of circular value chains. In order to achieve this, ports need to integrate circularity into their long-term strategies and create local networks. Analysing material flows can provide insights in circular opportunities but building strong regional collaborations is essential to implement them in practice. Ports, businesses, and policymakers need to work together to achieve the sustainability transition. There are great economic, environmental and social benefits to be gained, and ports can help lead the way in sustainable resource management.

Index

Reading guide

In Chapter 1, the research is introduced in the context of the larger sustainability transition and the role for ports. The wider REDII Ports project is explained and the potential of circularity in ports is discussed and combined with several existing examples.

Chapter 2 will elaborate on the method used (material flow analysis) and how the circular transition and energy transition go together. The three case study ports that were used for this research will be introduced.

In chapter 3 the results for each case study port will be discussed in detail, highlighting opportunities for more circular material usage and biofuel in particular.

Finally, in the last chapter the general learnings and conclusions are shared.

01 Ports in transition

INTRODUCTION TO THE REDII PORTS PROJECT AND CIRCULAR POTENTIAL IN PORT AREAS

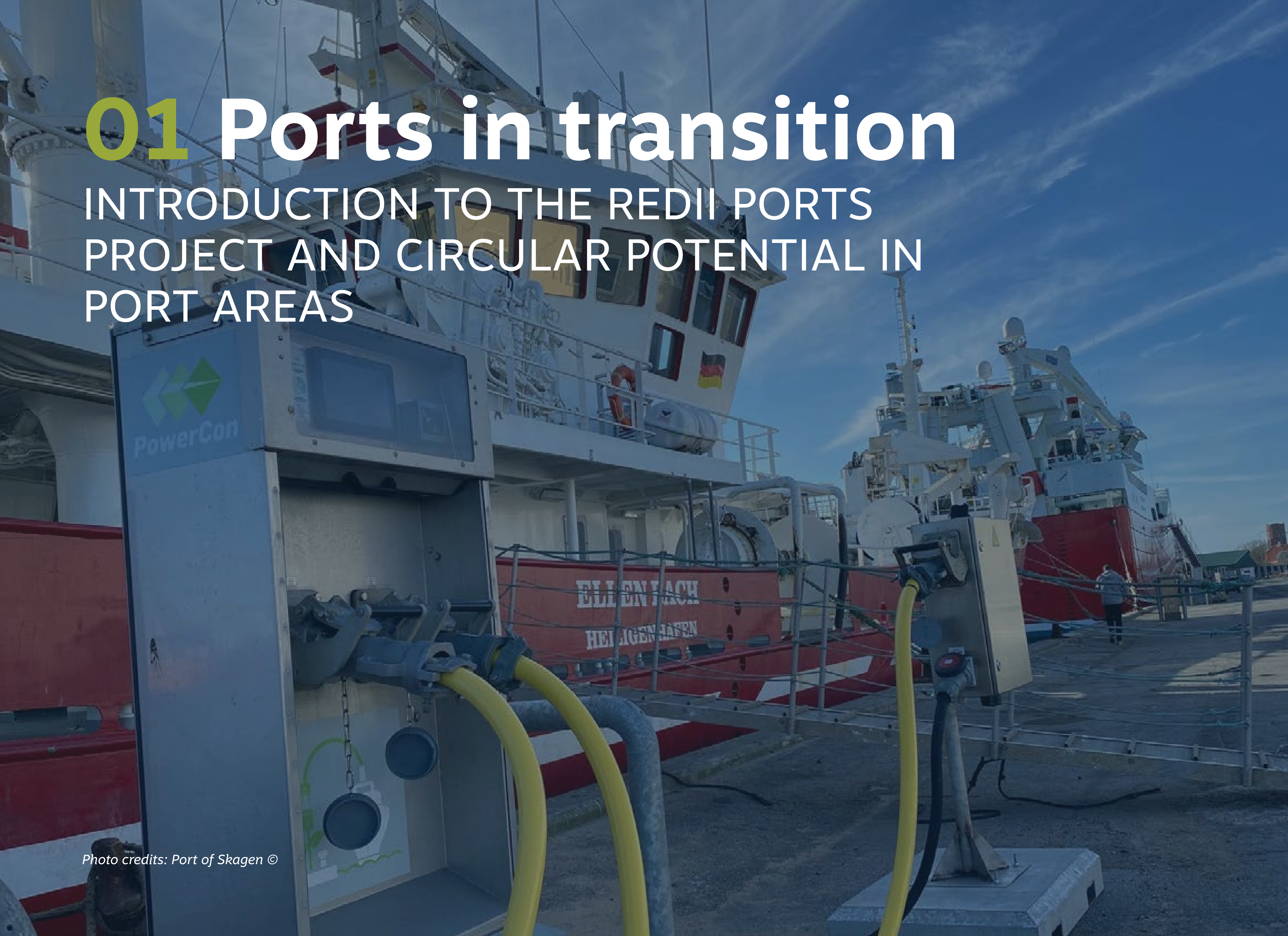


Photo credits: Port of Skagen ©

1.1 INTRODUCTION

Ports serve as vital components of the global economy. They handle roughly 75% of the total volume and 50% of total value in global merchandise trade. There is an urgent need to transition to a more sustainable global economy. Our current economy is crossing multiple planetary boundaries* and falling short in providing socio-economic basic needs to all. The most well-known planetary boundary is probably *climate change*. International agreements (e.g. the Paris agreement) have been made to reduce carbon emissions and thereby the negative effects of climate change on nature and communities. However, more is needed than solely reducing carbon emissions, to restore the balance and return within the planetary boundaries to maintain a livable planet for us humans. At the same time it is important to improve global basic human needs such as food, safety, equity, health and wellbeing. The 7 pillars (figure 1) describe the main aspects to keep into account in the transition towards a sustainable global economy.

Ports have the potential to play a key role in this transition. They can transform into central players in a sustainable global value chains by facilitate long-lasting material and energy loops, fostering symbiotic relationships between industries and reducing the need for extraction of primary resources, while facilitating fair trade and decent jobs, they can contribute to paving the way for a fundamentally sustainable global system.

This research

This report shares the findings of a small part of the larger REDII Ports project (see the info box on the next page for more details on the project). The REDII Ports project focuses on generation and storage of renewable energy and alternative fuels such as biofuels.

The focus for the research presented in this report was specifically on analyzing excess materials in port areas and their industrial hinterlands. Initially, the aim was to solely look into materials that might serve as feedstock for biofuels, as the REDII ports project is generally heavily focused on the energy transition. However, this scope was widened as the goal of the energy transition is to contribute to the larger sustainability transition. And from the perspective of the larger sustainability transition, it is necessary to systematically make changes and consider other transitions as well.

The energy and material transitions (need to) go hand in hand

The transition to renewable energy is needed to reduce our carbon footprint and prevent further climate change. However, carbon is not the only planetary boundary that is crossed. The larger sustainable transition is about more than just greenhouse gas emissions and renewable energy. An important aspect in the sustainability transition is the transition towards a circular economy: closing material, water and energy loops and restoring the balance between our economy and ecosystems, improving the resilience of both. The energy and material transition need to go hand in hand to reach the overarching sustainability goals.

In our economy, material and energy usage are heavily intertwined. Huge amounts of energy are used for the mining or harvesting of raw materials, to manufacture products out of them and transport and use these. And in order to transition to renewable energy, huge amounts of materials are needed for the production of wind turbines, solar panels, batteries and more. Energy and materials can not be separated from each other and therefore their sustainable transitions should not be studies in isolation. Blindly focusing on just one, could cause negative side-effects or lock-in effects for the other transition. These risks will be further discussed in the next chapters of this report. For now it is important to know that this research was executed with the wider sustainability transition in mind, therefore focusing not only on energy but also circularity more broadly.

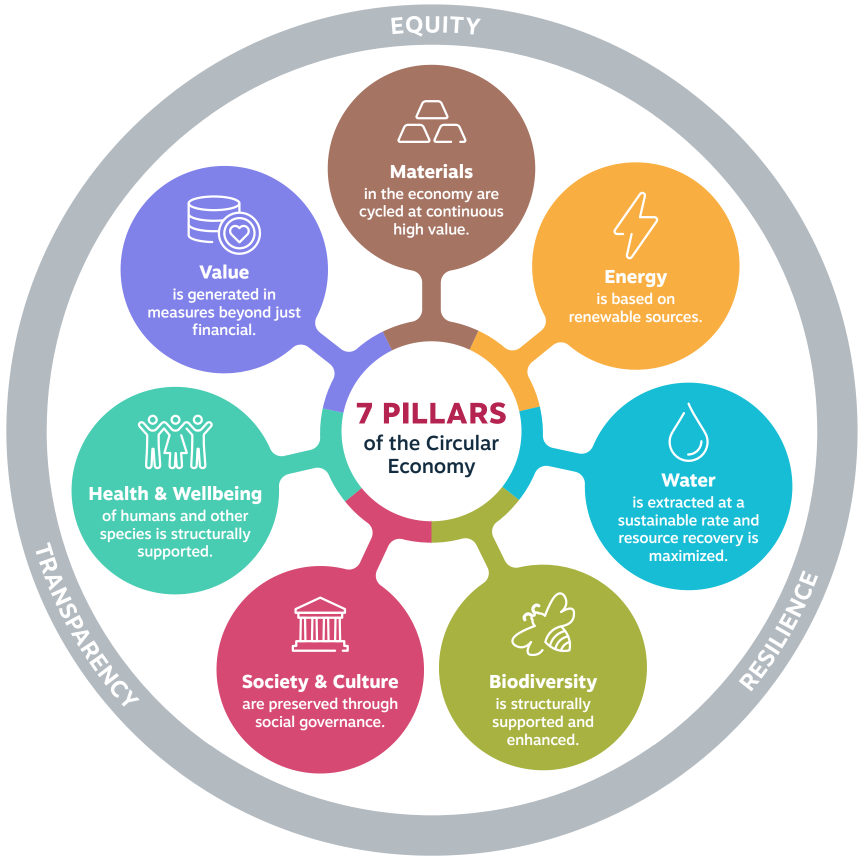


Figure 1 *The 7 pillars of the Circular Economy and the three prerequisites for the transition. (source: Metabolic, 2017).*

*****[Planetary boundaries]*are the critical thresholds representing the safe operating space for humanity within Earth's ecological systems, encompassing limits on factors such as climate change, biodiversity loss, and freshwater use, among others. See chapter 2 for more information on this.*

PART OF THE REDII PORTS PROJECT

The research presented in this report is part of a larger European project called Renewable Energy Development and Intelligent Implementation in Ports (REDII Ports). The REDII Ports project is part of the European Interreg North-Sea Region Programme.

Project aim in short

The REDII Ports project aims to use resources for generation, storage and consumption of cleaner energy and fuels in ways that are technically feasible and economically affordable.

- Electricity generation by e.g. wind, solar, tide, hydro-power
- Storage by e.g. shore, battery, hydro-power
- Alternative fuels e.g. biodiesel, hydrogen and ammonia/methanol

The results of this EU project will provide insights to ports and related organisations globally, increasing knowledge and sharing best practices, thereby improving the capacity to take informed decisions. All results will be shared publicly through the *project website*.

Workpackages

To achieve these goals, REDII Ports works with a 3-step approach moving from local sources, to production and storage in ports, to market.

- **WP1** aims to identify local excess material streams ("waste") through a material flow analysis and seeks to develop an online tool to enable the trading of these excess materials and disseminate knowledge and learnings on this;
- **WP2** is focussed on renewable energy generation and storage and aims to identify gaps, challenges and opportunities for ports;
- **WP3** aims to go from ports to market and to estimate the potential trading volume demand of the different types of energy that can be utilized to provide the wider port community with energy.

In total the REDII Ports project contains 13 pilots that are executed by 8 ports, supported by several other organizations that are partners in this project.

This report describes the first part of the research done in WP1 that feeds into the platform and strategies that will be developed for the ports (see figure 2). Furthermore, it feeds into the activities of WP3 to develop business cases for reusing waste as biofuel feedstock.

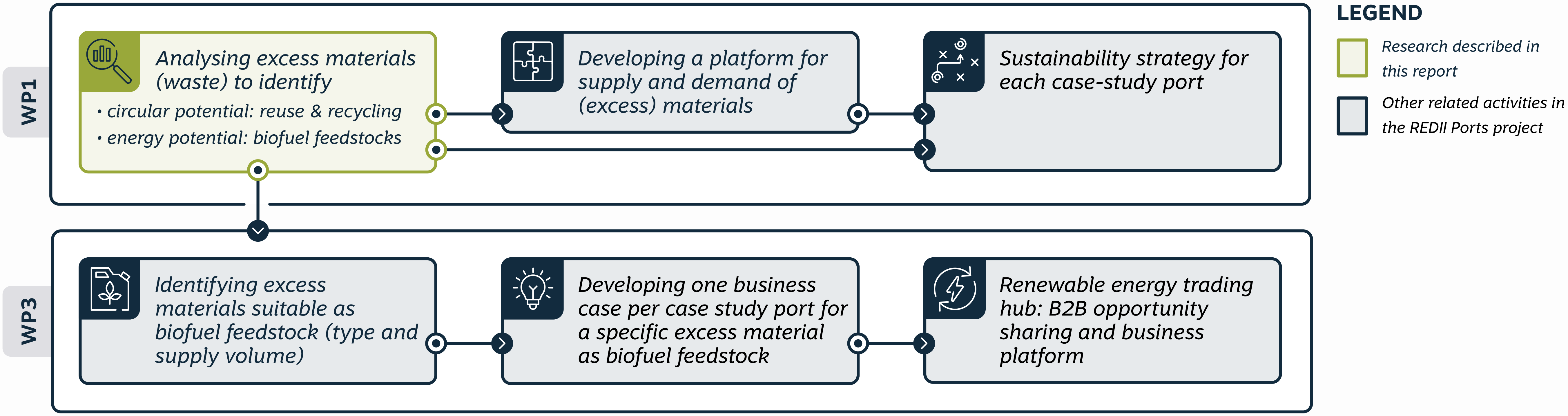
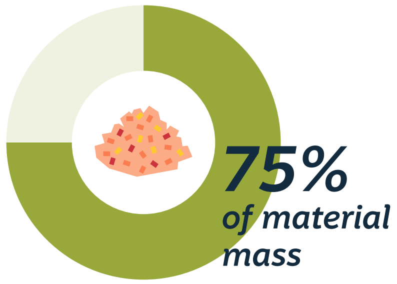


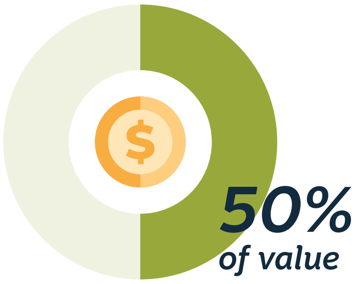
Figure 2 *Diagram to indicate how the research presented in this report relates to the rest of WP1 and to WP3.*

1.2 CIRCULARITY IN PORTS HAS POTENTIAL FOR MAJOR POSITIVE IMPACT

The current role of ports

Ports play a central role in the functioning of the global economy, with marine trade accounting for more than 75 to 80% of the total volume, and at least 50% of total value in global merchandise trade (as measured in 2015). Within this network of well over a thousand ports, there are a number of central ports that handle the majority of worldwide trade. About 50% of *imported* traded volumes is handled by only 56 ports in the world. This trade plays an important role in the movement of globally extracted materials, with at least 15% of extracted materials being traded in 2010.





Ports form the foundation for the current system of global trade and enable the continuing expansion of the global economy. Our global economy uses large amounts of energy, water and resources to extract, manufacture and transport material goods and services. This results in large impacts on our ecosystems, for example decreasing freshwater availability and quality, and heavily degrading biodiversity. The planet has nine crucial boundaries that determine the health of ecosystems in which species, including humans, can thrive.

Our current economy is crossing all of the planetary boundaries, disturbing the natural balance and putting our future at risk. Therefore, we need to transition towards a more sustainable economy that operates within the planetary boundaries and at the same time provides solid socio-economic foundations.

The potential role of ports in a sustainable economy

Maritime trade and ports can fulfill a fundamental role in changing the paradigm towards a fundamentally sustainable system. Trade between countries will keep playing an important role, but also local resilience will need to improve or be reestablished. Right now, our trade system has become very centralized with only a few central nodes that supply certain goods, e.g. food from the USA or Brazil. TThis makes the current system vulnerable to disruptions (e.g. covid-crises, wars, natural disasters). Circularity can help to increase local resilience and strengthen international (marine) trade, while simultaneously allowing nature to thrive and regenerate.

Ports are not only the global hubs where raw materials first arrive, they are closely connected to surrounding industry that further processes materials into products that go back to the ports again for further shipping, and eventually ports also handle a lot of materials that are discarded as “waste”. By reusing materials, value can be retained to the economy and the need for mining or harvesting primary materials reduced. The aim is to minimize primary material usage as their extraction, manufacturing and transport requires lots of energy, water and resources, and has a large impact on the environment.

By introducing a circular approach to ports as their baseline mode of operation, we can transform these keystones of material but also energy flows, from simple facilitators of a globally economy with high environmental footprint, into central players in a fundamentally sustainable status quo.

Ports can become the hubs that cycle materials in long-lasting loops, where companies can exchange materials that are given a second, third or fourth life, producing goods with clean energy sources and within the natural limits of a thriving ecosystem. Ports can become circular processing locations where secondary materials are collected, (dis)assembled and processed by attracting the right companies for reuse and recycling.

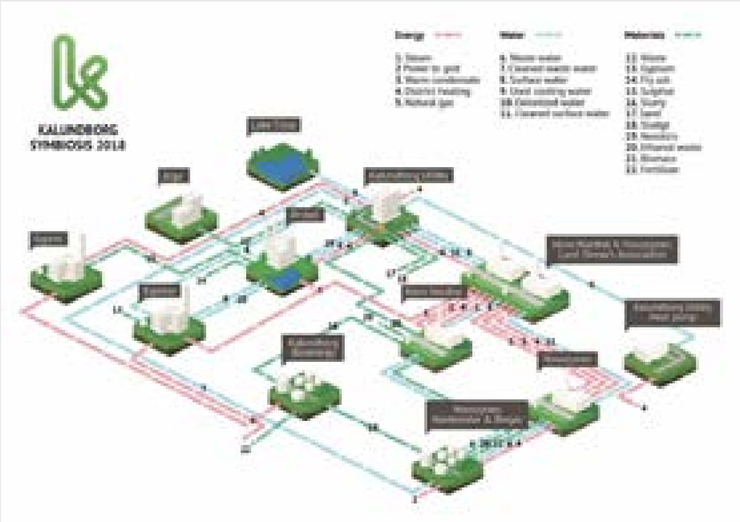
Circular practices and examples

There are many circular solutions that can aid ports in becoming circular. Numerous examples exist of circular practices that can be further developed or scaled. A few examples are highlighted on the next page.

An inspiring concept within the transition towards the circular economy is ***industrial symbiosis***. In nature, waste does not exist and resources are simply used again and again by other species. Ultimately, industries can strive for the same concept; a system, where different companies within a certain area exchange materials, water and energy and reuse excess and by-products. One of the most famous examples of industrial symbiosis is in the port area of Kalundborg in Denmark (see next page).

An important initial step for creating this and other circular solutions is analysing all material flows in a certain (industrial) region to identify opportunities for reuse. The next chapter will further elaborate on the concept of material flow analysis.

EXAMPLES OF SEVERAL CIRCULAR SOLUTIONS IN PORTS



Industrial symbiosis in Kalundborg

The industrial area in Kalundborg, Denmark, showcases successful *industrial symbiosis*. This is a collaborative approach, where companies (both from similar and different industries) exchange materials, energy, and water to reduce primary material usage and waste production and increase resource efficiency. This lowers negative environmental and social impacts globally and reduces costs while enhancing local resilience.

In Kalundborg there is exchange of energy (incl. heat), water and (waste) materials among industries like a refinery, power plant, and pharmaceutical companies, leading to environmental gains and significant cost savings.

Find more examples in the LOOP Ports report

Reusing dockwater

The Belgian port of Antwerp is stimulating circular innovations by providing funding. One of the *projects* is by Dockwater BV, which aims to utilize water and effluent water from industrial companies in the port (including Evonik and Covestro), to be processed into high-quality process water. This significantly reduces water demand from the industry and thereby reduces pressure on fresh water sources in Flanders.

Sharing excess heat

In a number of ports throughout Europe, excess heat produced by industries is reused by surrounding commercial and residential areas. An example is the *WarmtelinQ' project* in the port of Rotterdam. Excess heat serves as an energy source for residential buildings and companies e.g. greenhouses for food production.

Using byproducts from necessary processes like dredging

Several ports, e.g. the ports of Aalborg and Marseille, are already actively utilizing sand gained from dredging to make cement or other uses. Although dredging is generally considered harmful to aquatic ecosystems, in places where it is a necessity, materials gained can be used to reduce the need for other environmentally harmful activities.

In *Aalborg*, the materials gained from dredging are used in cement production, substituting primary materials that would otherwise be dug out in large quarries, and avoiding trucks moving sand from quarries to the factory meaning less carbon emissions. Besides this, the port also shares its excess heat for residential heating.

02 Analysing Material Flows in Ports

WHY AND HOW: FRAMEWORKS AND METHOD

This chapter further explains why analysing materials is useful in relation to the transition to a more sustainable economy. It explains the connection between the energy and material transition by looking at embedded impacts of materials and their life cycle. Different strategies (called R-strategies) for keeping materials in the loop are discussed, as well as why higher R-strategies are preferred in the transition. In relation to the objective of this research (see chapter 1) to identify potential feedstocks for biofuel, the organic waste processing hierarchy is discussed. Finally, the method that is used in this research for analysing materials in the three case study ports is explained.

2.1 WHY ANALYSE MATERIALS?

Analyzing materials is crucial for understanding and reducing our impacts on the environment and ensuring sustainable resource management. Our current economy is crossing multiple planetary boundaries* and falling short in providing socio-economic basic needs to all. There are nine planetary boundaries (figure 3), e.g. climate change, biodiversity, land-system change and freshwater usage. They highlight the critical thresholds beyond which the Earth's systems may be irreversibly damaged, thereby making the earth unlivable for different species, including humanity at its current scale. The most well-known and discussed planetary boundary is probably climate change. International agreements (e.g. the Paris agreement) have been made to reduce carbon emissions and keep global warming below 1.5°C and thereby mitigate the negative effects of climate change on nature and communities. However, more is needed than solely reducing carbon emissions, to restore the balance and return within the planetary boundaries to maintain a livable planet for us humans, as currently 6 out of 9 have been crossed into the zone of uncertainty. At the same time it is important to improve global basic human needs such as food, safety, equity, health and wellbeing. The 7 pillars (figure 1) described in the introduction give the main aspects to keep into account in the transition towards a sustainable global economy.

