Croatia Circular Economy Approaches in Solid Waste Management (P173141)

ACTIVITY 1.1: Diagnostic analysis for a Circular Economy in Croatia

Task 3a: Material Flow Analysis for Circular Economy

(Annex 4)

CIRCULAR ECONOMY APPROACHES IN SOLID WASTE MANAGEMENT

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List of Acronyms, Abbreviations, and Units of Measure

CBS	Statistics Netherlands
CE	circular economy
CO2e	carbon dioxide equivalent
C&DW	construction and demolition waste
CM_IF	Circularity Metric and Indicators Framework
CMUR	Circular Material Use Rate
DE	Domestic Extraction
DMC	Domestic Material Consumption
DMI	Domestic Material Input
DPO	Domestic Processed Output
EE	Environmental Extension
EPR	Extended Producer Responsibility
GHG	greenhouse gases
GPP	Green Public Procurement
GVA	gross value added
GWP	Global Warming Potential
IF	Indicators Framework
IOA	Input-Output Analysis
LC-MFA	Lyfe-Cycle Material Flow Accounting
LULUCF	Land use, land-use change and forestry
MCV-W	Mass-Carbon-Value-Waste
MFA	Material Flow Analysis
MFAc	Material Flow Accounting
Mt	million tonnes
MoESD	Ministry of Economy and Sustainable Development
MR-IOT	Multi-Regional Input-Output Tables
NACE	Statistical classification of economic activities in the European Community
PBL	Netherlands Environmental Assessment Agency
RMC	Raw Material Consumption
RME	Raw Material Equivalents
RoW	Rest of the World
SEM	Socioeconomic Metabolism

Glossary: Terms and Definitions

Domestic Material Consumption (DMC) expresses overall impacts related to the consumption of goods and services generated within an economy. It considers only the direct material footprint and excludes materials used abroad to create products and services consumed domestically. [Source]

Greenhouse gases (GHG) constitute a group of gases contributing to global warming and climate change. The term covers seven greenhouse gases divided into two categories. Converting them to **carbon dioxide equivalents** (CO2e) makes it possible to compare them and to determine their individual and total contributions to global warming. [Source]

Global Warming Potential (GWP) is the heat absorbed by any greenhouse gas in the atmosphere, as a multiple of the heat that would be absorbed by the same mass of carbon dioxide (CO2). GWP is 1 for CO2. For other gases it depends on the gas and the time frame. [Source]

Mass-Carbon-Value (MCV) nexus provides a dynamic conceptual framework for identifying and evaluating key variables. Three different lenses—Mass, Carbon, and Value—are used to scrutinise the combined inputs and outputs from these steps and understand fully how these activities contribute to meeting humanity's societal needs. It shows the development for material extraction (Mass), greenhouse gas emissions (Carbon), and financial value creation (Value). A systemic MCV approach can be employed to illustrate how four resource groups (Non-metallic Minerals, Metal Ores, Fossil Fuels and Biomass) satisfy the seven societal needs. [Source]

Material footprint describes the demand quantification for material extractions (Non-metallic Minerals, Metal Ores, Fossil Fuels and Biomass) triggered by consumption and investment by households, the public sector and businesses. [Source]

Material flows present the amounts of materials in physical weight that are available to an economy. These material flows comprise the extraction of materials inside the economy and the physical imports and exports (*id est,* the mass weight of goods imported or exported). Air and water are generally excluded. [Source]

Material metabolism essentially builds on the schematic material footprint diagram by linking how four resource groups (Non-metallic Minerals, Metal Ores, Fossil Fuels and Biomass) satisfy the seven key societal needs and wants (Housing, Nutrition, Mobility, Communications, Services, Consumables and Healthcare).

Raw material consumption footprint expresses overall material impacts related to the consumption of goods and services, including trade. This is based on raw material equivalents and therefore includes materials wasted and lost abroad. [Source]

Raw Material Equivalents (RME) is a virtual unit that measures how much material was extracted from the environment, domestic or abroad, to produce the product for final use. Especially for finished and semi-finished products, imports and exports in RME are much higher than their corresponding physical weight. For example, traded goods are converted into their RME to obtain a more comprehensive picture on the 'material footprints'; the amounts of raw materials required to provide the respective traded goods. [Source]

Raw Material Consumption (RMC) represents the domestic final use of products in RME. RMC, also called 'material footprint', captures the total amount of raw materials required to produce the goods used by the economy. In other words, the material extraction necessary to enable the final use of products. [Source]

Secondary materials are waste materials collected for recycling and recycled materials that can be used in manufacturing processes, either instead of or alongside 'virgin' raw materials. [Source]

Sector is a term to describe any collective of economic actors involved in creating, delivering and capturing value to consumers tied to their respective economic activity. Different levels of aggregation were applied here—aligned with classifications as used in Exiobase V3. These relate closely to the European sector classification framework NACE Rev. 2.