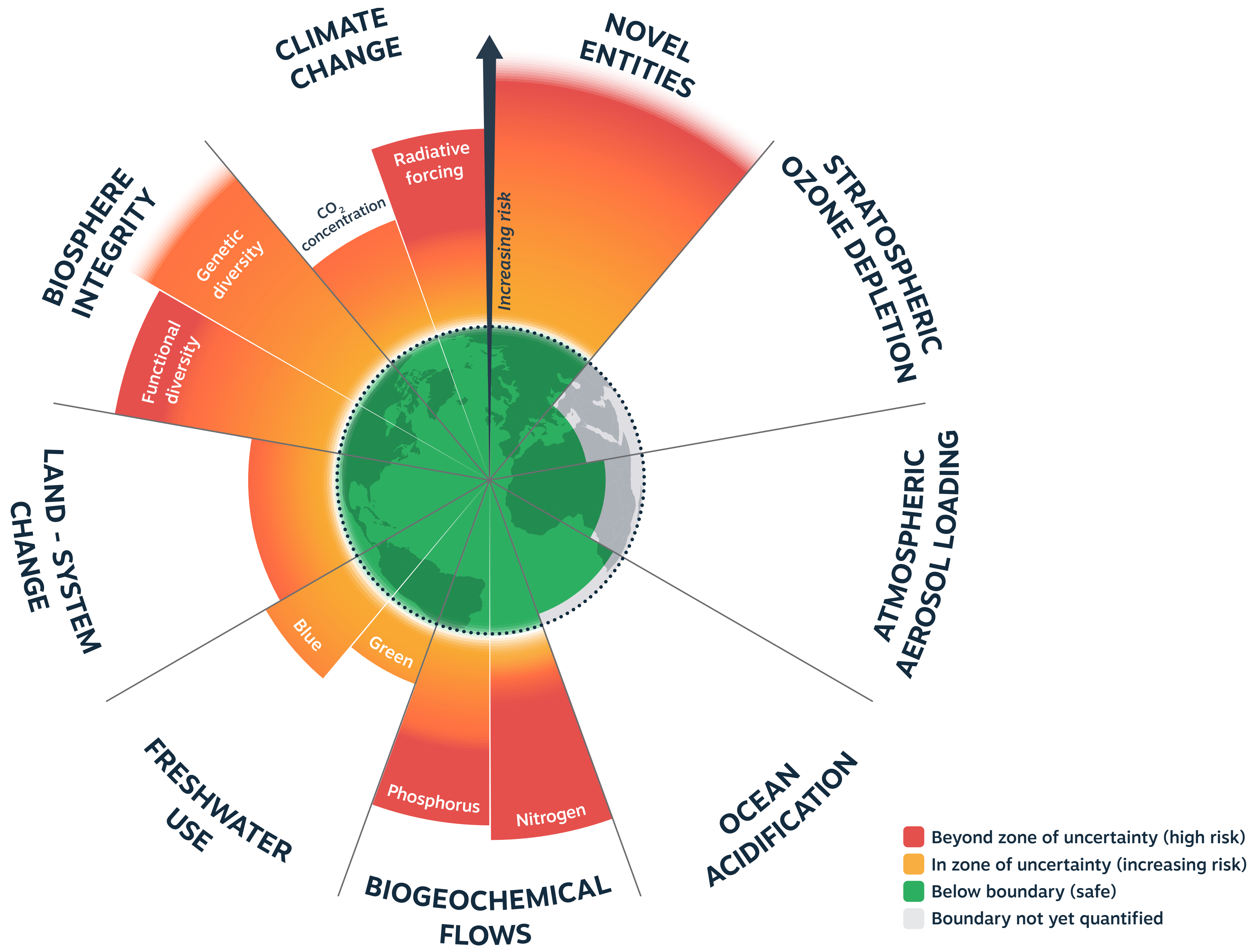


Figure 3 *Visual overview of the 9 planetary boundaries that describe the critical thresholds for the safe operating space for humanity within Earth's ecological systems. Currently 6 out of 9 are in or beyond the zone of uncertainty placing a risk on the livability of our planet for humans.*

Materials play a key role in this transition, also due to their embedded impacts (more on this in the next section). Analyzing materials and their flows helps us to take actions to return within the boundaries and develop a fundamentally sustainable economy in balance with natural ecosystems.

2.2 EMBEDDED IMPACTS IN MATERIALS

Embedded impacts are the impacts that have been made during the life cycle of a material or product; from raw material mining, manufacturing, assembly transportation, retail and optionally also disposal (figure 4). During these different steps to create a certain material or product, several inputs are needed; e.g. energy, water, land, labor and other materials. Also certain outputs are generated during these processes besides the final material or product; e.g. emissions, waste water, solid waste and by-products. These inputs and outputs have an impact on the environment. For example, land-use has impacts on biodiversity and water usage on fresh water availability. And outputs like emissions and waste have an influence on air, water and soil quality. These in- and outputs are different for different materials (figure 5). All these impacts related to the inputs and outputs necessary for the production of materials together are called embedded impacts.

Embedded impacts are also called indirect impacts, footprint or scope 3 impacts (often used when describing emissions). They encompass the indirect impacts associated with a everything up until the usage of a material or product. The impacts made during the usage are called direct impacts or scope 1 or 2 impacts. Embedded impacts are generated "upstream" in the value chain before the use phase (mining, manufacturing etc.) or "downstream" after usage (everything after disposal).

When we reuse or recycle materials, we're not only preventing the waste of the material itself but also avoiding the unnecessary disposal of all the resources, energy, and effort invested in its production throughout the supply chain. The longer a material is used, the smaller its embedded impact becomes compared to the its lifetime making it more sustainable. This is why reusing and recycling materials is so important.

By minimizing embedded impacts both in absolute terms and in relative terms by extending the lifetime of materials, we can significantly reduce the overall social and environmental footprint associated with our material usage. It is crucial for the larger sustainability transition that we do not only address direct issues with e.g. waste or energy usage, but also take embedded impacts into account to improve supply chains fundamentally.

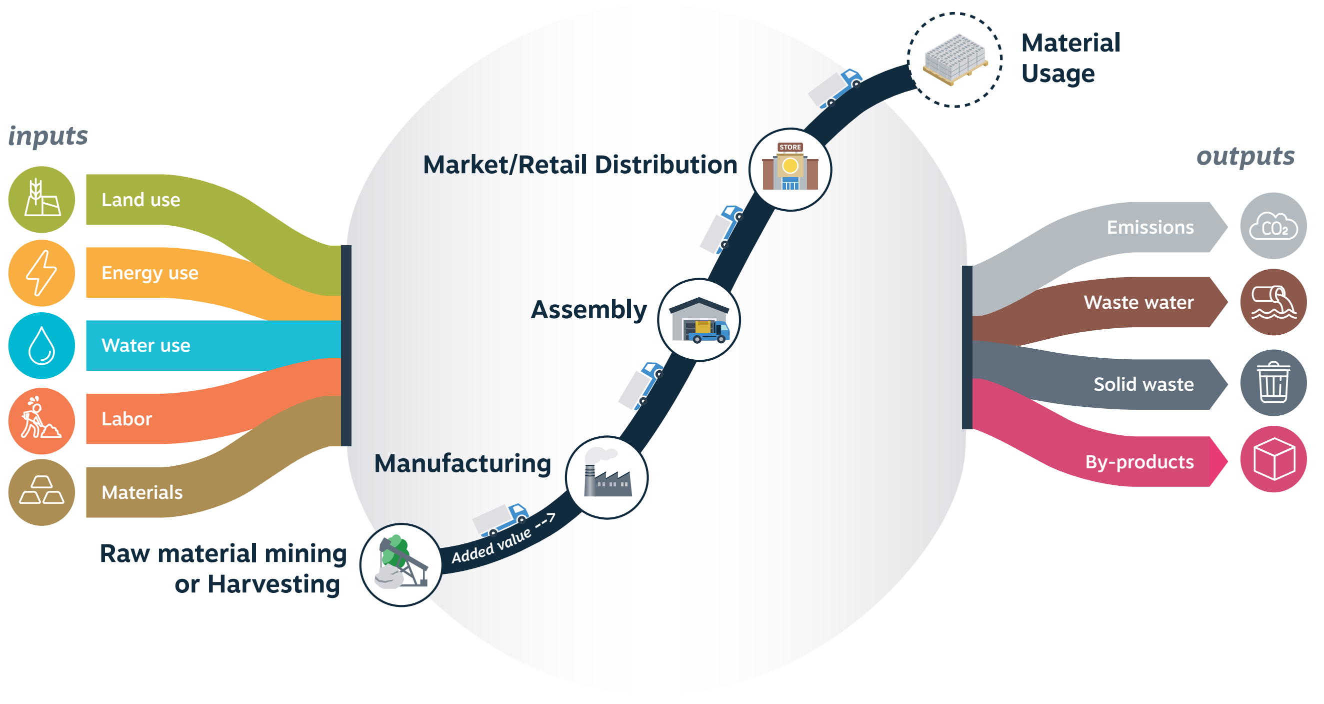


Figure 4 *Visualising the lifecycle phases before the use-phase with the inputs needed and outputs generated during these steps, which result in impacts on the environment. (Source: Metabolic).*

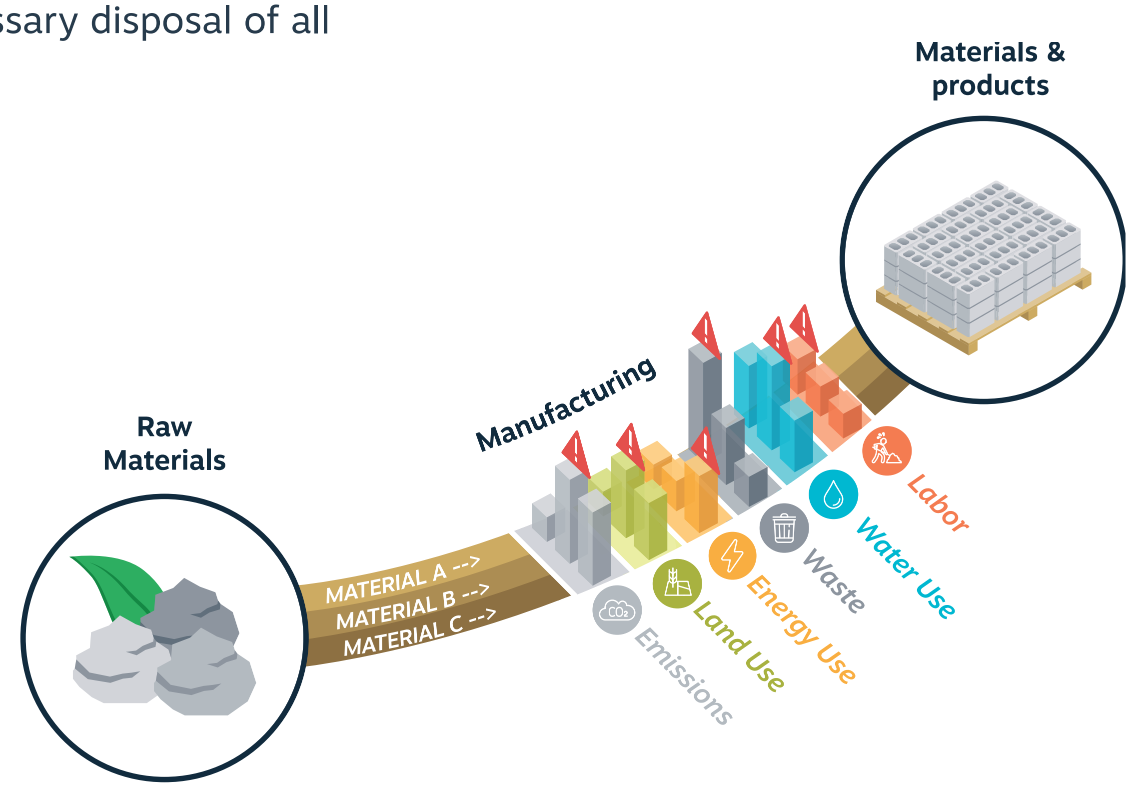


Figure 5 *Visualising the difference in inputs and outputs needed for producing different materials (A,B,C), which means each materials has a different embedded impact.*

2.3 RETAINING MATERIAL VALUE WITH HIGHER R-STRATEGIES

The lifecycle of materials or products consists of several phases. Manufacturing, assembly and retail add value to materials and products. In the linear economy, after usage when a product is disposed all this value is lost when the product is landfilled or burned (red arrow in figure 6). In the circular economy however, we aim to retain the value of products and materials. There are several strategies for doing so, called R-strategies. There is a hierarchy in these R-strategies with preference for the ones retaining the highest material value. This hierarchy is also sometimes called the R-ladder.

The R-strategies that keep products or materials at high value are called higher R-strategies. Before products are even made we can Rethink the actual need for a product and Refuse it (avoiding impacts altogether) or Redesign it using more sustainable materials or methods. During manufacturing and usage we can Reduce the amount of materials, energy and water that is used. After usage, we first want to Reuse and Repair products to retain them at high value. Alternatively, we can Remanufacture or Refurbish products.

Finally, if none of the higher R-strategies are possible, we can go to lower R-strategies to Revalorise and Recycle materials. These strategies require more effort to add value again, which is usually paired with negative impacts. For example, metals are a material that can be recycled quite well but this requires a lot of energy. We need to

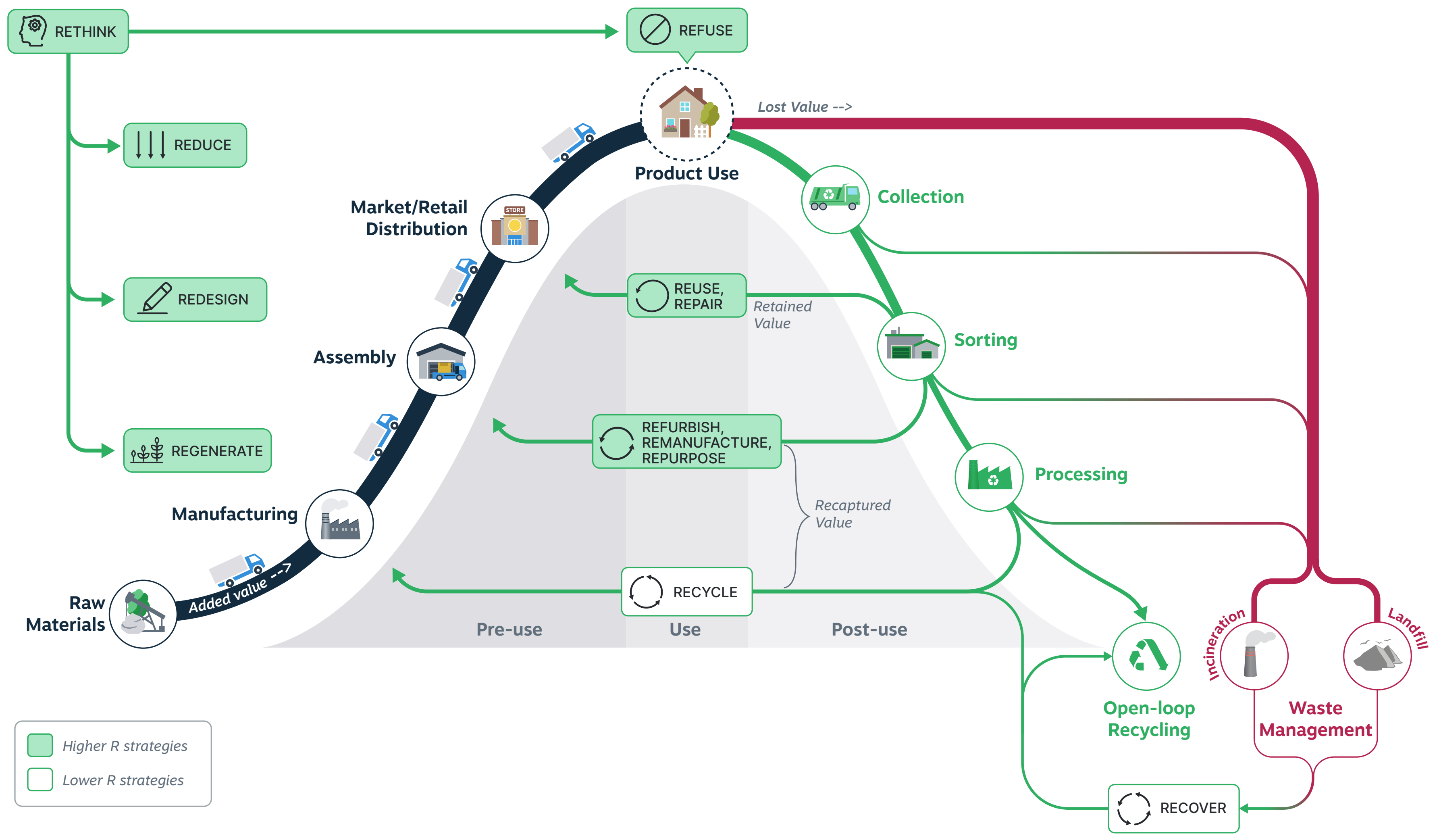


Figure 6 *The material/product value hill showing the different phases in the lifecycle that add or lose value and the different R-strategies for managing materials and maintaining value.*

first aim to reduce the amount of metals used and extend their lifetime as much as possible to make a positive impact. Recycling is not the quickfix for this transition. Also, this underlines the importance again for the material and energy transition to collaborate rather than compete. Ultimately, as the last option in the hierarchy, we can recover energy from materials.

Analyzing materials helps determine the most effective interventions to minimize resource depletion, energy consumption, and environmental impacts. By prioritizing higher R-level strategies, such as Reduction and Reuse, we can minimize the need for extraction and processing of new primary materials, thereby reducing environmental impacts.

2.4 ORGANIC WASTE PROCESSING HIERARCHY

Initially, one of the objectives of this research was to identify waste streams that could potentially be used as feedstock for biofuel production (see chapter 1). As mentioned before, the energy and material transition can not succeed in isolation so a broader lens is required to avoid negative side-effects or lock-ins.

In a circular system, biofuel would not be the primary option for utilizing organic waste (figure 7). Firstly, it's preferable to reduce consumption of organics to within planetary boundaries, and prevent waste of organic materials such as food. If they are disposed, they could replace primary materials. The next step would be to return organic waste streams back to the land to recycle nutrients and organic matter and close the loop.

However, if this isn't feasible due to various factors, such as contamination or unsuitability for land application, the next preferred alternative application would be biofuel production. Using organic materials as biofuel is preferred over incineration for energy recovery, as we have other sources for sustainable electricity generation such as solar, wind and hydrogen. There is still a necessity for fuels within certain sectors like shipping, where sustainable alternatives aren't as readily available yet on large scale. Therefore, sourcing fuel from organic waste provides a more sustainable solution for meeting energy needs in these sectors when compared to current fossil fuels, ensuring a transition towards greener practices while still meeting practical demands.

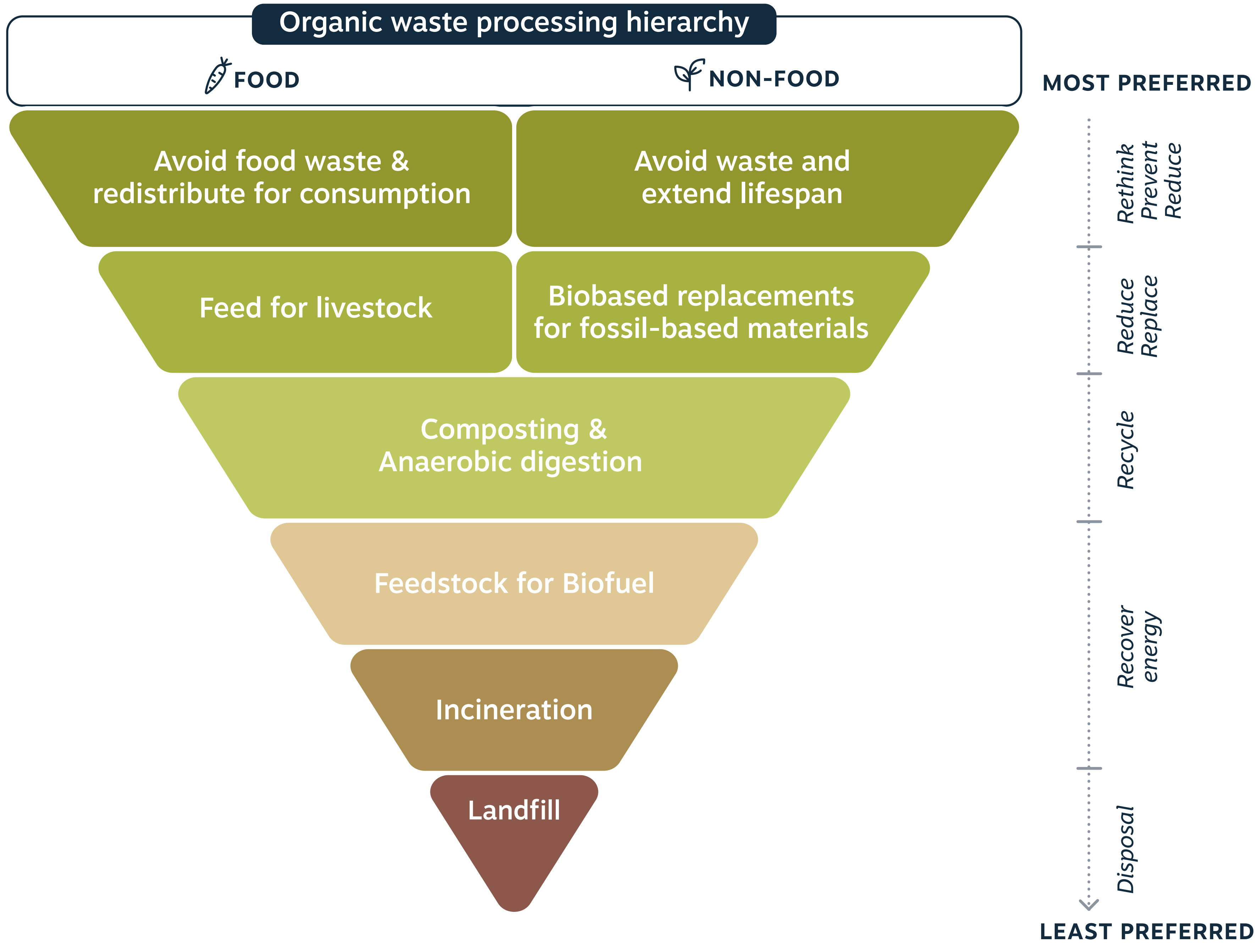


Figure 7

Diagram of the hierarchy for processing organic materials (Source: adaptation of Moerman's ladder which is in turn an adaptation of Lansink's ladder focused on food).

2.5 MATERIAL FLOW ANALYSIS

The previous sections of this chapter have explained why the transition towards a sustainable economy within planetary boundaries involves efficiently and sustainably managing (raw) materials and closing cycles a high value. Material Flow Analysis (MFA) plays a key role in achieving this goal by systematically assessing the flows and stocks of materials within a defined system over time and space. MFA looks at the movement of materials between organizations or regions and their potential transformation into other materials, goods and other applications. Visualizing this data through so called Sankey diagrams helps illustrate the flow of materials, between different organisations or regions and how materials are used or further processed.

MFA provides insights in inefficiencies and opportunities for more sustainable material usage. A MFA quantifies material inputs, outputs, and stocks (the amount of materials present at a given situation) within a defined system. In this way inefficiencies can be identified; what are waste generation hotspots, where are water and energy lost, and which material usage can be reduced or avoided completely? It also highlights opportunities for optimizing the usage of resources; where can alternative materials or processing methods be used to decrease primary material demand and energy usage? Which excess or “waste” streams have potential in quality and quantity to be used elsewhere?

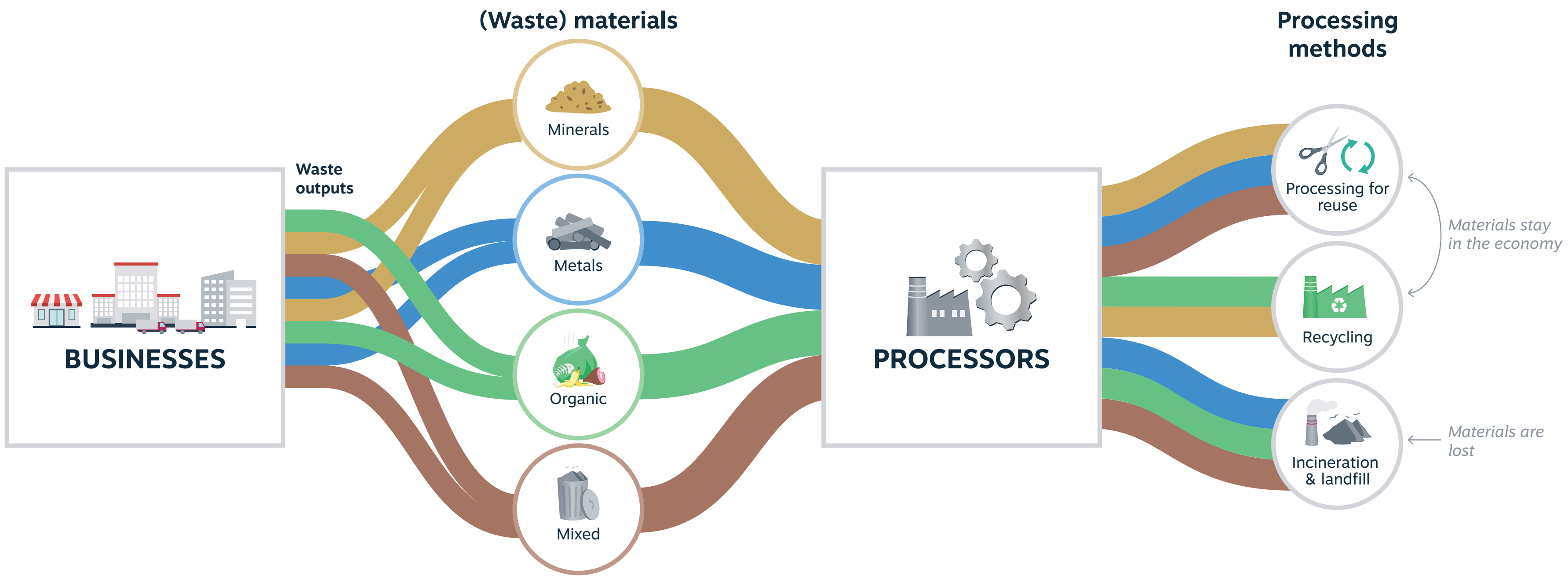


Figure 8 *Schematic overview of a Material Flow Analysis that looks at excess materials (“waste”) from businesses and how they are processed.*

MFA informs decision-making processes towards more sustainable material use and material (or “waste”) management practices. This can help achieve sustainability goals and transition our economy to one that is more resilient and within planetary boundaries.

Focusing on excess materials (“waste”)

This research specifically focuses on analyzing excess materials that are disposed of and labelled as “waste”. The sankey diagram in figure 8 provides a simplified overview of the method used for the case study ports. In the MFA, the thickness of the flows indicates the mass and the colour indicates the material type.

For this research, the MFA looks at the businesses in the port region and the excess materials (“waste”) they dispose of (left side of figure 8). Next the excess materials are grouped by type; e.g. minerals, metals, organic and mixed streams. This gives an idea of the total amount of material types available in the region. These materials then go to different processing companies, who use different processing methods. Generally, they can be divided into three categories; reuse, recycling or incineration & landfill. The first two are preferred as materials stay in the economy, while the third means that materials and their embedded value are lost. From this analysis inefficiencies and opportunities can be identified for the three case study ports.

03 Three case study ports

A MATERIALS ANALYSIS TOWARDS CIRCULARITY

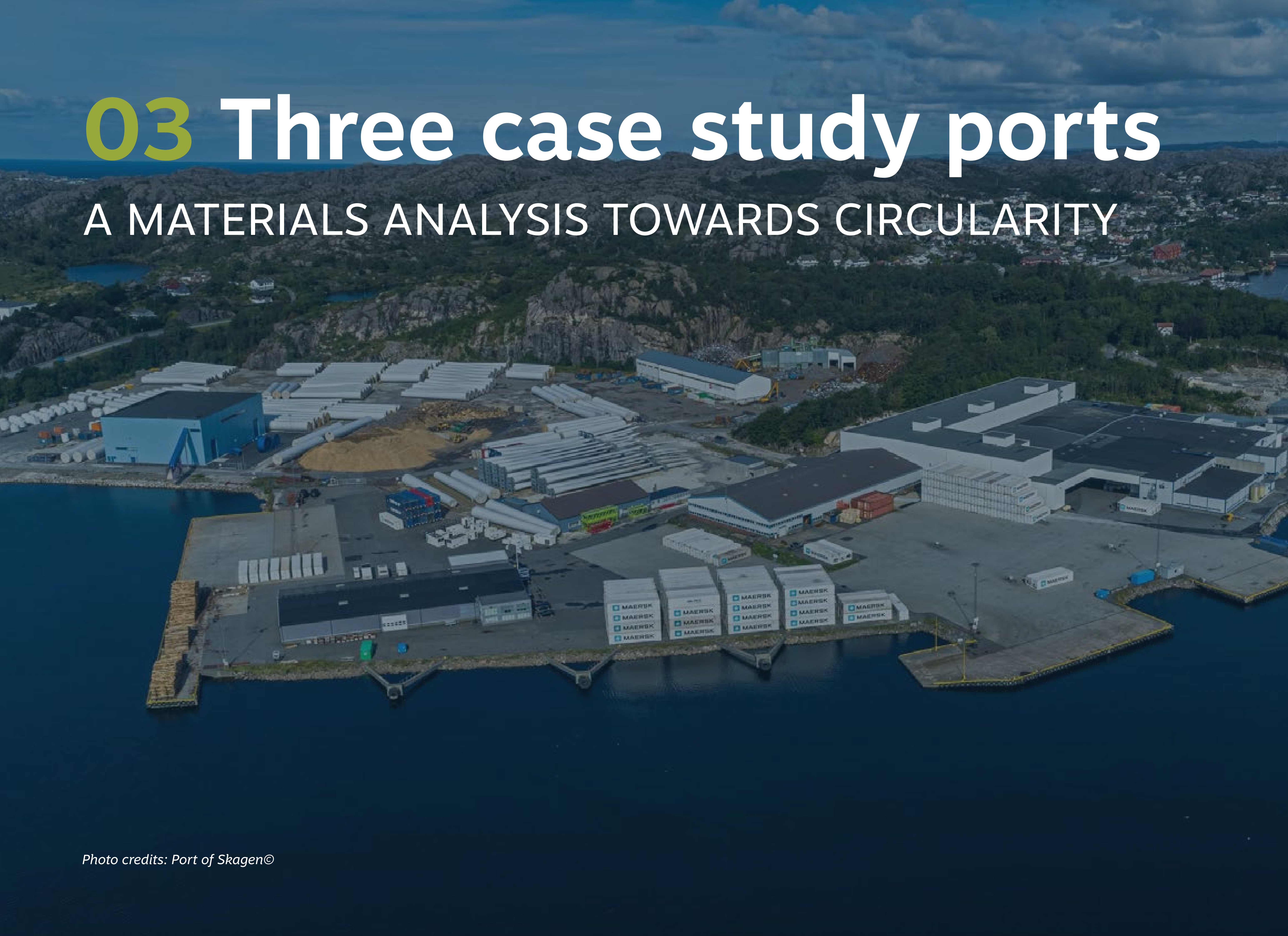


Photo credits: Port of Skagen©

THREE CASE STUDY PORTS

As part of the REDII Ports project, three case study ports were selected to conduct a material flow analysis and gather insights. These insights are in the first place meant for the three specific ports and will help to develop the resources platform and port strategies in the further research of this WP1 (as indicated in chapter 1). Later in the REDII Ports project (in WP3) the results from these case studies will form the basis for further research to identify possible business cases for using excess materials as (bio)fuels.

Besides this, the insights of these case studies can serve as examples more widely for ports and other industrial areas on analyzing excess materials flows and form incentives for more circular material usage.

The three ports that were chosen as case study ports are partners in the wider REDII Ports project. In addition, they indicated to be willing to collaborate in the data gathering process. The chosen ports are:

- SKAGEN HAVN – Port of Skagen in Denmark
- EIGERSUND NÆRING OG HAVN KF – Port of Eigersund in Norway
- PORT OF ZWOLLE PORT OF OPPORTUNITIES – Port of Zwolle in the Netherlands

In the rest of this chapter the results for each case study port will be shared and discussed.

Figure 9 *Map of North-Western Europe indicating the locations of the three North-Sea ports that are used as case studies.*

Port of Skagen (Denmark)

3.1.1 SCOPE

For the Port of Skagen, the analysis focused on the industrial activities in the municipalities of Frederikshavn and Hjørring. The analysis includes all excess materials that have been registered as waste from companies. All companies in both municipalities are taken into account, so not only the ones with direct port related business. This is done as the industry in the larger region has close ties to the ports, and the potential for industrial symbiosis between businesses therefore exists on a regional scale.

Two perspectives on excess materials

For the analysis for the Port of Skagen a distinction was made between two perspectives; excess material production and processing.

The first perspective looks at all excess materials (waste) ***produced*** in the two municipalities. It also shows how these have been processed, regardless whether this is happening within the two municipalities or elsewhere in Denmark or abroad. Not all materials stay in the region itself for processing.

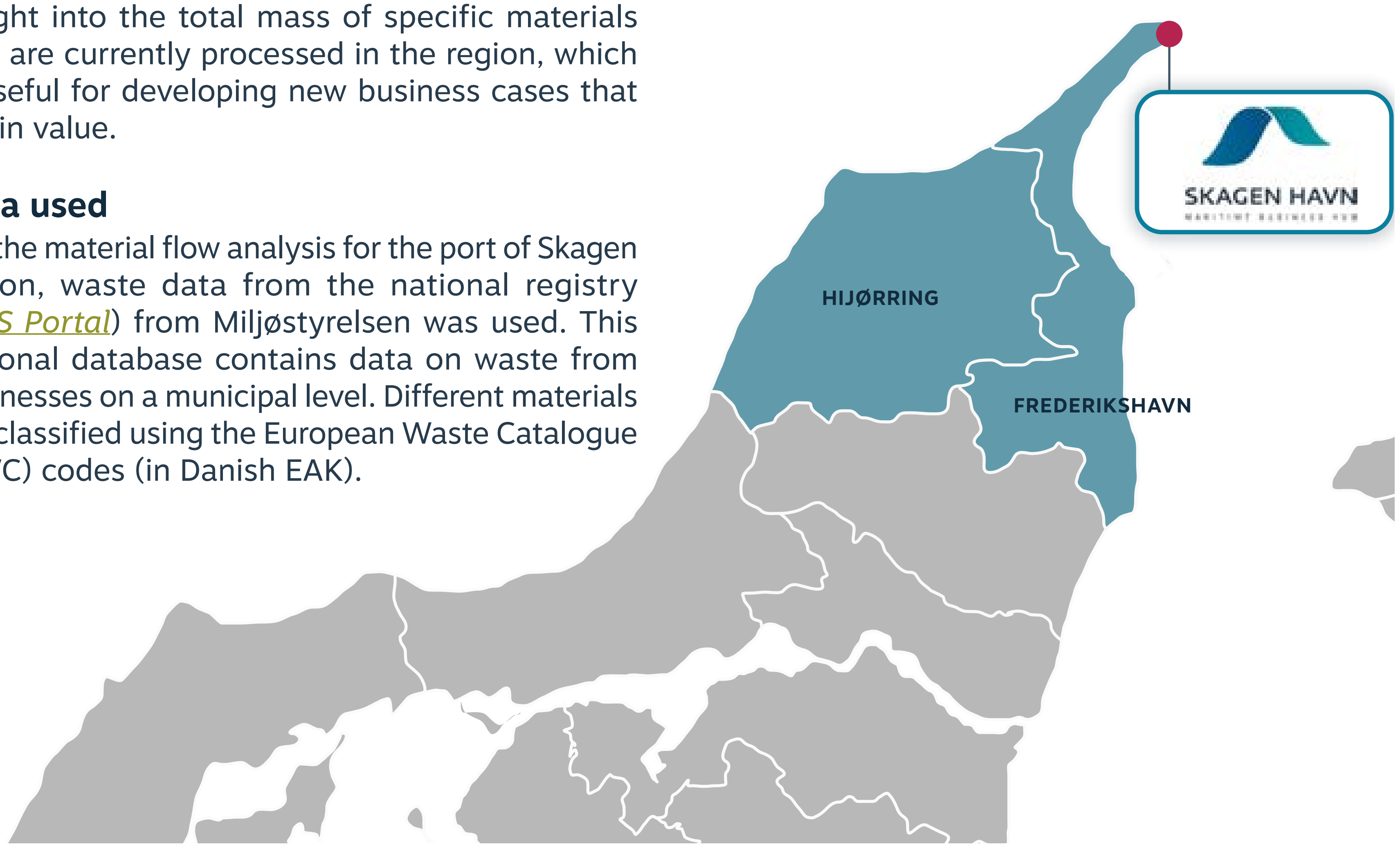
The second perspective looks at all the excess materials that are ***processed*** in these two municipalities. Besides processing some of the waste that was created within the two municipalities themselves, they also receive and process various materials from other municipalities.

Analyzing both the excess materials that are regionally produced, as well as the excess materials that are regionally processed, can provide interesting insights. The first perspective can be used to look into opportunities for reducing or replacing certain materials so they are not produced as excess (waste) in the first place (rethink, reduce). Besides that, both give the opportunity to reconsider how excess materials are being processed and how different methods could be used to retain more value. The first perspective can give insights in which are preferably kept and reused locally. The second perspective gives insight into the total mass of specific materials that are currently processed in the region, which is useful for developing new business cases that retain value.

Data used

For the material flow analysis for the port of Skagen region, waste data from the national registry (ADS Portal) from Miljøstyrelsen was used. This national database contains data on waste from businesses on a municipal level. Different materials are classified using the European Waste Catalogue (EWC) codes (in Danish EAK).

Businesses are not specified by name, but information is present about the sector in which the waste was produced. These sectors were grouped to improve readability (see appendix B for grouping). Furthermore, the data specifies the locations: in which municipality what types and amounts (tons) of waste materials are produced, as well as where and how they are being processed. The processing methods are indicated by using the European coding. In general the processing methods are split into two categories; recovery and disposal, each containing several methods.



Excess materials produced by businesses in Frederikshavn & Hjørring

(based on data from 2022)

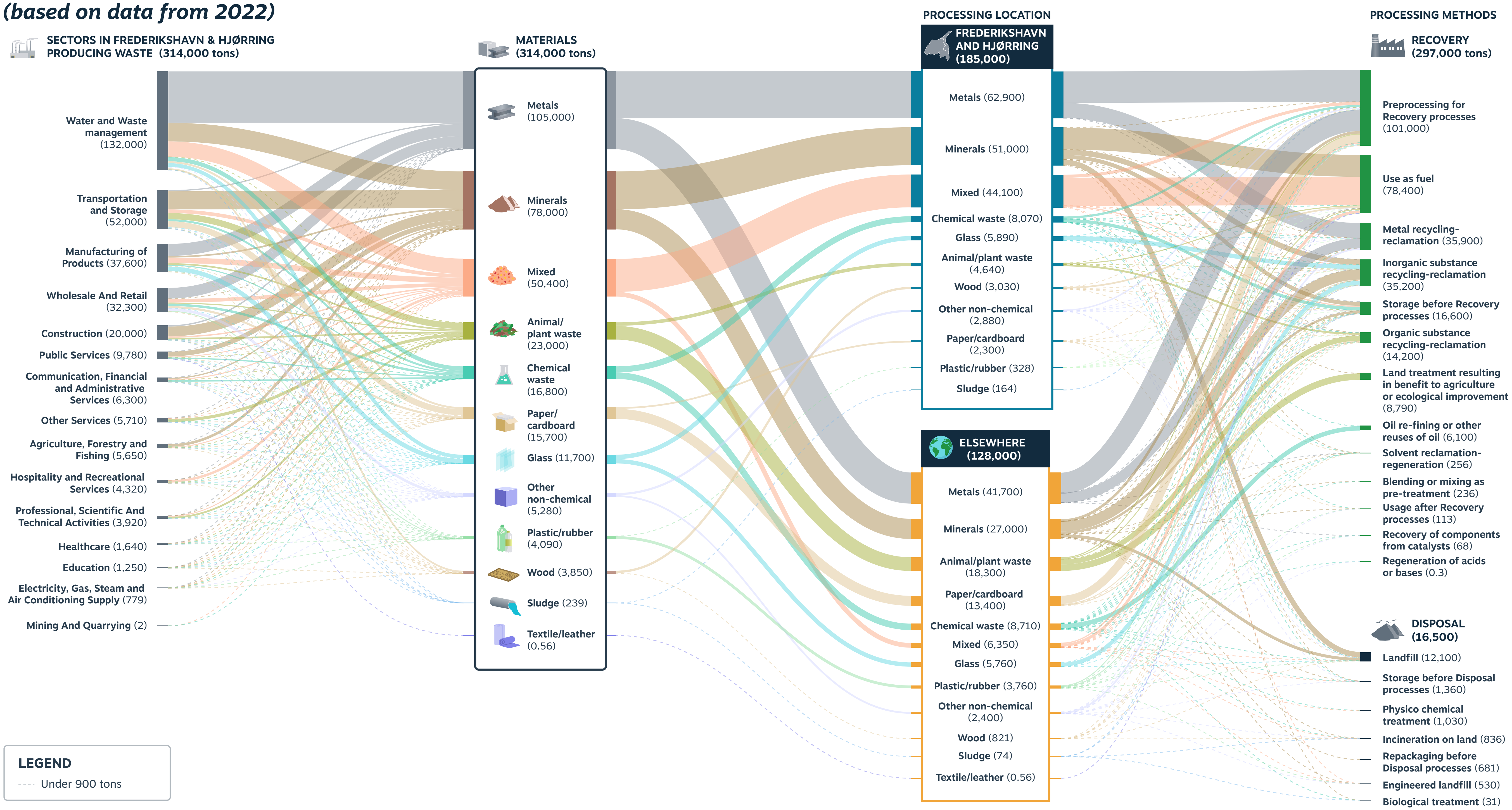


Figure 10 *Material flow analysis for the excess materials ("waste") produced in Hjørring and Frederikshavn including from left to right the sector of origin, the type of materials, their processing location and processing method.*

3.1.2 EXCESS MATERIALS PRODUCED IN FREDERIKSHAVN AND HJØRRING

The first analysis is from the perspective of excess materials (waste) ***produced*** in the municipalities of Hjørring and Frederikshavn (Figure 10). Starting on the left side, it shows all the materials (314,000 tons) that are reported as waste in these municipalities by businesses working in different sectors. Next, it shows the general material categories, followed by where these materials are going for processing; either staying in the two municipalities or going outside to other parts of Denmark or abroad. Lastly, on the right side of the diagram, it shows how they are being processed, regardless of where this happens. Please note that it does not show the waste that is produced in other municipalities.

Sectors producing the waste

In total, all sectors combined produced 314,000 tons of excess materials that are reported as waste in 2022. The largest amount of materials came from the Water and Waste Management sector (42%) followed by the Transportation and Storage sector (17%). This is no surprise with the amount of port related businesses in, not only the port of Skagen, but also the other ports in these two municipalities.

Material types

The majority of excess materials were metals (33%). This is due to the shipyards and especially a large ship dismantling facility located in the region. The next section (1.3) focuses further specifically on the organic material flows plant/animal based, wood and sludge, together forming 9% of the total mass (figure 13).

Location of processing

The majority of the excess materials (59%) stayed in the two municipalities for processing. In terms of materials, more than half of the metals, two thirds of the minerals, almost all mixed waste, half of the chemical waste and almost all the wood stayed. In contrast, most of the organic waste (animal/ plant waste), paper and cardboard, and plastics are processed outside the two municipalities.

Processing methods

In general, 95% of the excess materials end up being recovered through a variety of methods, and 5% are treated with disposal methods. The main method of disposal is landfilling, and it is mostly minerals that are landfilled.

The largest amount of materials is preprocessed for recovery processes (32% of total). This can be various procedures such as separation, cleaning, cutting, shredding etc. Often metals are cut or shredded into smaller pieces before they can be recycled. A quarter of all the excess materials is used as fuel, which means incineration of (waste) materials with energy recovery (heat or electricity).

Opportunities

Opportunity with Minerals

Business in the two municipalities generated 78,000 tons of mineral waste in 2022 (brown flow in figure 10). Currently a large part of these excess mineral are being processed as fuel. This means they are being incinerated with energy recovery. However, there are other and more circular opportunities to reuse these minerals. Mineral waste usually comes from construction. In order to improve usability, it is important to collect rather than demolish buildings to retain value (see circular demolition box below). For an example of circular usage of minerals see the box on the next page.

Circular demolition

Circular demolition is carefully deconstructing or disassembling structures and buildings rather than demolition that destroys and mixes all materials. By carefully dismantling structures, materials like steel, wood, and concrete can be recovered at higher quality and reused or recycled at higher value. Increasingly, traditional demolition companies transform themselves and start providing circular services. E.g. Tscherning (DK) or Heezen BV (NL).

MINERALS EXAMPLE

Utilizing new processing techniques to enable the reuse of construction minerals

By utilizing more advanced techniques of 'crushing' or processing the rubble resulting from demolition in the built environment, sand, gravel and other materials can be obtained in a state where reuse in the built environment at a similar value to novel products, is possible. An example of this process is proposed by so-called 'Smart-Crushers' which utilize techniques to keep different components of concrete rubble intact during processing, enabling a conversion where it might be possible to create almost climate neutral new concrete from concrete waste.

Find more circular examples in Appendix A

Opportunities

Prioritize reusing bilge oil

In a circular system, the aim is to use materials, energy and water within the limits of the planetary boundaries and in ways that allow natural ecosystems to thrive. When (re)using materials, there is a certain hierarchy or preference ladder in order to retain materials at high value (as discussed in chapter 2). This hierarchy is taken into account when analysing the flows of excess materials.

There is 16,800 tons of chemical waste produced in the two municipalities. The majority of this (65%), is bilge oil from ships. Bilge oil is oil that leaks and accumulates inside the lower spaces of a ship (the bilge) and usually mixes there with large quantities of water. Most of this bilge oiled is recovered and refined or reused, either directly (51%) or after storage (43%) (figure 11). However, some bilge oil (6%) is used as a fuel for incineration with energy recovery (most likely electricity) and some (1%) is incinerated on the land, meaning there is not energy recovery at all.

As a non-circular resource (bilge-oil in itself is of course a fossil fuel product), it would be preferred to avoid using this energy source in general. However, as current methods of shipping often necessitate the utilization of such fuels, and till there is no direct alternative created from renewable feedstock, the only use for such oils would be to utilize it where alternatives do not exist, and otherwise to store it whilst aiming for a reduction in demand and supply. Incinerating the oil for electricity generation is therefore not a viable option, even though this might seem circular in its essence. There are different means to generate clean electricity (solar, wind) and therefore can better reuse these excess fuels for the shipping industry which still depends on them heavily. It would be relevant to aim to recover the last 7% as well, which is about 730 tons of bilge oil in one year.

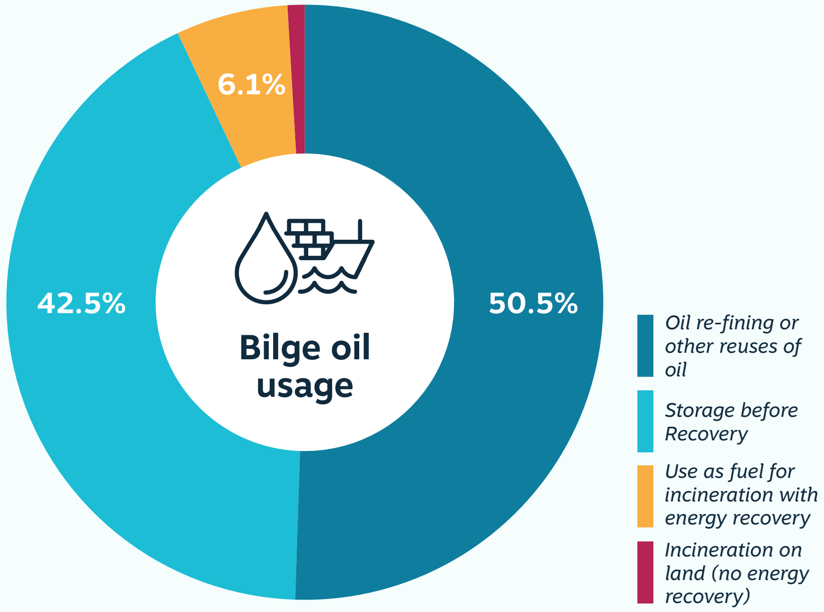


Figure 11 *Piechart diagram showing how the bilge oil from the two municipalities was reused or processed in 2022.*

Embedded impacts of the excess materials

Figure 12 shows the embedded impact of the excess materials (registered as waste) that are produced in the two municipalities. The amount of material in terms of its mass, is not the only, nor the best indicator to judge the necessity for reuse or recycling, as explained in chapter 2. The embedded impacts* of these materials on the environment have been indicated based on global averages**. Figure 12 shows the relative share of the different materials in terms of mass and three types of embedded impacts; land use, CO_2-eq. emissions and water usage.

This shows that, while metals make up 33% of the total mass, they contain almost 80% of the embedded CO_2-eq. emissions and nearly half of the water usage. This underlines the importance of using metals as long as possible, and after that recycling them. If we want to reduce our overall impact on the environment, we will have to also reduce the need for newly extracted materials like metals, so the gains from recycling are not undone. Another interesting observation is that, while paper/cardboard makes up 5% of the total mass, it accounts for 35% of the land used for all these materials.

*Please note the following: these are the embedded impacts and not the direct impacts of the processing method. Please refer to chapter 2 for an explanation.

**Also note that these impacts are indicative as they are based on global averages. They are not specific for the region, and can thus not be used for monitoring.

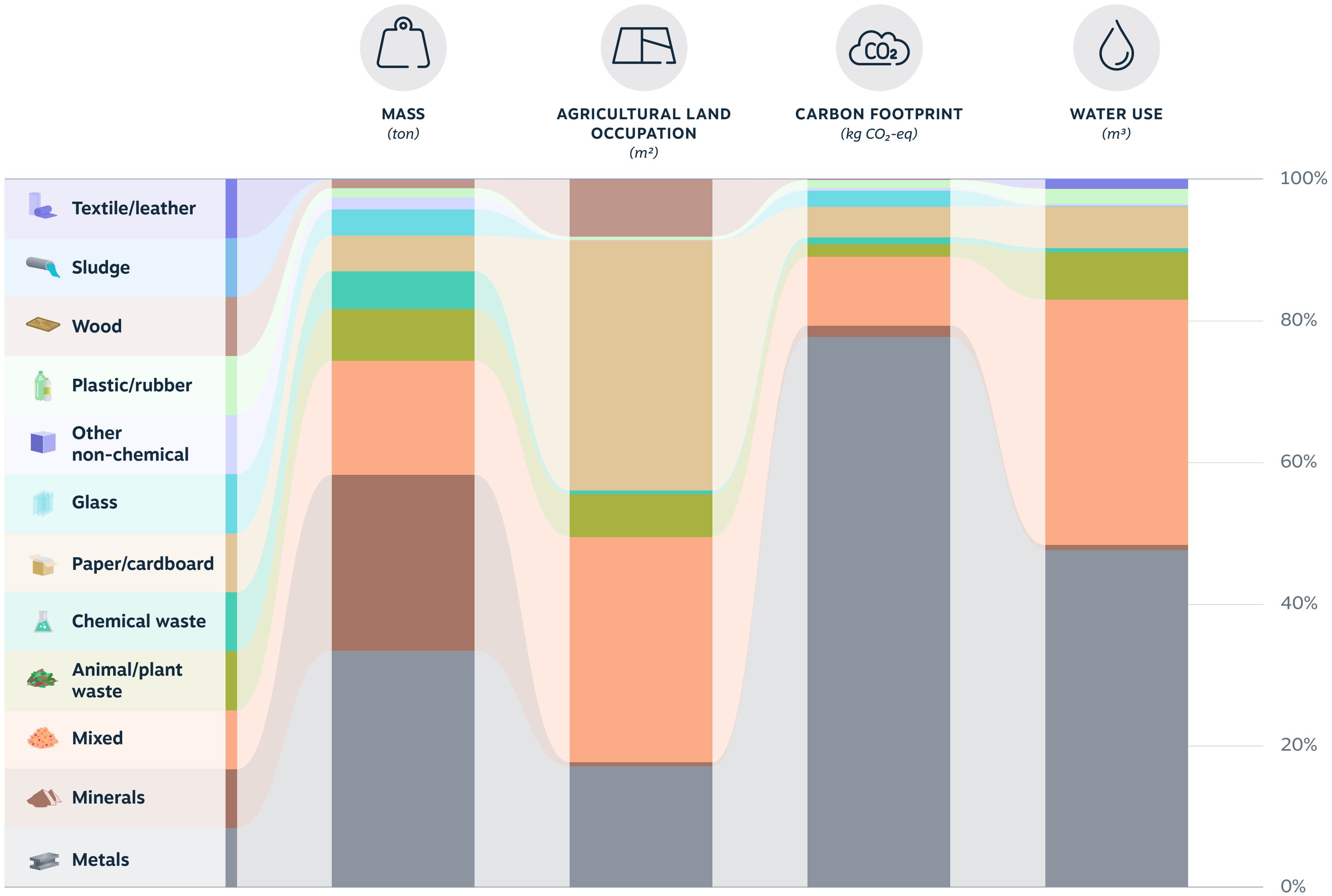


Figure 12

Impact graph showing the relative share (%) of the different materials in terms of mass and three types of embedded impacts; land use, CO_2-eq. emissions and water usage.

Co-funded by the European Union

Organic waste produced in Frederikshavn & Hjørring

Organic flows: animal/plant, wood and sludge (based on data from 2022)

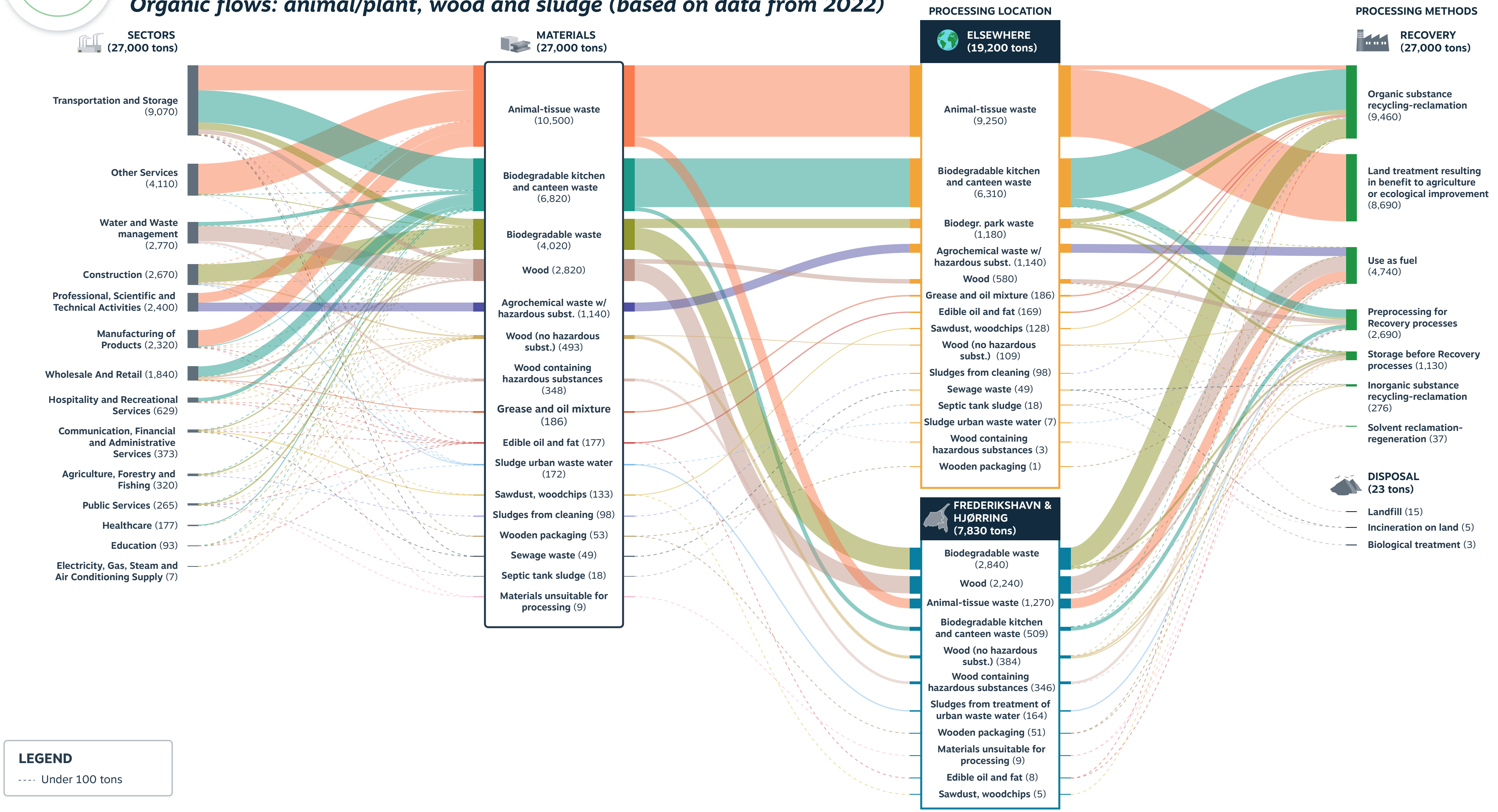


Figure 13 *Material flow analysis for the organic waste produced by businesses in Frederikshavn and Hjørring. Including from left to right the sector of origin, the type of materials, their processing location and processing method.*

3.1.3 ORGANIC WASTE PRODUCED IN FREDERIKSHAVN AND HJØRRING

This section of the analysis zooms in further on the organic waste flows ***produced*** in the two municipalities, which formed 9% of all excess materials (figure 13). A specific analysis was made to look at organic materials in more detail and identify opportunities for biofuel feedstocks, one of the objectives of this research that will feed into another part of the larger REDII Ports project (see figure 2, chapter 1).

For this analysis, the following three material categories were filtered out of the previous MFA (figure 10):

- Animal / Plant based materials
- Wood
- Sludge

These three categories contain various materials. To provide more detail, the entire six digit European Waste Catalogue codes were used. This is the most detailed way to describe materials in the European waste registration.

The left side of the MFA shows the total organic waste reported by businesses across various sectors in these municipalities (27,000 tons). Then, the analysis outlines where the different organic waste materials are going; whether they remain within the two municipalities, or are processed elsewhere (other parts of Denmark or abroad). Finally, on the right side the MFA shows how the waste materials are being processed.

Sectors producing waste

In total, all sectors combined produced 27,000 tons of organic residuals that are reported as waste in 2022. The largest share of materials came from the Transportation and Storage sector (around 34%), likely mostly located within the harbours.

Material types

The majority of organic waste was animal-tissue waste (around 39%), mostly from the fishing industry. This is followed by biodegradable kitchen and canteen waste from businesses (around 25%), biodegradable waste from public green spaces (including waterfronts) (15%) and wood (10%) (all different types wood combined together form 14% of the total).

Location of processing

The majority of the organic waste leaves the two municipalities (71%) and is processed in other parts of Denmark or abroad. Nearly all Animal-tissue waste and Biodegradable kitchen and canteen waste is processed outside the two municipalities. In contrast, the majority of the biodegradable waste from public green spaces is processed in Frederikshavn and Hjørring, as well as most of the wood.

Processing methods

In general, nearly all organic materials (99.9%) are processed using Recovery methods and only 23 tons are processed using disposal methods, mostly by landfill.

A substantial amount of organic materials are processed by Organic substance recycling-reclamation (35%), mostly biodegradable kitchen and canteen waste, as well as biodegradable waste from public green spaces. Recycling-reclamation can consist of various procedures such as composting and anaerobic digestion.

Next, a major amount of organic waste, mostly animal-tissue waste, is used for Land treatment (32%), usually for agricultural applications. This is in line with European ambitions for creating more circular agricultural systems and bringing nutrients and organic matter back to the soil to improve soil health.

Next, a large amount of organic materials (18%) is used as fuel for incineration with energy recovery in the form of heat and/or electricity (note that this does not include anaerobic digestion). This is one of the least preferred processing methods as it results in materials and their value being lost from our economy (see chapter 2, figure 7 for organic waste hierarchy). On the next page, a few examples are highlighted for circular usage of organic materials and wood. All examples can be found in appendix A.

Opportunities

Opportunity to reuse organic materials and avoid incineration

In total 4740 tons of organic materials were incinerated in 2022. This included mainly:

- Wood
- Animal-tissue waste
- Agrochemical waste containing hazardous substances
- Wood containing hazardous substances

There are opportunities to process these streams in more circular ways to retain value, reduce material usage and thereby impacts.

The wood could be reused (example on the right) or recycled into construction materials (see appendix A). If the quality of the wood is not suited for such applications, it could be used as a biofuel feedstock. This is preferred over incineration as there are different ways to generate clean electricity (solar, wind), while the shipping industry still heavily depends on fossil fuels (see organic waste hierarchy in chapter 2).

For animal-tissue, usage in agriculture (land treatment) would be preferred, to bring nutrients and organic matter back to the soil. However, if the animal-tissue is unsuited for agricultural application, this could also be an interesting potential feedstock stream for biofuel production (appendix A).

ORGANIC EXAMPLE

Using organic residual streams to improve soil health

In Denmark, ComFerm ApS is pioneering a closed and automated composting facility. The goal of this user-friendly system is to empower growers or grower groups to produce compost locally or at a company level. Simultaneously, it aims to conserve nitrogen that would otherwise be lost through leaching by converting it into a concentrated fertilizer. The ComCrop facility operates as a fully enclosed system, transforming local waste streams into soil enhancers and high-quality by-products such as CO_2 and heat for greenhouse cultivation, clean water, and ammonium fertilizer.

Find more circular examples in Appendix A

WOOD EXAMPLE

Wood hubs with secondary building materials

In the port of Rotterdam there is the woodhub *Buurman* which provides secondary building materials that have been harvested/reclaimed from demolition or deconstruction. These secondary materials are more affordable than primary and help reducing environmental impacts by reducing demand for primary materials. Their customers are both businesses and consumers. They also have a workshop where people can borrow tools and repair or create wooden furniture and other structures. They occasionally provided courses to educate people. Craftsmanship and repair skills are very useful in a circular economy.

In the port of Kampen, *Weever Circulair* has also started a woodhub with wood reclaimed from circular demolition. They mainly sell to businesses that use the wood for larger construction projects.

Excess materials processed in Frederikshavn & Hjørring

(based on data from 2022)

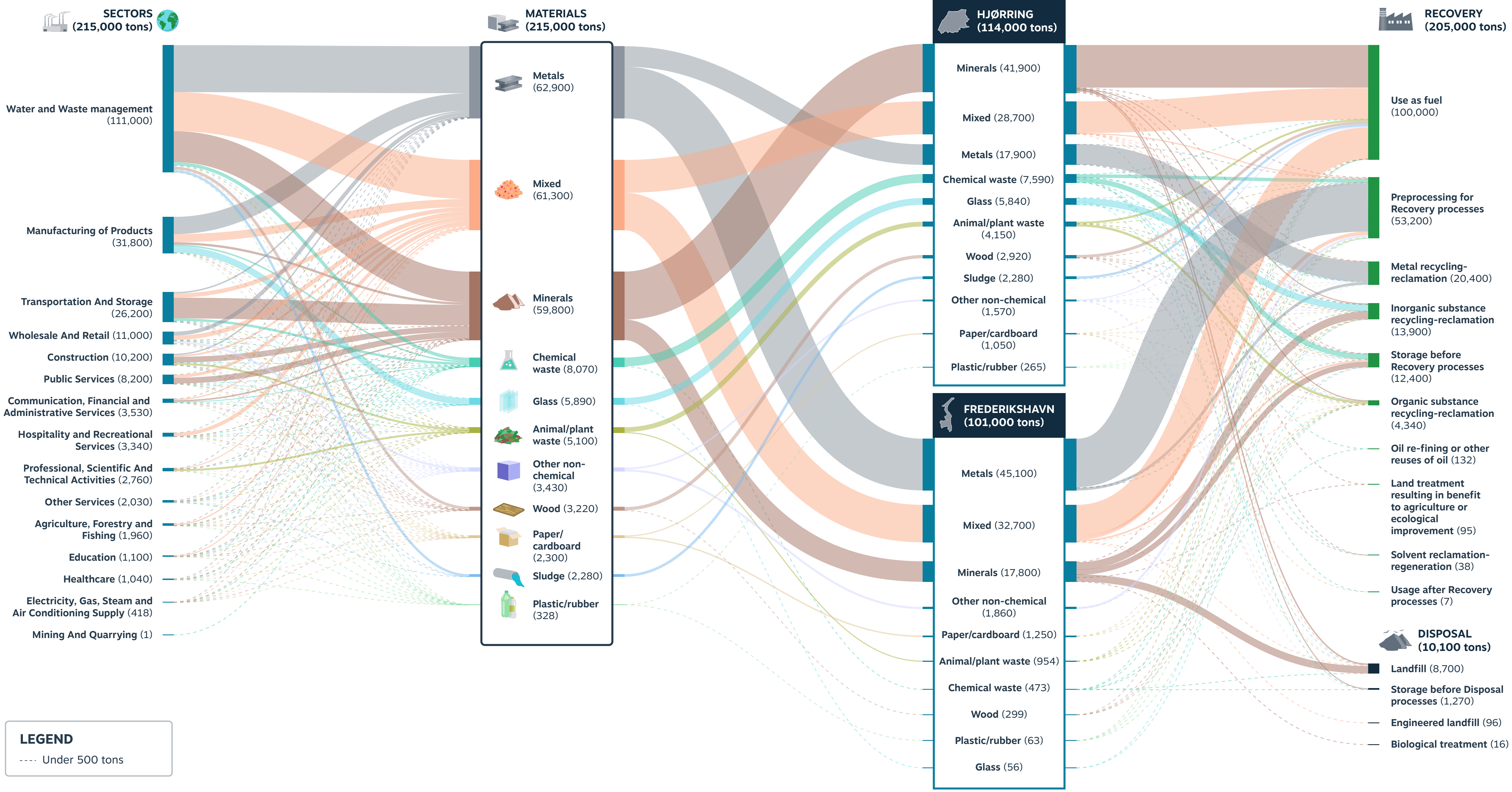


Figure 14 *Material flow analysis for all the waste processed in Frederikshavn and Hjørring including from left to right the sector of origin, the type of materials, the municipality where it is processed and processing method.*

3.1.4 PROCESSED MATERIALS IN HJØRRING AND FREDERIKSHAVN

The second analysis is from the perspective of excess materials (waste) that are processed in the municipalities of Frederikshavn and Hjørring (Figure 14). Besides processing some of the waste created within the two municipalities themselves, there are also many materials from other municipalities or abroad that are received and processed here.

Starting on the left side of the Material Flow Analysis, it shows all the materials (215,000 tons) that are reported as waste by businesses from different sectors. These excess materials can come from anywhere in the world, they are shown here as long as they are being processed in either Frederikshavn or Hjørring. These excess materials can come from anywhere in the world. Next, it shows the different types of materials grouped by general categories. Followed by where these materials are being processed; either in Frederikshavn or Hjørring. Lastly, on the right side of the diagram, it shows how the materials are being processed.

Sectors producing waste

In total, all sectors combined produced 215,000 tons of excess materials that are reported as waste in 2022. The majority of materials came from the Water and Waste Management sector (52%) followed by the Manufacturing of Products and Transportation and Storage sectors (15%)

Material types

A substantial part of excess materials are Metals (29%), which are produced in region as the first MFA (figure 10) showed. As mentioned, this can be explained by the shipyards and ship dismantling facility located in the region. Besides metals, a lot of Mixed waste (29%) and Minerals (28%) are processed in the two municipalities.

The next MFA discussed in section 1.5, will zoom in further on the organic material flows; plant/animal based materials, wood and sludge, that together form 5% of the total mass.

Location of processing

About half of the excess materials (53%) are processed in Hjørring; the majority of the minerals and about half of the mixed waste. The other half is processed in Frederikshavn; the majority of the metals and half of the mixed waste.

Processing methods

In general, 47% of the excess materials end up being used as an input for fuel, which means incineration of with energy recovery (heat and/or electricity). This indicates a significant possibility for improvement here to retain value that will be discussed on the next page.

Nearly half (48%) of all the excess materials are either preprocessed for recovery processes, or directly reclaimed through recycling.

About 5% of all the excess materials (mostly minerals) are processed with disposal methods, mainly landfilling. This means these materials are lost from the economy.

Opportunities

The current tax system makes it hard for secondary materials to compete with primary

In the Port of Skagen region, used fishing nets and gear is collected and recycled. The nylon from the nets is recycled into new fishing nets and other products (e.g. by Plastix). These fishing nets are thus made of secondary materials, reducing the need for primary materials and thereby reducing negative environmental impacts.

However, currently products from secondary (recycled) materials tend to be more expensive, as labor costs in Europe are relatively high and labor is taxed much higher than materials. The current tax system creates an unlevel playing field for circular innovation. These are external circumstances that need to change in order for secondary materials to become more competitive and to accelerate the transition.

The European Green Deal brings forward many new laws and regulations to help improve this and create a more level playing field for circular solutions. In the coming years many new laws will be implemented suchs as the EPR, CSRD, SUP and ESPR. The platform CircuLaw aims to provide insights in these new and upcoming European legislation to help governments and businesses in the transition (currently the website is in Dutch but an English version is coming later in 2024).

Opportunities

Opportunities with wood and sludge

A large part of the collected wood (3,220 tons) and sludge (2,280 tons) are being used as a fuel source, which means they are incinerated and the materials are lost. There are various different applications that fulfill more valuable and more circular purposes.

For example, wood can be upcycled into novel products such as building materials or packaging, which would mean a reduction in the demand for primary wood, avoiding additional cutting and processing of trees. An example of circular wood usage can be found on the right. More examples can be found in appendix A.

For example, sludge can be utilized as an agricultural input supplying nutrients (see the sludge example on the right). In this way the loop can be closed bringing back nutrients from our food to the soil. If the sludge is not suited for this, it can also be used as a biofuel feedstock (see the example in appendix A).

Find more circular examples in Appendix A

WOOD EXAMPLE

Upcycling wood scraps into novel products

The global interior manufacturer Unilin, produces large parts of its chipboards with recovered wood. This excess wood comes from streams delivered by other industries, but also a share from households. Thanks to a combination of techniques (magnets, wind sifters, centrifuges, infrared, etc.), impurities from the residual streams can be removed from the wood residual streams. These impurities are collected and then also find their way to other industries to be reused or recycled.

SLUDGE EXAMPLE

Using sludge to generate both biogas, retrieve nutrients for agricultural and develop biofuel

By treating sludge through dehydration at a high temperature (so-called Torwash process), biogas can be produced from the squeezed out water and the dissolved phosphate recovered which can be used for agricultural application. The residue (almost dry sludge) serves a green fuel and TNO is now investigating its application in, for example, cement production or in the generation of heat and electricity. The pilot project resulted in the total volume of incinerated sludge to be reduced by 85%.

Embedded impacts of the excess materials

Figure 15 shows the embedded impact of the excess materials (waste) that are ***processed*** in the two municipalities. The amount of material in terms of its mass, is not the only, nor the best indicator to judge the necessity for reuse or recycling, as discussed in chapter 2. The embedded impacts* of these materials on the environment have been indicated based on global averages**. Figure 15 shows the relative share of the different materials in terms of mass and three types of embedded impacts; land use, CO_2-eq. emissions and water usage.

This shows that, while metals make up 29% of the total mass, they contain almost 80% of the embedded CO_2 eq. emissions and more than a third of the water usage. This underlines the importance of using metals as long as possible, and after that recycling them. If we want to reduce our overall impact on the environment, we will have to also reduce the need for newly extracted materials like metals, so the gains from recycling are not undone. Besides that, there is a substantial mass of mixed waste (29%) which accounts for the majority of land usage (roughly 65%) and water usage (nearly 60%).

Please note the following: these are the embedded impacts and not the direct impacts of the processing method. Please refer to chapter 2 for an explanation.

***Also note that these impacts are indicative as they are based on global averages. They are not specific for the region, and can thus not be used for monitoring.*

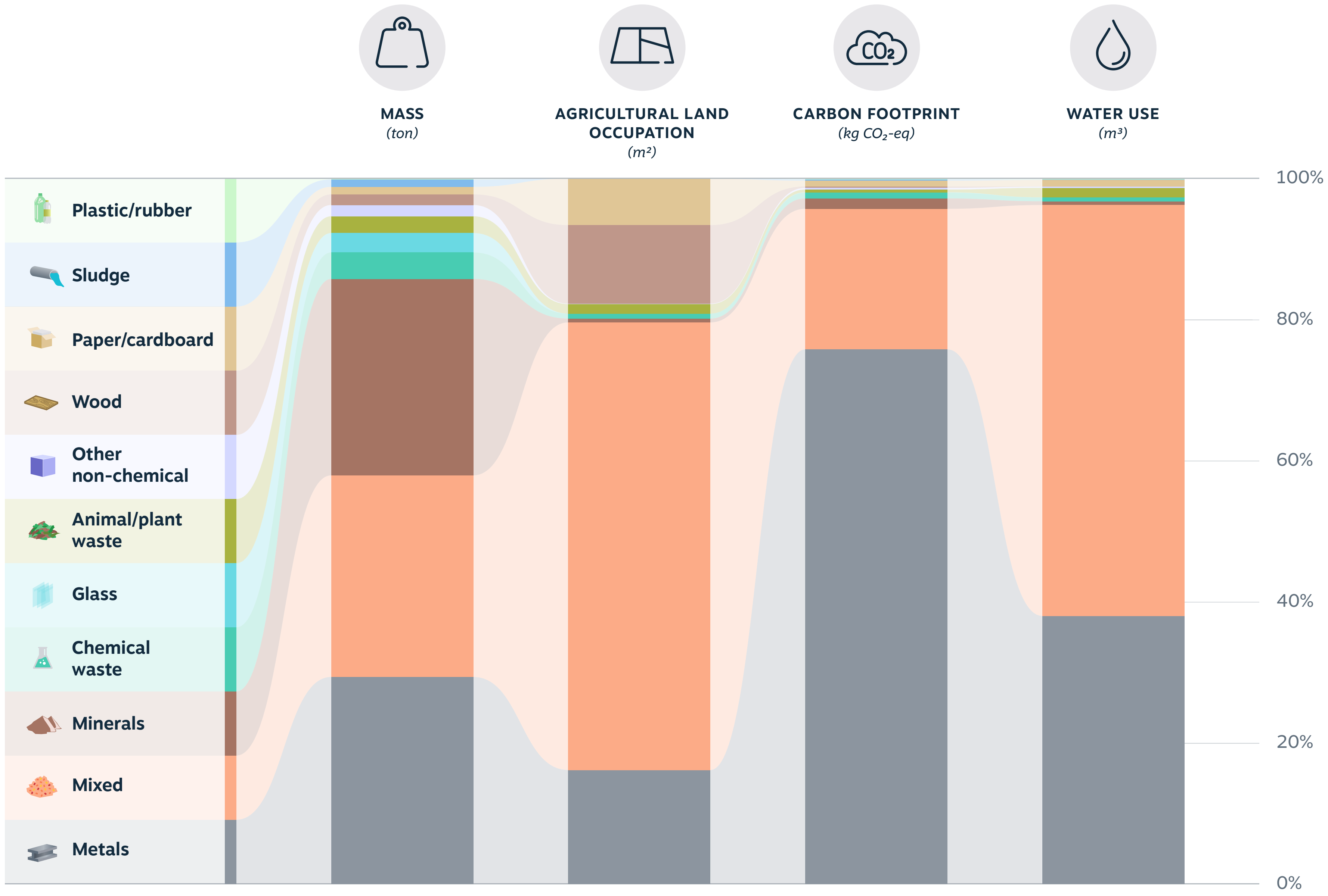


Figure 15 *Impact graph showing the relative share of the different materials in terms of mass and three types of embedded impacts; land use, CO_2-eq. emissions and water usage.*

Opportunities

Opportunity with Mixed

There is a substantial mass of mixed waste present (61,300 tons)(29 % of total mass) which accounts for an even larger share of the land usage (65%) and water usage (nearly 60%). Opportunities for improved management of this material stream, for example by singling out the most impactful types of materials, exist and can be explored to improve circularity.

Ideally, separation at the source would be improved to avoid further energy usage and costs. In order to achieve this, businesses would need to cooperate and local authorities could find ways to stimulate and facilitate sorting and collecting of different fractions.

Another, option is to sort out different waste streams afterwards, by using Mixed Waste Sorting (MWS) processes. An example is provided on the right hand side.

SORTING GENERAL

Mixed waste sorting to recover materials

Mixed Waste Sorting (MWS) processes are very useful to purify streams and thereby increase reuse and recycling opportunities and the ability to retain material value and avoid incineration. Examples of automated mixed waste sorting include waste processor AVR in the Netherlands, which separates plastic waste from mixed household waste streams. The company now recovers 12 times the amount of plastic for recycling with mixed waste sorting – an enormous boost in recycling rates and greenhouse gas reduction benefits. However, proper sorting at the source would of course avoid even more energy usage and thereby emissions, thus would be preferred first.

Organic materials processed in Frederikshavn and Hjørring

(based on data from 2022)

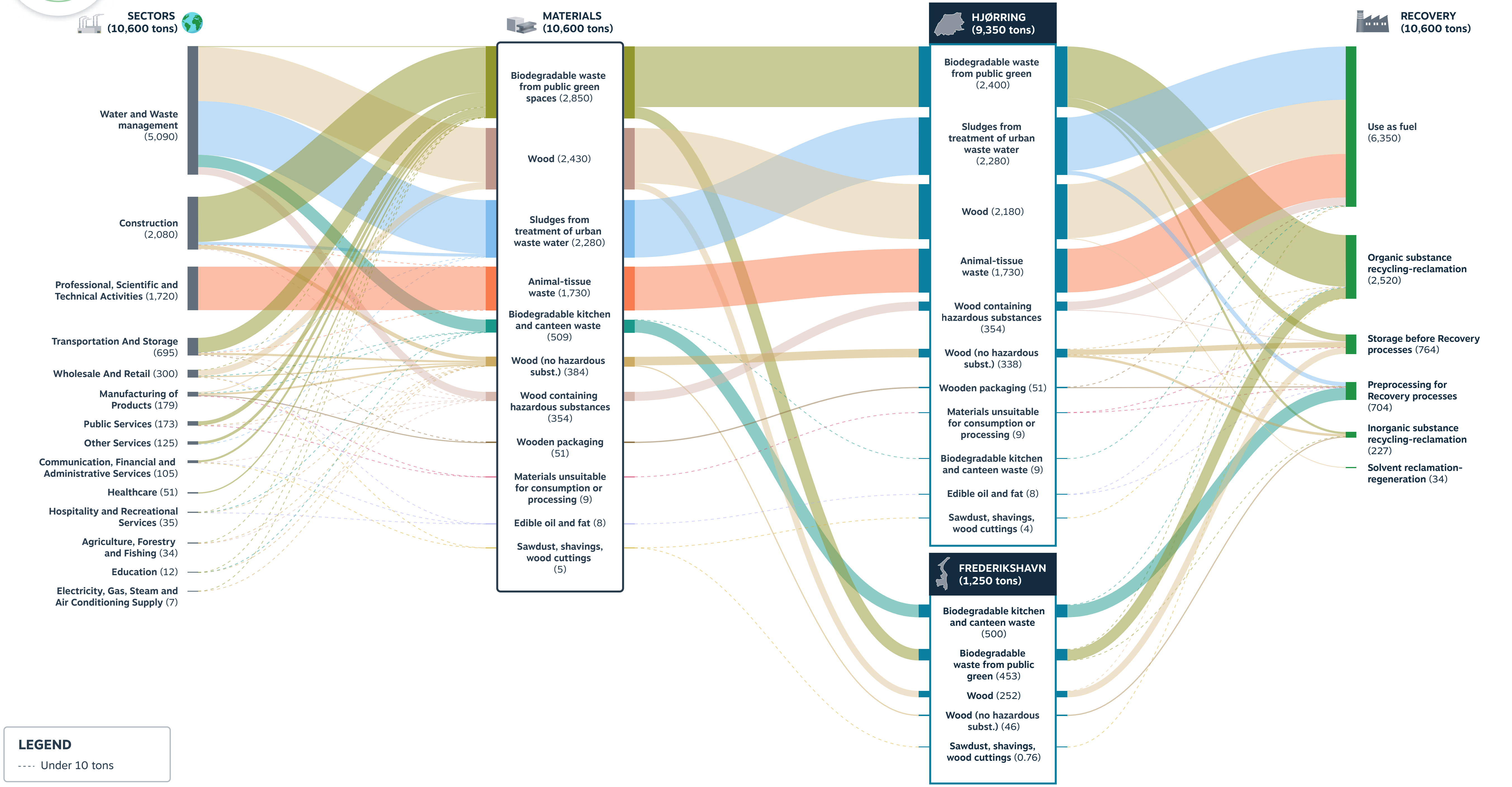


Figure 16 *Material flow analysis for the organic waste processed in Frederikshavn and Hjørring. The MFA shows from left to right the sector of origin (regardless of location), the type of organic materials, the processing location (either of the two municipalities) and processing method.*

3.1.5 ORGANIC WASTE PRODUCED IN FREDERIKSHAVN AND HJØRRING

This section zooms in further on the organic waste flows ***processed*** in the two municipalities (figure 16). This formed 5% of all excess materials processed in the region (figure 14). A specific analysis was made to look at organic materials in more detail to identify circular opportunities and also specifically look for opportunities for biofuel feedstocks, one of the objectives of this research that will feed into other parts of the REDII Ports project (see figure 2, chapter 1).

For this analysis, the following three categories were filtered out from the previous MFA (figure 14):

- Animal / Plant based materials
- Wood
- Sludge

These three categories contain various materials. To provide more detail, the entire six digit European Waste Catalogue codes were used. The left side of the MFA (figure 16) shows the total mass of organic materials that were processed in the two municipalities (10,600 tons in 2022). This organic waste can be produced anywhere in and outside Denmark. Next it shows the different material types, in where they are processed (Frederikshavn or Hjørring) and how they are processed.

Sectors producing waste

In total, the two municipalities processed 10,600 tons of organic excess materials that were discarded by businesses anywhere in- or outside Denmark. The largest share of organic materials came from businesses in the Water and Waste management sector (48%), followed by the Construction (20%) and Professional, Scientific and Technical Activities (16%) sectors.

Material types

A substantial part of excess materials were Biodegradable waste from public green spaces (27%), Wood (23%), Urban wastewater sludges (22%) and Animal-tissue waste (16%).

Processing location

The vast majority of organic excess materials is processed in Hjørring (88%); nearly all Biodegradable waste from public green and Wood, and all of the Sludge and Animal-tissue. Only 12% of the organic materials is processed in Frederikshavn.

Processing method

A large share (60%) is processed as a fuel, mainly Wood, Sludge and Animal-tissue. This means the materials are incinerated with energy recovery, which is one of the least preferred processing methods as it results in materials and their value being lost from our economy (see figure 7, chapter 2 for organic waste hierarchy). This indicates an opportunity for a more sustainable application that retains more value (see box on the right). In contrast, the majority of the Biodegradable waste from public green spaces, is being recycled. Still, also here there might be opportunities for higher value recycling for certain waste fractions.

Opportunities

Opportunity to reuse organic materials and avoid incineration

There is an opportunity to use the organic materials that are now incinerated (6,350 tons in 2022) in a different way that retains more value.

For example, nutrients from the sludge can be recovered and used as an agricultural input. The organic matter from the sludge can also be used for agricultural purposes or serve as a biofuel. For examples of circular usage of sludge see appendix A.

Similarly, for Animal-tissue waste, usage in agriculture would be preferred as it brings nutrients and organic matter back to the soil. If the animal-tissue is unsuited for agricultural application, it could also be an interesting potential feedstock for biofuel.

The wood could be reused or upcycled into e.g. construction materials. See examples for circular usage of wood in appendix A. If the quality of the wood is not suited for such applications, it could also be a potential biofuel feedstock, which is preferable over incineration (see organic waste hierarchy in chapter 2).

3.1.6 SUMMARY OF OPPORTUNITIES & LEARNINGS

These material flow analyses showed there are various opportunities for more circular material usage in the industrial area surrounding the port of Skagen (municipalities of Frederikshavn and Hjørring). Using materials in a more circular manner enables closing loops regionally and retaining value. This has the potential to not only provide environmental benefits but also socio-economic benefits by reducing costs and improving resilience and independence. In this section the opportunities and learnings of this case study are summarized.

Opportunities

Opportunities for biofuel

- *Sludge and organic streams that are not suitable for composting and agricultural usage can be used as a biofuel feedstock.*
- *Wood that can not be reused or recycled into construction materials, can be shredded and used as a biofuel feedstock.*

Opportunities

Opportunities to increase circular material usage

Minerals: *instead of incineration, minerals can be reused and recycled. Circular demolition or deconstruction aids in retaining high value of materials.*

Wood reusing: *circular demolition and deconstruction helps reclaim wood. Wood hubs can provide these secondary materials in an affordable way, reducing both costs and environmental impacts.*

Wood recycling: *to create new building materials e.g. chipboards, MDF panels, pulp for paper, wood-concrete composites for construction, and pallet elements.*

Animal tissue waste: *if usage in the food or otherwise feed value chain is no longer possible animal tissue can be composted using anaerobic digestion and nutrients can be looped back to agriculture.*

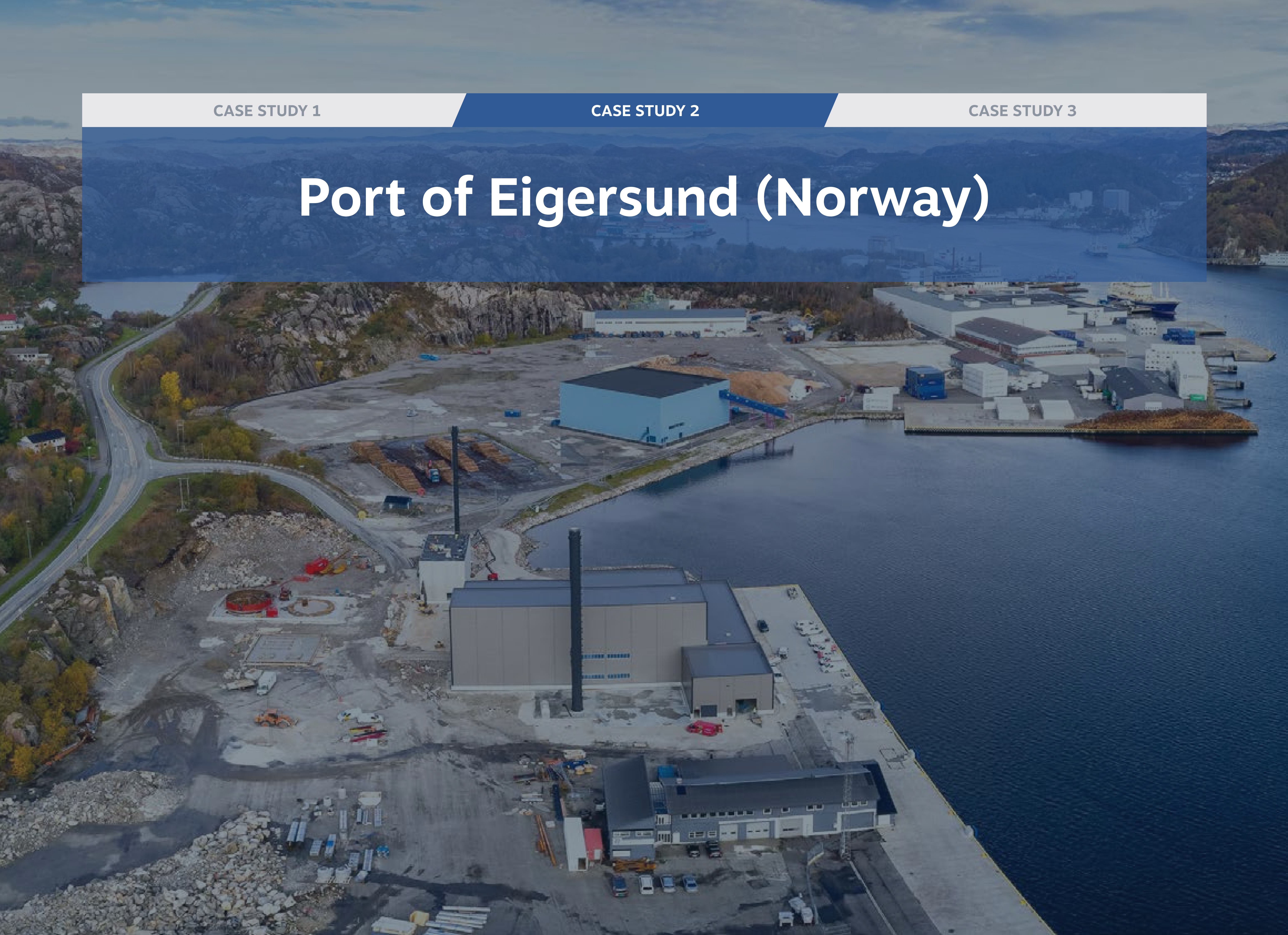
Sewage sludge: *Currently burned for energy (releasing CO_2), it can be processed to recover nutrients for agriculture, capture biogas and create biofuel feedstock.*

Mixed waste: *first aim should be to stimulate better separation at the source. Alternatively, sorting processes can be used to retain valuable materials for reuse and recycling.*

Learnings

- **Using two perspectives**, looking at both production and processing of waste streams in the two municipalities, has given an indication of the total volumes available which is relevant for developing new business cases.
- The current tax system makes secondary materials relatively more expensive than primary materials due to higher taxes on labour. The **current tax system supports the old linear system** and thereby obstructs the transition. Governments need to help creating a level playing field for the circular economy.
- Currently there is **little insights into non-waste material streams** (by-products) as they remain largely undocumented, this makes it more difficult to know what amounts are available for higher value retainment.
- **Material flow analysis is only the first step** in the process towards a more sustainable system and regional industrial symbiosis. Analyzing materials gives insights in the current status; which materials are available, how much and how are they currently processed. From here collaboration and building local networks is needed to transition to a more sustainable way of working. Several collaborations already exist and the port aims to facilitate more exchange of energy, water and materials.

Port of Eigersund (Norway)



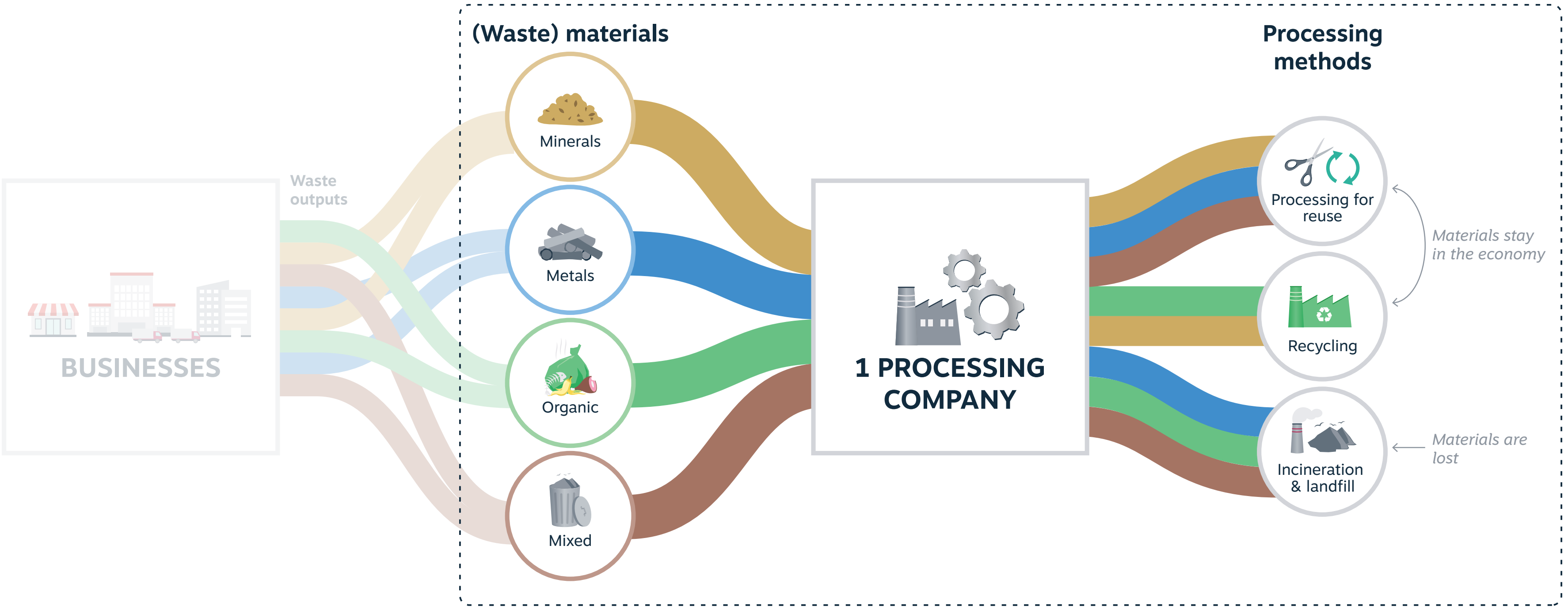


Figure 17 *Diagram of the MFA method where the line indicates the scope for this case study. There was a smaller scope for the analysis as no data was available on the origin of the excess materials (neither by sector nor business).*

3.2.1 SCOPE

Due to the limited data availability, this case study focuses only on the two waste processing companies in the Eigersund port area. Unfortunately, as Norway is not an European member state, it does not abide to all the European rules and regulations. Hence, they are not by obliged to have a national waste registry with waste data from businesses.

The data analysis only focuses on the (waste) materials received by the two processors and the processing methods applied by them. As no data was available on the origin of the materials (by sector or business), the analysis only focuses on the last three nodes of the MFA approach (figure 17).

Data used

The lack of an accessible national registry meant that the data could only be collected through companies themselves. The budget and timeline of this case study project did not allow for data collection of all individual companies in the port (37 companies), let alone its industrial hinterlands. Especially because besides the communication that the collection would require, also the cleaning of the data would take significant time, which would be necessary as there is no uniform waste registration framework in place like the European Waste Catalogue codes (EWC codes).

In collaboration with the port of Eigersund, the five main waste processing companies in the port region were approached. Data was received from two of the processing companies in the region, for privacy reasons they will be referred to as Processing company A and B. Since little is known about the data they provided, and they do not use uniform coding for that materials nor processing methods (like the EWC codes), the data of the two processors could not be combined. The data specifies the mass of materials and their processing method. However, the origin of the materials (by sector or businesses) was not given specifically per material type.

Waste materials processed by Processing company A

(based on data from 2022)

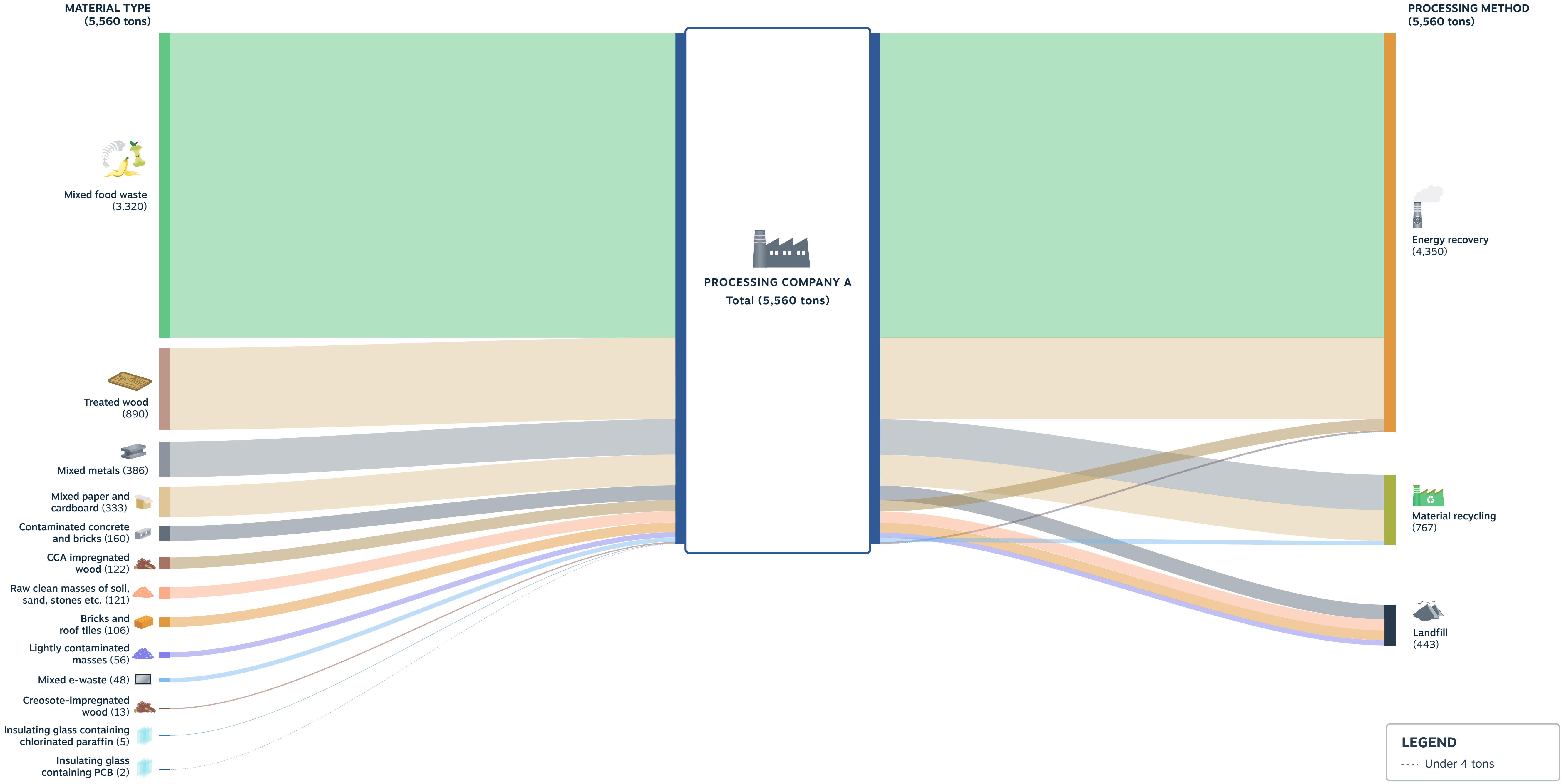


Figure 18 *Material flow analysis for the waste processed by Processing company A. The MFA includes on the left side the type of materials received and on the right side the processing method. The colours indicate the type of material, the thickness of the flows are in proportion to their mass. The mass is in tons and the data is for the year 2022.*

3.2.2 EXCESS MATERIALS PROCESSED BY PROCESSING COMPANY A

The material flow analysis (MFA) shows the materials received and processed by Processing company A in the year 2022 (Figure 18). A total of 5560 tons of excess materials were collected and processed. On the left side of the figure it shows the different materials that came in and on the right side it shows how they were processed.

Sectors producing waste

Processing company A did not share data on the type of businesses that they receive the excess materials from by type and amount. They did give a general indication on the source of materials. They indicated they mainly receive excess materials from food retail businesses, the municipality and the construction sector.

Material types

The main material processed by Processing company A was mixed food waste (3,320 tons) (60%) in 2022. This if followed by different types of wood (1,025 tons in total), forming 18% of all materials processed. The majority of wood is treated wood (890 tons), 16% of all materials.

How is it processed?

The majority of materials are incinerated (78%), with energy recovery in the form of heat or electricity. Besides that materials are recycled (14%) or landfilled (8%). Both landfill and incineration means that materials are lost and do not return to our economy. This provides ample opportunities for more circular material usage. The opportunities and several examples will be discussed in more detail on the following pages.

Opportunities

Opportunity to reuse minerals

In 2022, a total of 387 tons of minerals were landfilled; Contaminated concrete and bricks (160 tons), Raw clean masses of soil, sand, stones etc. (121 tons) and Bricks and roof tiles (106 tons). Potentially these could be reused in the construction sector. There are methods for cleaning contaminated building materials (e.g. recycling asbestos will be discussed in section 2.3). As for clean construction materials there are many opportunities to reuse them in new development projects for infrastructure and buildings. For example, in making concrete, secondary concrete can be used as input material again. As there is a concrete factory in the harbour region, there are opportunities to connect excess concrete (waste) to the factory as input again. This reduces primary material usage and transportation and thereby reduces impacts, e.g. in terms of CO_2 emissions.

MINERALS EXAMPLE

New processing techniques to enable the reuse of construction minerals

Advanced techniques for processing the residual stream (rubble) resulting from demolition in the built environment can help reclaim resources. Sand, gravel and other materials can be obtained in a state where it is possible to reuse them at a similar value into new products in the built environment.

An example of such processing methods are so-called '<u>Smart-Crushers</u>' which utilize techniques to keep different components of concrete rubble intact during processing, enabling a conversion where it is potentially possible to create nearly climate-neutral concrete products from concrete waste.

Find more circular examples in Appendix A

Embedded impacts in excess materials

Figure 19 shows the embedded impact of the excess materials that are received by Processing company A. The amount of material in terms of its mass, is not the only, nor the best indicator to judge the necessity for reuse or recycling, as explained in chapter 2. The materials from MFA have been grouped under main material categories. The embedded impacts of these material categories on the air, land and water have been indicated.* Figure one shows the relative share of each material in four categories; mass, land use, CO_2 eq. emissions and water usage. This shows that wood waste has a relatively big land, footprint, compared to its mass share.

This shows that animal/plant waste has a relatively large land, carbon and water footprint, compared to its mass share. Similarly, wood has a large land footprint relative to its mass share. This makes it even more important to make good use of these excess materials as a lot of impact has been generated to make them in the first place. Opportunities are discussed on the next page.

It also shows that while metals are just 7% of the total mass, they contain almost 20% of the total embedded CO_2-eq. emissions. This underlines the importance of using metals as long as possible, and after that recycling them. The focus should first be on reducing materials and extending the lifetime, as recycling costs a lot of energy and is thus not the quickfix towards sustainability.

Figure 19 *Impact graph showing the relative share of the different materials in terms of mass and three types of embedded impacts; land use, CO_2-eq. emissions and water usage.*

**Please note the following: these are the embedded impacts and not the direct impacts of the processing method. Please refer to chapter 2 for an explanation.*

***Also note that these impacts are indicative as they are based on global averages. They are not specific for the region, and can thus not be used for monitoring.*

Opportunities

Opportunity to use mixed food waste

The 3320 tons of food that were incinerated in 2022 could be used at a higher value. Rather than incinerating, it could be used for composting with anaerobic digestion (to kill any pathogens and win back energy). The compost can then be used for land treatment to return nutrients and organic matter to the soil.

An example of composting can be found in the box on the right side.

Opportunities

Opportunity to use excess wood

The treated wood (890 tons) and impregnated wood (135 tons) can be reused or upcycled into construction materials and other products (see example on the right, more examples with wood can be found in appendix A). If the quality of the wood is not suited for such applications, another purpose could be found in using wood as biofuel. This is preferred over incineration as we have different means to create clean electricity (solar, wind), while the shipping industry still heavily depends on fuels, which are currently mostly fossil fuels and can improve by transition to biofuels if sourced sustainably.

ORGANIC EXAMPLE

Using organic residual streams to improve soil health

In Denmark, ComFerm ApS is pioneering a closed and automated composting facility. The goal of this user-friendly system is to empower growers or grower groups to produce compost locally or at a company level. Simultaneously, it aims to conserve nitrogen that would otherwise be lost through leaching by converting it into a concentrated fertilizer. The ComCrop facility operates as a fully enclosed system, transforming local waste streams into soil enhancers and high-quality by-products such as CO_2 and heat for greenhouse cultivation, clean water, and ammonium fertilizer.

Find more circular examples in Appendix A

WOOD EXAMPLE

Upcycling wood scraps into novel products

There are ways to process excess wood that offer more value and reduce the need for newly grown wood. Take for example the global interior manufacturer Unilin, which produces large parts of its chipboards with recovered wood, which comes straight from residual streams delivered by other industries, but also households. Thanks to a combination of techniques (magnets, wind sifters, centrifuges, infrared, etc.), impurities from the residual streams can be removed. These impurities then also find their way to other industries to be reused.

Waste materials processed by Processing Company B
(based on data from 2023)

Figure 20 *Material flow analysis for the waste processed by Processing company B including on the left side the type of materials received and on the right side the processing method. The colours indicate the type of material, the thickness of the flows are in proportion to their mass. The mass is in tons and the data is for the year 2023.*

3.2.3 EXCESS MATERIALS PROCESSED BY PROCESSING COMPANY B

The Material flow analysis (MFA) shows the materials received and processed by Processing company B in the year 2023 (Figure 20). A total of 128,000 tons of materials was collected and processed. On the left side of the figure the different materials that were collected by the company are shown. On the right side it is shown how these materials were processed.

Sectors producing waste

Processing company B indicated that in an average year, 65% of all waste they receive is generated by the construction sector during construction and demolition projects. Around 15% is drilling waste (including offshore drilling projects). Around 15% are ashes from waste incineration plants.

Material types

Processing company B mainly receives soil/mud (26%) and concrete (23%). Followed by sawdust (13%), mixed inert waste (11%), bottom ashes (11%) and ordered residual waste (11%).

Processing methods

Nearly all materials are landfilled by Processing company B (96%), expect for some metal recycling (4%). This means the materials are lost from our economy and can not be reused or recycled. This provides several opportunities for more circulare material usage to retain value.

Opportunities

Opportunities to increase circular concrete usage

Instead of landfilling the 29,200 tons of concrete found in the material streams collected by Processing company B, there are a number of different methods to reuse or recycle the materials at a higher value. For example, advanced processing methods (see example discussed previously in section 2.2) can be used to recover reusable streams of concrete to a state where it can be used to create almost new concrete. As there is a concrete factory in the harbour region, there are opportunities to connect excess concrete (waste) to the factory as input again. This reduces primary material usage and transportation and thereby reduces impacts (embedded impacts are further discussed on the next page).

Opportunities

Opportunity for recycling asbestos

In 2023, a relatively small but significant stream of 859 tons of asbestos have been received and landfilled by processing company B. Even for asbestos novel recycling methods are being developed to decompose them, removing toxicity and bringing material components back into the economy in a safe way (see example on the right).

MINERALS EXAMPLE

Taking care of toxic substances in waste mineral flows: neutralizing asbestos

In some of the case study ports, asbestos is part of the minerals waste stream. This toxic substance is often mixed with different building materials, which are often disposed of together. Health implications of this material resulted in a ban in NL. Until now these materials were landfilled. However, in recent years novel technologies have developed to process asbestos. Since 2017, Asbeter has been developing an innovative process in which asbestos is processed. In 2018, the Rotterdam-based company launched an experiment for processing of asbestos cement corrugated sheets started with the first pilot installation. In this plant, asbestos is processed with residual products from other companies on the same industrial park. The asbestos and recovered cement are to be processed in the plant into new building material in the form of silica.

Find more circular examples in Appendix A

Embedded impacts of excess materials

Figure 21 shows the embedded impact of the excess materials that are received by Processing company B. The amount of material in terms of its mass, is not the only, nor the best indicator to judge the necessity for reuse or recycling, as explained in chapter 2. The materials from MFA have been grouped under 4 main material categories to match them with impact factors. The embedded impacts of these material categories on the air, land and water have been indicated.* Figure 21 shows the relative share of each material in four categories; mass, land use, CO_2 eq. emissions and water usage. This shows that wood waste has a relatively big land, footprint, compared to its mass share. This analysis underlines the importance of making good use of "waste" materials as a lot of impact has been generated in mining, manufacturing and transporting them.

The analysis shows that while wood only forms 13% of the total mass of excess materials, these materials are responsible for about 75% of the land use footprint. On the next page, opportunities for wood (saw dust in this case) are further discussed. The embodied impact analysis also show that while mixed waste is just 11% of the total mass, it contains the majority of the carbon and water footprint. This makes it more urgent to improve utility of this stream. For mixed waste large value can be yielded from better separation at the source. Furthermore, waste sorting can improve usability of this stream (see example on the next page).

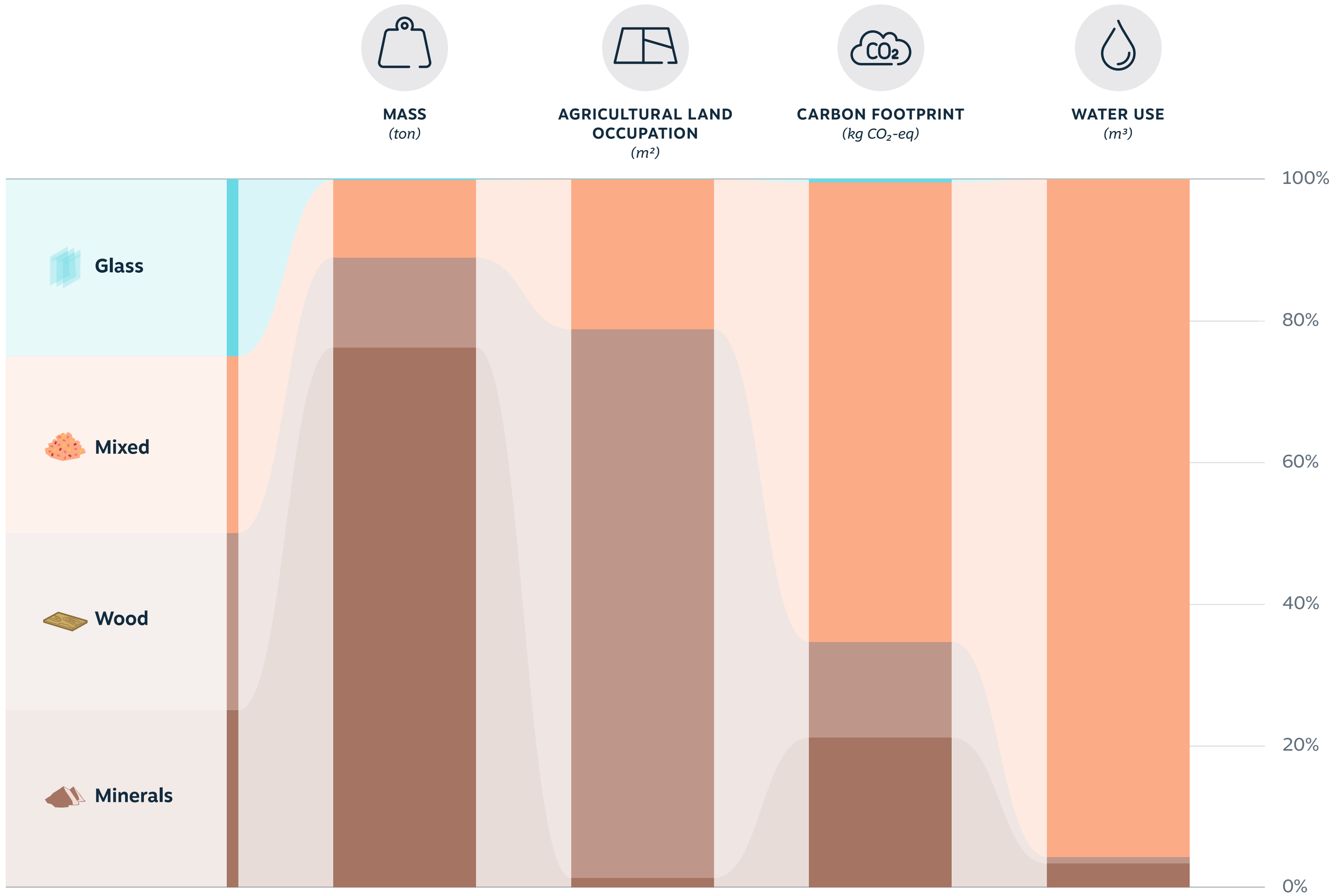


Figure 21
Impact graph showing the relative share of the different materials in terms of mass and three types of embedded impacts; land use, CO_2-eq. emissions and water usage.

**Please note the following: these are the embedded impacts and not the direct impacts of the processing method. Please refer to chapter 2 for an explanation.*

***Also note that these impacts are indicative as they are based on global averages. They are not specific for the region, and can thus not be used for monitoring.*

SORTING GENERAL

Mixed waste sorting to recover materials

Mixed Waste Sorting (MWS) processes are very useful to purify streams and thereby increase reuse and recycling opportunities and the ability to retain material value and avoid incineration. Examples of automated mixed waste sorting include waste processor AVR in the Netherlands, which separates plastic waste from mixed household waste streams. The company now recovers 12 times the amount of plastic for recycling with mixed waste sorting – an enormous boost in recycling rates and greenhouse gas reduction benefits. However, proper sorting at the source would of course avoid even more energy usage and thereby emissions, thus would be preferred first.

Opportunities

Opportunities for bottom ash and soil

A large quantity of bottom ash, 14,300 tons, arrives at the Processing company B, of which the majority is landfilled. There are different and more innovative ways to utilize bottom or ground ashes (see example on the right).

Besides this, it would be useful to investigate why a significant quantity (33,300 tons) of soil and mud is being landfilled. Possibly, this is to dilute and cover other landfilled materials (e.g. bottom ashes and asbestos). If these are recovered, the soil and mud can also be reused. In case of polluted soil, it would be relevant to look into purification methods to reuse the soil for construction projects or safely bring it back into natural ecosystems.

Opportunities

Opportunity to use sawdust

Currently, 16,200 tons of sawdust, an excess material from wood manufacturing, are being landfilled in 2023. There are many more opportunities for reusing sawdust, e.g. in composite materials for construction, as water remediator or as feedstock for biofuel. This research discusses several options. For examples of circular wood usage see appendix A.

MINERALS EXAMPLE

After incineration: secondary feedstock from ground ash from incinerators: Drainmix

At the request of the waste processor Suez Netherlands, a company developed a method to recover slag and ground ash from incinerators so that they can be processed into a water-buffering foundation as an alternative to primary raw materials such as sand and gravel. This method, called , and the produced secondary raw materials were successfully applied in the foundation of a schoolyard in the Dutch province of Limburg. In this way, the residue of household waste, which is normally incinerated by Suez, is offered again as a building material and a local cycle.

3.2.4 SUMMARY OF OPPORTUNITIES & LEARNINGS

These material flow analyses showed there are opportunities for more circular material usage for both processing company A and B in the port region of Eigersund. Besides this, there are general learnings with regards to the data gathering process that proved challenging in this case study. They have been summarized in this section.

Opportunities

Opportunities to increase circular material usage

Instead of primarily utilizing materials as fuel or landfilling them, there are opportunities to redirect them into more circular value chains. Using materials in a more circular manner enables closing loops regionally and retaining value. This has the potential to not only provide environmental benefits but also socio-economic benefits by reducing costs and improving resilience and independence. More circular applications exists for the different material streams processed by the two companies. Several examples have been provided throughout the report and all examples can be found in appendix A.

Minerals: *is currently landfilled can be sorted and recycled into secondary construction materials.*

Wood: *currently burned for energy can be reused or recycled into secondary construction materials. Alternatively, streams such as chips and sawdust can be used for biofuel production.*

Food-waste: *is currently incinerated and can be turned into compost (and biogas) using digestion methods to use for agricultural purposes.*

Asbestos: *can be treated by using novel technologies to decompose toxic substances, reuse compounds and avoid landfilling of toxic materials in proximity of natural areas.*

Bottom-ashes: *are currently landfilled but can be reused in construction projects for water buffering foundations.*

Mixed waste: *first aim should be to stimulate better separation at the source. Alternatively, sorting processes can be used to retain valuable materials for reuse and recycling.*

Opportunities

Opportunities for biofuel

- **Food-waste:** *if this stream is not suited for composting it can be used as feedstock for biofuel production.*
- **Wood:** *if excess wood (incl. sawdust) is not suited for reuse or recycling it can be used as feedstock for biofuel production.*

Learnings

- Data gathering proved more difficult for this case study than the other two due to the **lack of a national data register**. This is because Norway is not an European member state and thereby is not obliged to have a register with waste data from businesses. In order to support the transition it would be highly recommended to collect this data systematically using a harmonized way to label different material fractions like European Waste Catalogue (EWC) codes. In this way a register can be developed, perhaps first on a regional scale but preferably on a national scale. This will enable Norway not only to improve material circularity within the country, but will also improve international trade of excess streams.
- Due to the lack of data the current research has been **heavily data steered**. Perhaps different material streams are much more significant and thus relevant to focus on in the port region of Eigersund.
- **Material flow analysis is only the first step** in the process towards a more sustainable system and regional industrial symbiosis. Analyzing materials gives insights in the current status; which materials and what quantities are available. Next, collaboration and building local networks is needed to transition to a more sustainable way of working. The port organization already works closely together with several businesses in the port and aims to facilitate more exchange of energy and materials. Since much of the ground is owned by the port itself, this provides space for closing loops locally.

Port of Zwolle (The Netherlands)

Photo credits: Port of Zwolle ©

3.3.1 SCOPE

The Port of Zwolle is a collaboration of three ports; the port of Zwolle, Kampen and Meppel (see red dots in the map). All three ports are river ports and are closely connected. There is a lot of industry in the hinterlands of the ports. Therefore, as a scope for this material flow analysis, the industrial activities in the municipalities of Zwolle, Kampen, Zwartewaterland, Staphorst and Meppel were included (see orange area in the map).

The analysis includes all excess materials from companies that they dispose of and have been registered as waste. All companies in these five municipalities are taken into account, so not only the ones with direct port related business. This is done as the industry in the larger region has close ties to the ports, and the potential for industrial symbiosis between businesses therefore exists on a regional scale.

Data used

For the material flow analysis for port of Zwolle region, the Dutch national registry on waste data (LMA) was used. This database contains data on waste disposal by businesses on a municipal level. Different materials are classified using the European Waste Catalogue codes (EWC codes). Furthermore, the data specifies in which location what types and mass of waste materials are produced, as well as how they are being processed and by whom.

Excess materials produced by businesses

(based on data from 2022)

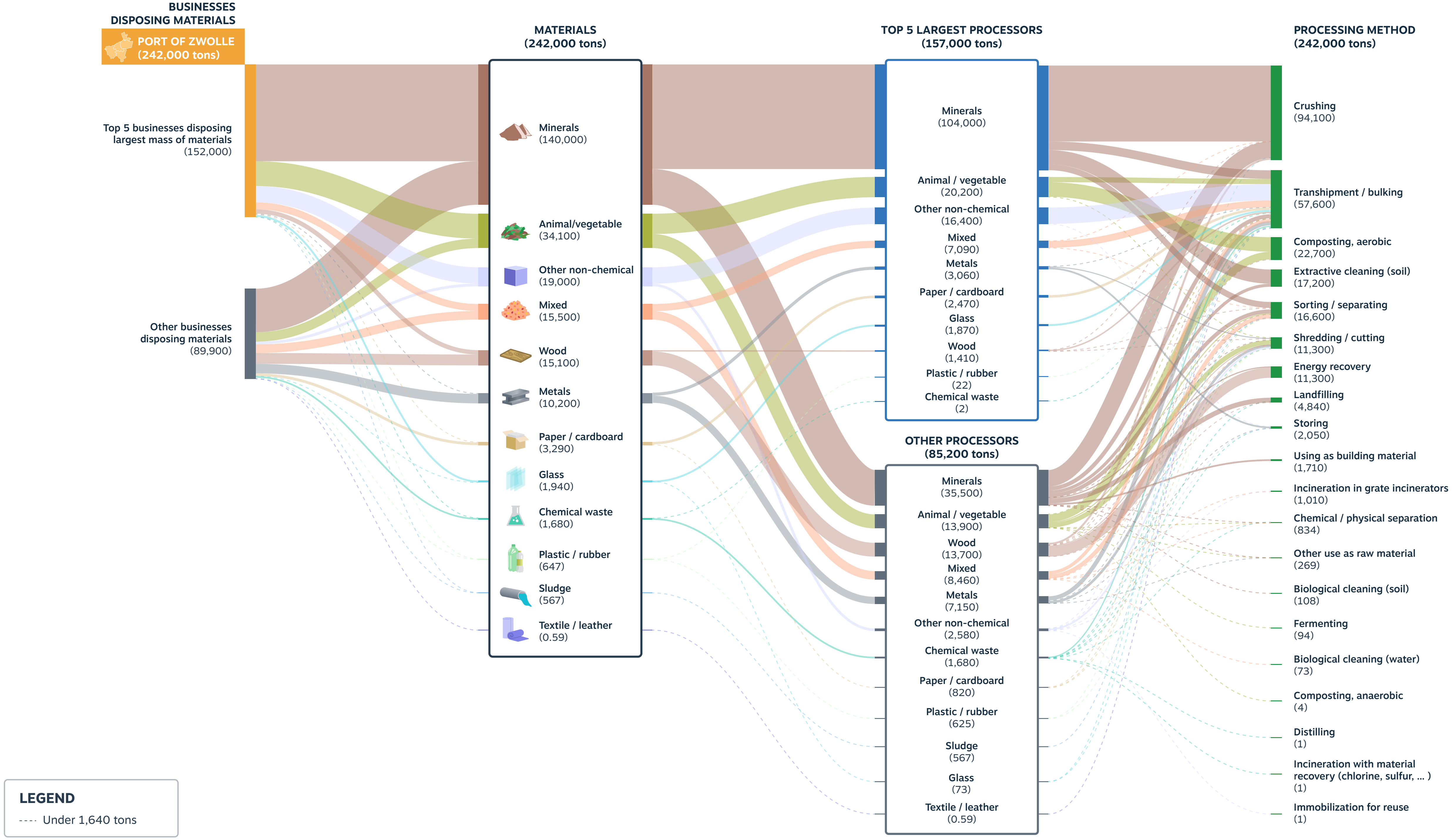


Figure 22 *Material flow analysis for the excess materials produced in the five municipalities encompassing the Port of Zwolle. From left to right it shows the sector of origin, the type of materials, the processors (split in the five largest and the others) and processing methods.*

Metabolic vives nice° REDII Ports Interreg North Sea Co-funded by the European Union

3.3.2 WASTE PRODUCED BY BUSINESSES IN THE REGION

The Material flow analysis (MFA) shows the excess of materials produced by the businesses in the five municipalities in the year 2022 (figure 22). On the left side it shows the businesses that dispose of "waste" materials. It is split into two groups; the 5 businesses disposing of the largest mass of materials, and all the other businesses. This gives an insight in the number of businesses disposing of the majority in terms of mass. This is relevant information for setting up new business models.

Next, it shows the total amounts of different materials types in tons. It shows who currently process these materials, again distinguishing between the 5 companies processing the largest amount and the others. And finally, on the right side, it shows which methods are used to process these materials. A total of 242,000 tons of materials were disposed of.

Businesses producing waste

The majority (63%) of all excess materials is disposed of by five businesses.

Material types

The main type of material that is disposed of is minerals (140,000 tons) (58%). Followed by animal/plant based materials (14%), non-chemical materials (8%) and mixed waste (6%).

Businesses processing waste

In terms of mass, the majority of waste materials are processed by five processors (65%). This provides potential opportunities for optimizing processing methods.

Processing methods

A large amount of materials (nearly all the minerals) is prepared for reuse through crushing processes (94,100 tons). Furthermore, the animal/vegetable material stream is largely being composted, potentially allowing for a high-value reuse of available nutrients and organic matter. Besides this, around 7% of the supplied excess materials end up being landfilled or incinerated and these materials are thereby lost from our economy.

Looking in more detail at impacts and organic materials

In the next sections the following will be discussed in more detail:

- the **embedded impacts** of the excess materials produced in the region (figure 23).
- the **sludge** produced and processed in the region and examples of using sludge in a circular way, e.g. retaining nutrients and using the rest as biofuel feedstock.
- the **plant/animal based organic materials** disposed in the region (figure 24, section 3.3) and examples of circular usage of organic materials;
- the excess **wood** flows in the region (figure 25, section 3.4)and examples of reuse, recycling and biofuel.

A specific analysis was made to look at organic materials (plant/animal based, sludge, wood) in more detail to identify circular opportunities and also specifically look for opportunities for biofuel feedstocks, one of the objectives of this research that will feed into other parts of the REDII Ports project (see figure 2, chapter 1).

Embedded impacts of excess materials

Figure 23 shows the embedded impact of the excess materials produced in the region. The amount of material in terms of its mass, is not the only, nor the best indicator to judge the necessity for reuse or recycling, as explained in chapter two. The embedded impacts of these materials on the air, land and water have been indicated.* Figure 23 shows the relative share of the different materials in terms of mass and three types of embedded impacts; land use, CO_2-eq. emissions and water usage.

Although minerals account for the majority of disposed materials in terms of mass (58%), their share of the total embedded impacts is relatively small. On the contrary, disposed wood as well as paper and cardboard products account for a large share of the total land footprint (30% and 20%) (more on wood in section 3.4). Other non-chemical materials account for 8% of the total material mass, however they make up the largest share of both the carbon (over 50%) and water (over 40%) footprints. Similarly, metals have relatively large share in the carbon (over 20%) and water footprint (over 10%) compared to their mass (4%).

This underlines the importance of using these materials as long as possible, and after that reusing and recycling them. If we want to decrease our impact on the environment, we will have to reduce the need for newly extracted materials. Furthermore, the focus should first be on reducing the demand and extending the lifetime, as recycling also costs a lot of energy and is thus not the quickfix towards sustainability either.

Figure 23 Impact graph showing the relative share of the different materials in terms of mass and three types of embedded impacts; land use, CO_2-eq. emissions and water usage.

*Please note the following: these are the embedded impacts and not the direct impacts of the processing method. Please refer to chapter 2 for an explanation.

**Also note that these impacts are indicative as they are based on global averages. They are not specific for the region, and can thus not be used for monitoring.

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Opportunities

Opportunity with Sludge

Sludge constitutes a relatively small share of the total disposed mass of materials by businesses in the wider port region; 567 tons of sludge were disposed of in 2022. The majority of sludge was disposed of by five companies (99%). The majority of sludge is iron-lime sludge (87%). The rest is sludge released during the (mechanical) cleaning of sewers, gullies and pumping stations (in Dutch RKG slib), and can contain oil residues, heavy metals and PAH.*

All sludge is processed by less than five companies. According to the data this is all bulked/transhipped and the data does not show what happens after this. Currently, in the Netherlands, sludge is mainly incinerated. By national law, usage of sludge for agricultural applications is not allowed, in contrast to other European countries (e.g. Italy). This is a missed opportunity as sludge contains many valuable nutrients. There are several high-value applications that utilize the different nutrients that are available in sludge streams. After re-winning the nutrients, the rest of the organic material can be used as biofuel feedstock (see example). As explained in chapter 2, biofuel is preferred over incineration (see figure 7, chapter 2). The sludge might contain contamination can potentially be cleaned (see example). More examples in Appendix A.

SLUDGE EXAMPLE

Creating agricultural inputs and biofuels from sludge

Burning sewage sludge releases CO_2. Minimizing the amount of sludge burned will therefore contribute to climate goals. To prevent the incineration of sludge, a Dutch consortium has been investigating high-quality processing techniques, whereby valuable raw materials can be recovered from the sludge. In this pilot, the sludge is processed through biological drying. Composting is used to dry the sludge to produce biogranulate and ammonium sulfate. The biogranulate is used as a biofuel for generating renewable energy. The ammonium sulfate is a nitrogen-rich fertilizer that is often used locally by farmers and will be disposed of there.

**NB. Please note that the details provided here for sludge are not directly readable in the MFA (figure 22). They have been extracted from the dataset itself.*

SLUDGE EXAMPLE

Utilizing symbiosis between sludge micro-nutrients and cleaning plants

Sludge can contain pollution in different shapes, depending on its origin. *RESANAT*, another European Interreg project in Flanders and the Netherlands, is experimenting with phytoremediation. This is a process in which certain plants and microorganisms capture, remove and convert contaminants in sludge. The nutrients from the burned sludge thus partially enter the plants, allowing the nutrients to be used multiple times. The cultivated plants can potentially be used as biomaterials for new products in the construction or manufacturing industry and as energy crops. The pilot is investigating ways in which the sludge can be purified, converting the pollutants into nutrients for the plants, which could be used as building materials.

Organic excess materials produced by businesses

(based on data from 2022)

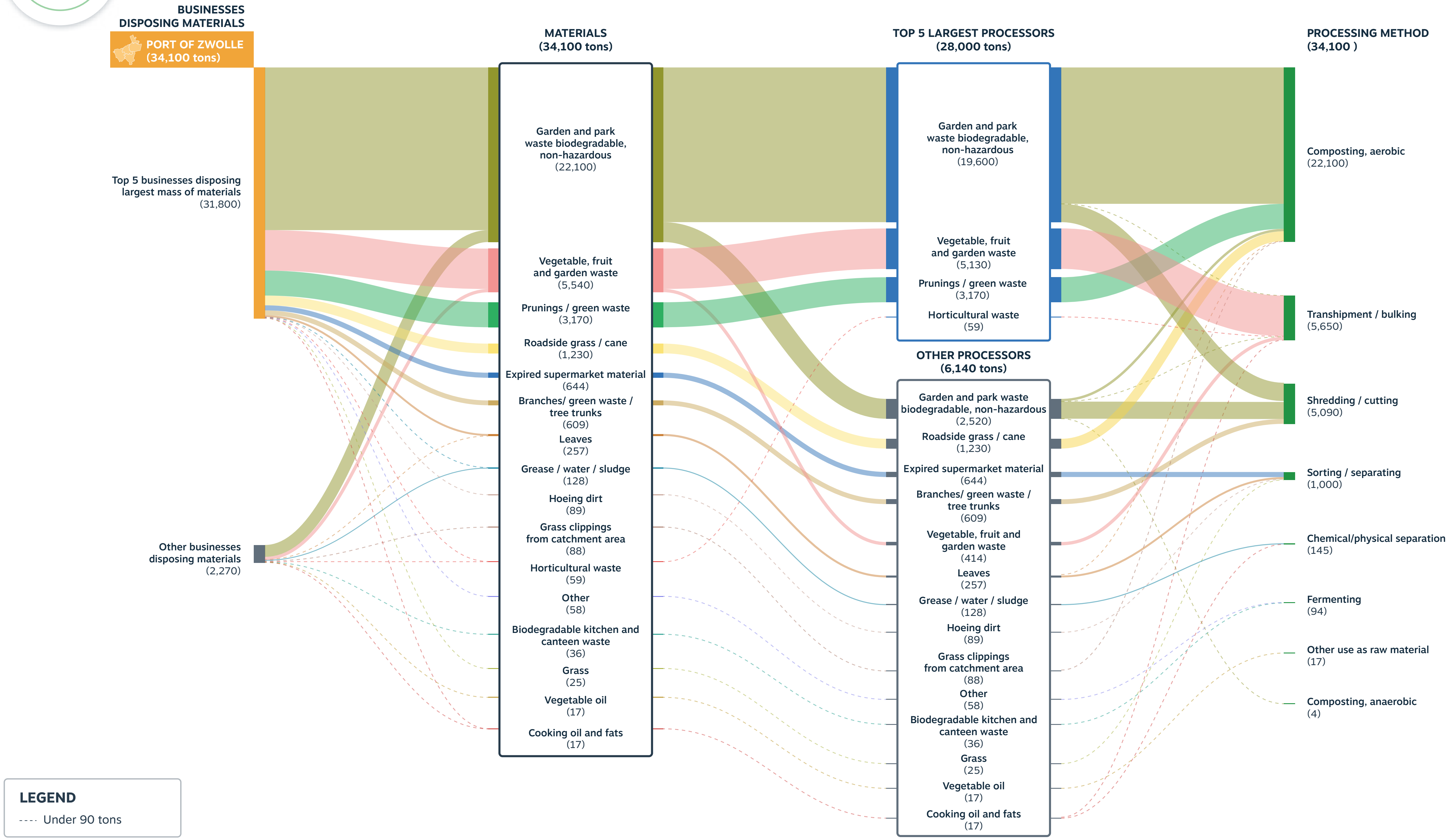


Figure 24 *Material flow analysis for the organic excess materials (excl. wood and sludge) produced in the five municipalities encompassing the Port of Zwolle. From left to right it shows the sector of origin, the type of materials, the processors (split in the five largest and the others) and processing methods.*

3.3.3 ORGANIC WASTE PRODUCED BY BUSINESSES IN PORT OF ZWOLLE REGION

This material flow analysis (MFA) takes a closer look at the ***organic*** materials (excl. wood and sludge) disposed of by businesses in the region around port of Zwolle (figure 24). It is a zoom in on the animal/plant based flow of the MFA of section 3.2 (figure 22). This is done because besides circular opportunities, one of the objectives is to identify potential biofuel feedstocks (see chapter 1).

On the left the businesses are divided in the five disposing the largest mass of organic materials and all other businesses. Next the materials are grouped by type of material. The level of material detail used in this MFA is the full six digit European Waste Catalogue (EWC) codes. Finally on the right it shows how these materials were processed. In 2022 a total of 34,100 tons of organic excess materials were disposed of in the region.

Businesses disposing organic materials

The large majority of organic materials is disposed of by five businesses in the region (93%).

Material types

The main type of material that is disposed of is Park and Garden materials (biodegradable, non-hazardous) (65%). Followed by Vegetable, fruit and garden waste (GFT) (16%) and Prunings / green waste (9%).

Businesses processing waste

The majority of organic materials are processed by five processors (82%).

Processing methods

The majority of organic materials is being composted (aerobic digestion) (65%), mostly garden and park waste and prunings/green waste. Next, a large amount is being stored (17%), mostly kitchen waste, and preprocessed by shredding or cutting (15%), mostly garden and park waste. The data does not indicate what happens to these materials next but they are likely to be reused or recycled as it would otherwise not be worth the storage or preprocessing efforts. Finally, only a small fraction of organic materials is being fermented (0.2%) or anaerobically digested (0.01%).

Opportunities

Other opportunities with organic residual streams

There are ample opportunities to reuse organic excess material streams at high-value stages. While composting is great to close nutrient loops, organic streams can also be upcycled into novel products such as building materials (example on the right). Some residual streams such as coffee-grounds can also directly be used to grow for food without composting. Used cooking oils and fats can be used as a feedstock for biofuel (see examples on next page).

ORGANIC EXAMPLE

Using roadside grass for biobased building materials

Parties in the Dutch province of North-Holland, have joined forces to develop an innovative chain where green waste is collected and converted into a high-quality building material: *GrassBloxxx*. Under that name a plant will process fibers from roadside grass into insulation mats. The released salty juices can be used as a circular de-icing agent.

Other ways of upcycling organic waste like grass could for example be the application of these streams in the creation of office gear. Roadside grass can be used to make office furniture. The furniture manufacturer VEPA, based in the Dutch town of Hoogeveen, produced in 2018 the first furniture from verge grass and has invested €10 million to explore further possibilities research and develop products. In the production of the boards, no glue but only natural materials as a binding agent so that it is a 100% organic material.

Find more circular examples in Appendix A

ORGANIC EXAMPLE

Creating novel products from residual food processing streams

Circle of Food, in the Dutch town of Meppel, processes residual streams from the food industry and temporary surpluses into circular and tasty food, e.g. oyster mushrooms grown on coffee grounds. In addition, Circle of Food supports local entrepreneurs by mapping organic "waste" streams streams in companies and developing an appropriate product with them from these excess materials.

BIOFUEL EXAMPLE

Turning used frying oil into biodiesel

Used frying and cooking oil can be used as a feedstock for the production of biofuel. In the harbour of Kampen the company *Sunoil Biodiesel* is located. They produce both pure bio-diesels, as well as diesel blends where a certain percentage is biodiesel and the rest is fossil fuel based. A by-product of this process is glycerine, which can be used again in the pharmaceutical or food industry or as an input for biogas installations, while this is least preferred.

Around the '00, the usage of biodiesel was stimulated strongly by the German government. Regulations had been created that required a certain percentage of biodiesel to be added to every regular diesel fuel and pure bio-diesels were tax free. These regulations helped create an attractive playing field, which is important for new business development.

How regulations and policy decisions can make high-value cycling of organic materials difficult

In this box a particular case will be discussed that came forward during a project meeting with partners of the harbour. In Kampen there is a recycling company that collects food and feed that has been damaged in some form (too hot, wet, polluted etc.). These are mostly bulk food/feed like grains, soy, cacao, coffee. These batches of food/feed are considered damaged and therefore not suitable for consumption anymore. At the same time, it is also not considered waste and therefore they are not tracked in the national database (LMA). Yearly, the recycling company processes about 100,000 tons of damaged food/feed. Currently, all this food/feed is anaerobically digested and composted afterwards. However, the recycling company would like to retain more value from these materials by e.g. extracting the oils from soya beans or their starch for the food production industry. However, current legislation on food-safety makes this type of valorization not possible.

Simultaneously, there is a sharp increase throughout Europe in demand for biomass to be used in biogas facilities. The question arises how we would like to utilize organic "waste" streams. From a circular economy perspective, they are reused at the value stage that offers the most environmental and societal benefits, thereby reducing the need for new primary inputs that need to be grown, harvested and processed again with the consequential impacts on the environment and society.

Such preferences might however be hampered by double incentives, e.g. due to demands from biogas facilities. The higher the need for biomass, the more these facilities will be willing to pay for these residual streams. This makes alternative businesses cases (that possibly retain more material value) increasingly difficult. Ultimately, these biogas facilities can create lock-in effects where even if we manage to reduce our foodwaste, they require organic material to keep them running. This means that choices have to be made on a governance level with relation to the sustainability transition as a whole (energy and materials) and the consequences this has for the impact we (want to) make.

Learnings from this:

- Currently there is little insights into such non-waste streams as they remain undocumented, this makes it more difficult to know what amounts are available for higher value cycling.
- The current regulations are not always helping to facilitate the transition towards a circular economy yet. Safety and circular opportunities need to become more balanced.
- Biofuel plants might create a lock-in effect requiring lots of biomass making prevention and valorization of organic materials less attractive giving the wrong incentive for the overarching sustainability transition. This is where the energy and the material transition need to collaborate rather than compete.

Opportunities

Using existing laws and regulations to accelerate the transition

The platform CircuLaw aims to provide (local) governments insights in existing laws and regulations and how they can be used to enable and accelerate the circular economy. Also, new (upcoming) European laws that are developed within the Green European Deal are explained here, e.g. EPR, CSRD, SUP and ESPR. Currently the website is in Dutch but an English version is coming in 2024.

Wood excess materials produced by businesses
(based on data from 2022)

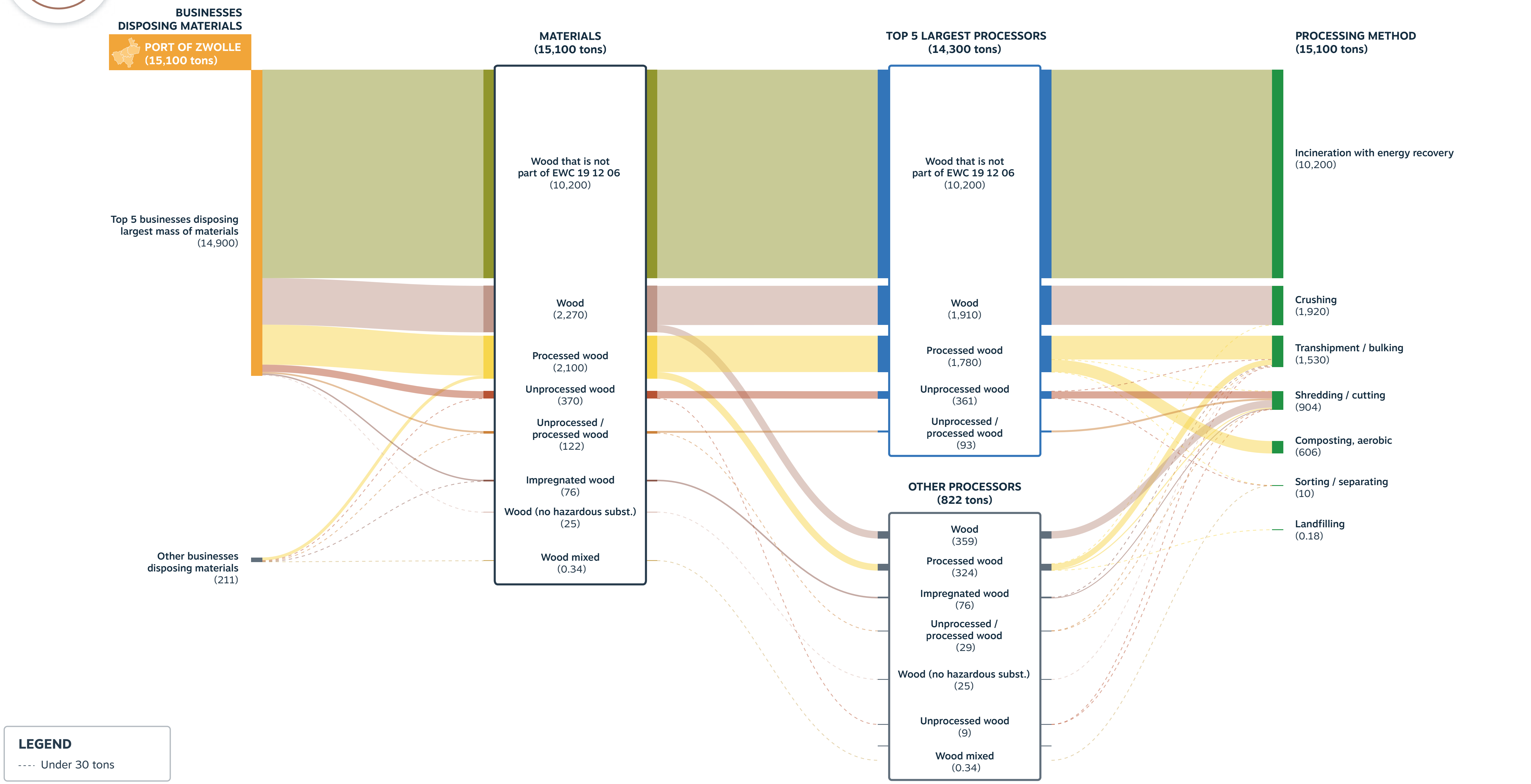
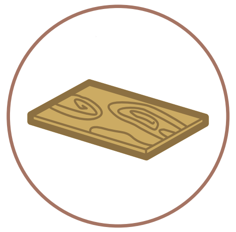


Figure 25 *Material flow analysis for **wood** excess materials produced in the five municipalities encompassing the Port of Zwolle. From left to right it shows the sector of origin, the type of materials, the processors (split in the five largest and the others) and processing methods.*



3.3.4 WOOD EXCESS MATERIALS PRODUCED BY BUSINESSES IN PORT OF ZWOLLE AREA

This material flow analysis (MFA) looks specifically at excess wood produced by businesses in the port region in 2022 (figure 25). It is a zoom in on the wood flow of the MFA of section 3.2 (figure 22). This is done because besides circular opportunities, one of the objectives is to identify potential feedstocks for biofuels (see figure 2, chapter 1).

A total of 15,100 tons of excess wood materials were disposed of. On the left side of the MFA, the businesses are shown, divided by the five disposing off the largest mass (in tons) of materials, and the others. Followed by the different types of wood, the processors and the processing methods.

Businesses disposing organic materials

The five business that dispose of the largest amounts of wood, together dispose of nearly all the wood (99%).

Material types

About two thirds (68%) of the wood that is discarded in the region, is categorized under the code “Wood that is not part of EWC 191206”. This means that the wood does not contain hazardous substances (as wood under EWC code 191206 does) but can also not be categorized under one of the other codes.

The other wood categories with substantial mass are Wood (15%) (characteristics are not specified but it is non-hazardous) and Processed wood (14%) (also called B-Hout in Dutch) which means it has been glued (e.g. plywood), painted or varnished.

Businesses processing waste

The 5 companies that process the largest amounts of wood, process nearly all the wood (95%) that is disposed of in the region. The fact that it's a selective number of companies both in terms of disposing and processing the wood in this region, makes it more feasible to get in contact with the right stakeholders to form a consortium and collaborate on alternatives.

Processing methods

The majority of the wood (68%) (all the “Wood that is not part of EWC 191206”) is incinerated with energy recovery, but the materials are lost from our economy. This provides potential opportunities for more circular usage to retain material value. This is further discussed in the box on the left and the next page.

Besides that, 19% of the different types of wood is being preprocessed by crushing, shredding/cutting and sorting/separating. Another 10% is bulked/ transhiped and it is not known what happens after this storage. Finally, 4% is being composted and a small fraction is landfilled.

Opportunities

Circular opportunities with wood

Currently, excess wood is often used as an energy source. There are other options to recycle wood at a higher-value and greater contribution to ecosystems and economies that can be utilized first. Eventually, at the end of the second, third or fourth cycle, when reuse or recycling is no longer feasible, wood can still be used for energy recovery but until that time we prefer to retain wooden materials at higher value.

Excess wood streams can be used to create products that would otherwise require harvesting new primary materials i.e. cutting down trees and processing them into products. Reusing and recycling wood can decrease primary material demands and thereby the impact on the environment that their harvesting and processing has. On the next page two examples can be found, the first one showing how hubs can facilitate reuse and the other how wood can be refurbished and recycled into new materials and products. Also the opportunity for biofuel feedstock is discussed.

Opportunities

Opportunity for biofuel when reuse and recycling is not feasible

If reuse or recycling of wood are not possible anymore, either due to hazardous substances or contamination that can not be removed, or material quality (e.g. if materials have already been cycled multiple times and it is technically not possible anymore to recycle them another time), then we want to look into opportunities to recover the energy from the materials (see organic processing hierarchy figure 7, chapter 2). This can either be done by anaerobic digestion which provides both energy and compost for afterwards. However, if it is not possible to compost the wood due to hazardous substances or contamination, it would be relevant to look into biofuel options.

For this region, in particular the fraction labelled "Wood that is not part of EWC 191206" seems to have potential as a feedstock for biofuel as it is currently incinerated and has a substantial mass (10,200 tons in 2022). Biofuel is preferred over incineration as we have other means to generate green electricity like solar, wind and hydropower (further discussed in chapter 2).

Find more circular examples in Appendix A

WOOD EXAMPLE

Wood hubs with secondary building materials

In the port of Rotterdam there is the woodhub Buurman which provides secondary building materials that have been harvested/reclaimed from demolition or deconstruction. These secondary materials are more affordable than primary and help reducing environmental impacts by reducing demand for primary materials. Their customers are both businesses and consumers. They also have a workshop where people can borrow tools and repair or create wooden furniture and other structures. They occasionally provided courses to educate people. Craftsmanship and repair skills are very useful in a circular economy.

In the port of Kampen, Weever Circulair has also started a woodhub with wood reclaimed from circular demolition. They mainly sell to businesses that use the wood for larger construction projects.

WOOD EXAMPLE

A diversity of products can be made from recycled wood

In Italy, the Rilegno association between different wood recycling entities, produces a wide range of different products from the retrieved wood residuals. For example, particleboard and MDF panels are produced, together with pulp for paper mills, wood-concrete composites for construction and pallet elements. In this way, wood is cycled multiple times before ending up as an energy source, in the meantime potentially reducing the need for primary materials.

3.3.5 SUMMARY OF OPPORTUNITIES & LEARNINGS

These material flow analyses showed there are many opportunities for circular material usage for the industries in the five municipalities surrounding the Port of Zwolle. Using materials in a more circular manner enables closing loops regionally and value retention. This has the potential to not only provide environmental benefits but also socio-economic benefits by reducing costs and improving resilience and independence.

Opportunities

Opportunities for biofuel

- *If reuse or recycling is not feasible, the waste fraction labelled "Wood that is not part of EWC 191206" (10,200 tons) could potentially be interesting for biofuel feedstock rather than its current incineration.*

Opportunities

Opportunities to increase circular material usage

Sewage sludge: *Currently burned for energy (releasing CO_2), it can be processed to recover nutrients for agriculture, capture biogas and create biofuel feedstock.*

Contaminated sludge: *Instead of disposal, phytoremediation uses plants and microorganisms to clean and convert nutrients, for agriculture or biobased building materials.*

Food waste: *Beyond composting, excess can be used to create nutritious food-products from food industry leftovers. This can support local businesses in utilizing their own "waste" streams.*

Organic waste: *Closed-loop composting systems transform organic waste into high-quality compost, fertilizer, and even resources for greenhouse cultivation, minimizing waste while conserving nutrients.*

Wood reusing: *circular demolition and deconstruction helps reclaim wood. Wood hubs can provide these secondary materials in an affordable way, reducing both costs and environmental impacts.*

Wood recycling: *companies are recycling excess wood in various products, including chipboards, MDF panels, pulp for paper, wood-concrete composites for construction, and even pallet elements.*

Learnings

- Currently there is **little insights into non-waste material streams** (by-products and rejected streams) as they remain largely undocumented, this makes it more difficult to know what amounts are available for higher value retainment.
- The current laws and regulations are not always helping to facilitate the transition towards a circular economy yet. A balance needs to be found between safety and circular opportunities. Governments need to help creating **a level playing field for the circular economy.**
- Similarly, the current tax system makes secondary materials relatively more expensive than primary materials due to higher taxes on labour. **The current tax system supports the old linear system** and thereby slows down the transition in particular for repair and recycling.
- **Biofuel plants might create a lock-in effect** requiring lots of biomass which makes the valorization of organic materials at a higher level less beneficial giving the wrong incentive for the entire transition. This underlines that the energy and material transition need to collaborate rather than compete.
- **Material flow analysis is only the first step** in the process towards a more sustainable system and regional industrial symbiosis. Analyzing materials gives insights in the current status; which materials are available and how much. From here building local networks is needed to transition to a more sustainable way of working.

04 Learnings & Conclusions

Photo credits: Port of Skagen©

LEARNINGS & CONCLUSIONS

This research with its three case studies showed that there are many opportunities for more circular material usage in general, and in case no higher value options are possible, potential feedstocks for biofuel. In general, ports have a key role to play in the transition to reach our sustainability targets and return our economy within the safe operating space of the planetary boundaries. Due to their central role in global trade and transport of materials, as well as the processing of materials in ports and their hinterlands, there are major opportunities for renewable energy and circular material usage. The transition towards clean energy and closing material loops should go hand in hand to avoid negative side effects or lock-ins.

In this conclusion, first the learnings and implications in relation to the material flow analysis done for the three case studies will be discussed. Besides the main results, the learnings related to the data needed and used are also presented. This is followed by a short reflection upon external conditions and challenges outside the ports influence, whilst noting the necessity for a holistic transition. Next, looking forward, it is discussed how the role of ports can change to support the transition towards a circular economy. Finally, it has to be remembered that material flow analysis is really only a first step, both in the larger REDII Ports project and for the transition in general.

Analyzing excess materials in the ports

This research consisted of three case studies on excess material ("waste") flows in the ports of Skagen (Denmark), Eigersund (Norway) and Zwolle (the Netherlands). The analyses showed that each port has a large amount of materials that are currently labelled as "waste" but are actually still resources that can be valorized by reusing or recycling them. Each port has numerous opportunities for more circular material usage. As discussed in chapter 2, a circular approach contains a hierarchy for using materials to retain most value. If reuse or recycling of materials is no longer possible, certain materials could potentially be used as a biofuel feedstock.

For example, in the Port of Skagen region, there are opportunities to regain materials from mineral waste streams by deconstruction and reuse or recycle wood, sludge and animal-tissue, or alternatively use them as biofuel feedstock. In the Port of Eigersund, opportunities for food-waste and wood reuse and recycling were highlighted. In the port of Zwolle region there is in particular an opportunity to reuse or recycle excess wood to retain higher value, or alternatively use it as biofuel feedstock.

Data learnings from case studies

The three case studies clearly revealed several data limitations and learnings.

Lack of national data registry in Norway

In the case study for Port of Eigersund, there was very little data available. This is because Norway is not an European member state and thereby is not obliged to have a national registry with waste data from businesses.

In order to support the transition to a circular economy, and resource exchange and symbiosis in particular, it would be highly recommended to develop a national registry and adopt a harmonized coding such as the European Waste Catalogue (EWC) codes.

Data steered research

The scope of the case studies was heavily determined by the data available for the region, making the cases strongly data-steered. Some countries had data available on the sources/origin of the excess materials, sometimes in the form of companies by name, other times by sector. Furthermore, some datasets specified the location where the waste was produced/disposed, and others also where it was processed. This was not consistent and gave the different case studies different angles and focus points.

Only materials registered as waste

The available data was only on materials registered/labelled as waste. This does not include non-authorized waste, by-products nor resources that could potentially be reused or recycled at higher value. There are many material flows that are losing value that are currently not registered as waste and therefore not included in this research. This lack presented itself both in the case study for Port of Skagen and Zwolle.

External conditions for the transition

The case studies brought forward several learnings relating to external conditions, outside the direct sphere of influence of the ports, that are important for the success and speed of the transition.

Current laws and regulations are not always helping to facilitate the transition towards a circular economy yet. For example, strict laws around food and feed are hampering the reuse of food-substances from rejected batches as discussed in case study 3. In these cases there exists a general need to find a balance between safety and circular opportunities. Another example of such a barrier is the current tax system, which makes secondary materials relatively expensive compared to primary materials, as labour is taxed more heavily. Circular activities like repairing, deconstruction, sorting and recycling materials require labour within the region. The relatively high taxes on labour in North-Western Europe thereby create higher costs when compared to primarily extracted materials processed elsewhere, and therefore form a barrier for the transition to the circular economy.

In order to create a level playing field the European Union is swiftly developing new rules and regulations to help steer countries into the right direction under the umbrella of the Green European Deal. Analyzing materials and starting conversations with stakeholders to create strong sustainable local networks will help ports and surrounding businesses adapt to new and upcoming European regulations and thereby become more futureproof.

Energy and material transition need to go hand in hand

Several examples came forward during these case studies that underlined the importance for a holistic systemic approach to avoid negative side effects or lock-ins. Think about the high energy demands for recycling, biomass plants demanding feedstock and thereby land-use to grow it, critical materials needed for products for the clean energy production such as solar panels. Recycling is not per definition the golden solution when moving towards a circular system, as it requires high energy demands and in turn might increase the need for raw materials to produce this energy. The energy and material transitions should therefore collaborate rather than compete. Above all, a major reduction in material and energy usage is needed in order to succeed in the general sustainability transition and return within the planetary boundaries, whilst creating a balanced economy.

Port companies transition into a new role

The transition to a sustainable economy provides, or arguably even requires, an opportunity for port organisation to pick up a new role. Currently, most port companies have the role of managers or administrators. In the transition they can (or need to) take up the role of facilitators or even accelerators to support the transition towards renewable energy and circular material usage. Such a new role requires additional expertise and close-knit collaboration with the industry in the port and its hinterlands. It also requires collaboration with (local) governments to create a level playing field.

Material flow analysis is a first step

As mentioned in chapter 1 (figure 2), this research is only the first step in the larger REDII Ports project. The insights of these analyses will be used to further develop strategies for the ports and identify business opportunities, in particular for biofuel production (follow further developments through the *project website*). Such interventions would not only locally have impact, but can potentially be scaled internationally as many ports have similar functions and needs.

Not only in this REDII Ports project, but also for the transition towards a fundamentally sustainable economy, material flow analysis (MFA) is only a first step. Analyzing materials gives insights in the current status and opportunities. More important is the building of strong regional networks and the fostering of collaborations in order to transition to a new more sustainable way of operating, as shown by the example of Kalundborg. Closing loops for materials, water and energy locally has both economical, social and environmental benefits as it reduces negative impacts and saves costs. There are further benefits for increased resilience and regional independence.

Beside creating circular systems for excess materials (“waste”), the aim should be to improve resource usage more broadly to balance it with the planet’s regenerative capacities. Currently, materials, water and energy are not always used in optimal ways but below their value potential. There are great benefits to be gained economically and environmentally by reducing and optimizing resource usage. The transition towards a circular economy is key for reaching sustainability goals such as the paris agreements and SDGs, by keeping our economy within planetary boundaries - there is a world at stake.

APPENDIX A

In this appendix all examples for circular materials usage in practice that have been given throughout the report can be found.

Sorting	Minerals	Wood	Organic materials	Sludge	Biofuel

SORTING EXAMPLES TO ENABLE CIRCULARITY

Sorting materials to have mono-streams rather than mixed streams is extremely important for the ability to reuse and especially recycle them. Two examples have been highlighted here.examples have been highlighted here.

SORTING GENERAL

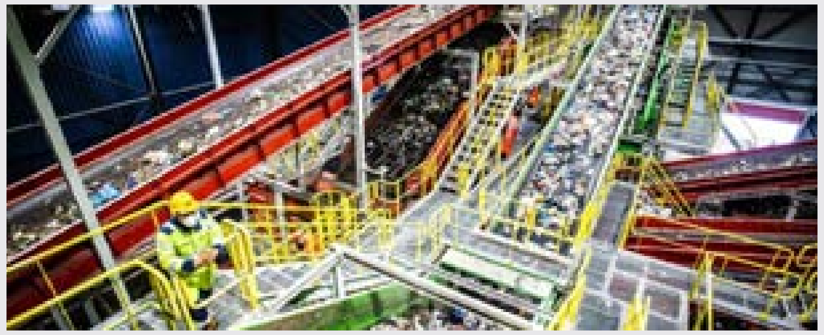
Circular demolition or deconstruction

Circular demolition is carefully deconstructing or disassembling structures and buildings rather than demolition that destroys and mixes all materials. By carefully dismantling structures, materials like steel, wood, and concrete can be recovered at higher quality and reused or recycled at higher value. Increasingly, traditional demolition companies transform themselves and start providing circular services and skills. For example, *Tscherning* in Denmark or *Heezen BV* in the Netherlands.

SORTING GENERAL

Mixed waste sorting to recover materials

Mixed Waste Sorting (*MWS*) processes are very useful to purify streams and thereby increase reuse and recycling opportunities and the ability to retain material value and avoid incineration. Examples of automated mixed waste sorting include waste processor *AVR* in the Netherlands, which separates plastic waste from mixed household waste streams. The company now recovers 12 times the amount of plastic for recycling with mixed waste sorting – an enormous boost in recycling rates and greenhouse gas reduction benefits. However, proper sorting at the source would of course avoid even more energy usage and thereby emissions, thus would be preferred first.



CIRCULAR EXAMPLES FOR MINERALS

Currently, excess minerals or mineral waste is often landfilled or used as fuel. However, there are other options to recycle minerals at a higher-value and greater contribution to ecosystems and economies. Three examples have been highlighted here.

MINERALS EXAMPLE

Utilizing new processing techniques to enable the reuse of construction minerals

By utilizing more advanced techniques of 'crushing' or processing the rubble resulting from demolition in the built environment, sand, gravel and other materials can be obtained in a state where reuse in the built environment at a similar value to novel products, is possible. An example of this process is proposed by so-called '*Smart-Crushers*' which utilize techniques to keep different components of concrete rubble intact during processing, enabling a conversion where it might be possible to create almost climate neutral new concrete from concrete waste.

MINERALS EXAMPLE

Taking care of toxic substances in waste mineral flows: neutralizing asbestos

In some of the case study ports, asbestos is part of the minerals waste stream. This toxic substance is often mixed with different building materials, which are often disposed of together. Health implications of this material resulted in a ban in NL. Until now these materials were landfilled. However, in recent years novel technologies have developed to process asbestos. Since 2017, *Asbeter* has been developing an innovative process in which asbestos is processed. In 2018, the Rotterdam-based company launched an experiment for processing of asbestos cement corrugated sheets started with the first pilot installation. In this plant, asbestos is processed with residual products from other companies on the same industrial park. The asbestos and recovered cement are to be processed in the plant into new building material in the form of silica.

MINERALS EXAMPLE

After incineration: secondary feedstock from ground ash from incinerators: Drainmix

At the request of the waste processor Suez Netherlands, a company developed a method to recover slag and ground ash from incinerators so that they can be processed into a water-buffering foundation as an alternative to primary raw materials such as sand and gravel. This method, called *DrainMix*, and the produced secondary raw materials were successfully applied in the foundation of a schoolyard in the Dutch province of Limburg. In this way, the residue of household waste, which is normally incinerated by Suez, is offered again as a building material and a local cycle.

CIRCULAR EXAMPLES FOR WOOD

The three case studies showed that excess wood is currently often incinerated with energy recovery. However, there are other options to reuse and recycle wood at a higher-value and greater contribution to ecosystems and economies. Three examples have been highlighted here.

WOOD EXAMPLE

Wood hubs with secondary building materials

In the port of Rotterdam there is the woodhub *Buurman* which provides secondary building materials that have been harvested/reclaimed from demolition or deconstruction. These secondary materials are more affordable than primary and help reducing environmental impacts by reducing demand for primary materials. Their customers are both businesses and consumers. They also have a workshop where people can borrow tools and repair or create wooden furniture and other structures. They occasionally provided courses to educate people. Craftsmanship and repair skills are very useful in a circular economy.

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WOOD EXAMPLE

A diversity of products can be made from recycled wood

In Italy, the *Rilegno* association between different wood recycling entities, produces a wide range of different products from the retrieved wood residuals. For example, particleboard and MDF panels are produced, together with pulp for paper mills, wood-concrete composites for construction and pallet elements. In this way, wood is cycled multiple times before ending up as an energy source, in the meantime potentially reducing the need for primary materials.

WOOD EXAMPLE

Upcycling wood scraps into novel products

The global interior manufacturer *Unilin*, produces large parts of its chipboards with recovered wood. This excess wood comes from streams delivered by other industries, but also a share from households. Thanks to a combination of techniques (magnets, wind sifters, centrifuges, infrared, etc.), impurities from the residual streams can be removed from the wood residual streams. These impurities are collected and then also find their way to other industries to be reused or recycled.

CIRCULAR EXAMPLES FOR ORGANIC EXCESS

The three case studies showed that organic excess materials are usually composted (which is preferable) or used as energy source (which is less preferable, see hierarchy in chapter 2). Before turning to biofuels or incineration, there are other options to reuse and recycle organic materials at a higher-value and greater contribution to ecosystems and economies.

ORGANIC EXAMPLE

Using organic residual streams to improve soil health

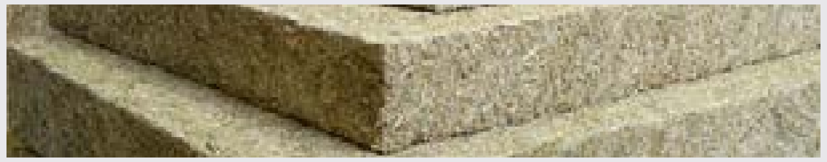
In Denmark, *ComFerm ApS* is pioneering a closed and automated composting facility. The goal of this user-friendly system is to empower growers or grower groups to produce compost locally or at a company level. Simultaneously, it aims to conserve nitrogen that would otherwise be lost through leaching by converting it into a concentrated fertilizer. The ComCrop facility operates as a fully enclosed system, transforming local waste streams into soil enhancers and high-quality by-products such as CO_2 and heat for greenhouse cultivation, clean water, and ammonium fertilizer.

ORGANIC EXAMPLE

Using roadside grass for biobased building materials

Parties in the Dutch province of North-Holland, have joined forces to develop an innovative chain where green waste is collected and converted into a high-quality building material: *GrassBloxxx*. Under that name a plant will process fibers from roadside grass into insulation mats. The released salty juices can be used as a circular de-icing agent.

Other ways of upcycling organic waste like grass could for example be the application of these streams in the creation of office gear. Roadside grass can be used to make office furniture. The furniture manufacturer VEPA, based in the Dutch town of Hoogeveen, produced in 2018 the first furniture from verge grass and has invested €10 million to explore further possibilities research and develop products. In the production of the boards, no glue but only natural materials as a binding agent so that it is a 100% organic material.



ORGANIC EXAMPLE

Creating novel products from residual food processing streams

Circle of Food, in the Dutch town of Meppel, processes residual streams from the food industry and temporary surpluses into circular and tasty food, e.g. oyster mushrooms grown on coffee grounds. In addition, Circle of Food supports local entrepreneurs by mapping organic "waste" streams streams in companies and developing an appropriate product with them from these excess materials.

CIRCULAR EXAMPLES FOR SLUDGE

The case studies showed that sludge is often incinerated. However, there are other options to recycle sludge at a higher-value and greater contribution to ecosystems and economies. Three examples are provided below.

SLUDGE EXAMPLE

Creating agricultural inputs and biofuels from sludge

Burning sewage sludge releases CO_2. Minimizing the amount of sludge burned will therefore contribute to climate goals. To prevent the incineration of sludge, a Dutch *consortium* has been investigating high-quality processing techniques, whereby valuable raw materials can be recovered from the sludge. In this pilot, the sludge is processed through biological drying. Composting is used to dry the sludge to produce biogranulate and ammonium sulfate. The biogranulate is used as a biofuel for generating renewable energy. The ammonium sulfate is a nitrogen-rich fertilizer that is often used locally by farmers and will be disposed of there.

SLUDGE EXAMPLE

Utilizing symbiosis between sludge micro-nutrients and cleaning plants

Sludge can contain pollution in different shapes, depending on its origin. *RESANAT*, another European Interreg project in Flanders and the Netherlands, is experimenting with phytoremediation. This is a process in which certain plants and microorganisms capture, remove and convert contaminants in sludge. The nutrients from the burned sludge thus partially enter the plants, allowing the nutrients to be used multiple times. The cultivated plants can potentially be used as biomaterials for new products in the construction or manufacturing industry and as energy crops. The pilot is investigating ways in which the sludge can be purified, converting the pollutants into nutrients for the plants, which could be used as building materials.

SLUDGE EXAMPLE

Using sludge to generate both biogas, retrieve nutrients for agricultural and develop biofuel

By treating sludge through dehydration at a high temperature (so-called *Torwash* process), biogas can be produced from the squeezed out water and the dissolved phosphate recovered which can be used for agricultural application. The residue (almost dry sludge) serves a green fuel and TNO is now investigating its application in, for example, cement production or in the generation of heat and electricity. The pilot project resulted in the total volume of incinerated sludge to be reduced by 85%.

EXAMPLES FOR BIOFUEL PRODUCTION

When reusing or recycling materials is no longer possible (see organic waste hierarchy in chapter 2), it is interesting to use them as a biofuel feedstock. Relevant materials are for example sludge, food residue and wood chips.

BIOFUEL EXAMPLE

Using sludge as biofuel

Burning sewage sludge releases CO_2. Minimizing the amount of sludge burned will therefore contribute to climate goals. To prevent the incineration of sludge, a Dutch consortium has been investigating high-quality processing techniques, whereby valuable raw materials can be recovered from the sludge. In this pilot, the sludge is processed through biological drying. Composting is used to dry the sludge to produce biogranulate and ammonium sulfate. The biogranulate is used as a biofuel for generating renewable energy. The ammonium sulfate is a nitrogen-rich fertilizer that is often used locally by farmers and will be disposed of there.

BIOFUEL EXAMPLE

Turning used frying oil into biodiesel

Used frying and cooking oil can be used as a feedstock for the production of biofuel. In the harbour of Kampen the company Sunoil Biodiesel is located. They produce both pure bio-diesels, as well as diesel blends where a certain percentage is biodiesel and the rest is fossil fuel based. A by-product of this process is glycerine, which can be used again in the pharmaceutical or food industry or as an input for biogas installations, while this is least preferred.

Around the '00, the usage of biodiesel was stimulated strongly by the German government. Regulations had been created that required a certain percentage of biodiesel to be added to every regular diesel fuel and pure bio-diesels were tax free. These regulations helped create an attractive playing field, which is important for new business development.

BIOFUEL EXAMPLE

Excess wood as biofuel

Excess wood (e.g. in the form of woodchips or sawdust) that can not be repurposed for production of secondary (construction) materials, e.g. due to contamination, can serve as a biofuel feedstock. Biofuels serve as a sustainable alternative for fossil fuels. As discussed in chapter 2, according to the hierarchy for organic waste (figure 8), biofuel usage is prefered over incineration as there are different means for creating clean electricity. Woodchips can be converted into biofuels such as ethanol or biodiesel, providing a versatile energy source for combustion.

The Norwegian Statkraft has found a novel way to produce biofuel from wood chips. Using high temperatures and pressure, Statkraft's "hydro thermal liquefaction" process turns wood and organic waste into diesel, producing allegedly a carbon neutral biofuel. They finalized the construction of a demonstration plant to test this new production technology at the Statkraft Tofte site in 2022 and aim to scale in 2025.

APPENDIX B. GROUPING OF SECTORS FOR CASE STUDY PORT OF SKAGEN (DENMARK)

The sectors in the data that was received from Miljøstyrelsen (ADS Portal) were renamed and grouped to improve readability of the material flow analyses for Port of Skagen region. The renaming and grouping can be found in the table below:

Original sectors in the data	Renaming and grouping for this analysis
Agriculture, Forestry And Fishing	*Agriculture, Forestry and Fishing*
Mining And Quarrying	*Mining and Quarrying*
Manufacturing	*Manufacturing of Products*
Electricity, Gas, Steam And Air Conditioning Supply	*Electricity, Gas, Steam and Air Conditioning Supply*
Water Supply; Sewerage, Waste Management And Remediation Activities	*Water and Waste management*
Construction	*Construction*
Wholesale And Retail Trade; Repair Of Motor Vehicles And Motorcycles	*Wholesale And Retail*
Transportation And Storage	*Transportation And Storage*
Information And Communication	*Communication, Financial and Administrative Services*
Financial And Insurance Activities	
Administrative And Support Service Activities	
Professional, Scientific And Technical Activities	*Professional, Scientific And Technical Activities*
Municipality	*Public Services*
Public Administration And Defence; Compulsory Social Security	
Education	*Education*
Human Health And Social Work Activities	*Healthcare*
Accommodation And Food Service Activities	*Hospitality and Recreational Services*
Arts, Entertainment And Recreation	
Real Estate Activities	*Other Services*
Activities Of Households As Employers; Undifferentiated Goods- And Services-producing Activities Of Households For Own Use	
Activities Of Extraterritorial Organisations And Bodies	
Other Service Activities	

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