Stressor, in Input-Output Analysis, is defined as the impact occurring within the region that is the subject of the analysis. There is therefore an overlap between stressor and footprint, as they both include the share of impact occurring within the region as a result of domestic consumption. Conversely, while the rest of the stressor is made of impacts occurring within the region as a result of consumption abroad (embodied in exports), the footprint includes impacts occurring abroad as a result of domestic consumption (embodied in imports).

Executive Summary

Croatia is 2.7% circular—leaving a Circularity Gap of 97.3%. This means that of all the materials funneled into meeting the country's needs and wants, the majority are not cycled. Croatia has a largely linear, service-oriented economy, characterised by high import levels and a booming tourism sector: yet its material consumption of 54.1 million tonnes amounts to 12.9 tonnes per capita per year—relatively low compared to other European nations such as the Netherlands and Norway. The nation's resource extraction comprises primarily non-metallic minerals, accounting for approximately two-thirds, and biomass, accounting for approximately one-third of extraction—but it must be noted that Croatia's consumption footprint tops its domestic extraction. This reveals its status as an 'importer of impacts': more resources are needed to feed its citizens' needs and wants than the country itself can produce.

Inside Croatia's Circularity Gap. Croatia's economy is 2.7% circular—but what makes up the other 97.3%? Ecological cycling—or the share of renewable primary biomass, from food crops and agricultural residues to wood—comes in at an estimated 23.2%. Non-circular inputs—the gasoline, diesel and natural gas burned for energy, which are inherently non-circular—make up 10.7% of the economy, while non-renewable inputs—non-fossil and non-biomass materials, like metals or plastics that are not cycled, account for just 1.1%. The largest portion—43.6%—of Croatia's dashboard of indicators is claimed by additions to reserves and stocks, like new buildings and infrastructure.

Key levers for change: closing the Circularity Gap in Croatia. While the country's low Circularity Metric of 2.7% is normal for a high-income nation, it calls for strategies that increase circularity by slowing (using longer), narrowing (using less), closing (using again) and regenerating (making clean) material flows. This report takes a multidimensional perspective, conducting a Material Flow Analysis and formulating mass, carbon, financial value and waste footprints for sectors with the greatest environmental and socioeconomic impacts: the key levers for change. The results of this study's Material Flow Analysis allow us to pinpoint four priority sectors for instigating the transition to a circular economy: food, construction, plastics and textiles manufacturing, for which barriers and enablers were explored across legal, cultural, economic and technological spheres.

Food. The food sector's footprint—amounting to 5.65 million tonnes—represents approximately one-tenth of the country's material consumption. It also acts as a significant source of waste, producing 0.11 million tonnes (most of which is landfilled) and emissions, releasing 1.65 million tonnes of CO2e. The sector was highlighted as a key lever for impact due to its ties with other core economic sectors—such as tourism—and its growing relevance in policymaking and social spheres. Strategies range from prioritising the products of fresh, local goods and making use of surplus food, to improving separate organic waste collection and processing and valorising such waste by scaling up biofuel production.

Construction. Construction takes the lead in material footprint and waste for the sectors explored, with consumption topping 11.5 million tonnes—equal to roughly one-fifth of the nation's economy. It accounts for one-third of Croatia's waste stream, producing 1.77 million tonnes, and about 13% of emissions, producing 3.64 million tonnes of CO2e. The sector is also characterised by high energy and water use, making it an especially potent hotspot. Strategies are based on closing flows by reusing building materials, designing for disassembly, adaptability and reduced energy consumption, and maximising the use and lifetime of current stocks.

Plastics. While the plastic sector's material and carbon footprints are low—just 0.21 million tonnes, responsible for an equal weight of emissions—its ubiquitous impact on marine life and biodiversity has brought it into the spotlight both politically and publically. The sector, and the pollution it generates, also pose a significant threat to tourism, one of the main engines of Croatia's economy, resulting in a recently enacted ban on single-use plastics. Strategies for the sector are based on maximising the recyclability and reusability of plastics through eco-design alternatives, implementing take-back schemes and developing improved recycling infrastructure.

Textiles. This sector's material footprint is also relatively low, coming in at 1.6 million tonnes, and it emits about 0.80 million tonnes of CO2—less than 3% of Croatia's total emissions. However, the textile sector has garnered attention across the globe in recent years for its resource-intensive, polluting nature—momentum that is reflected in policy action. Strategies in this sector revolve around bolstering eco-design, increasing separate collection rates, developing improved infrastructure for cycling and stimulating the uptake of repair services and second-hand offerings.

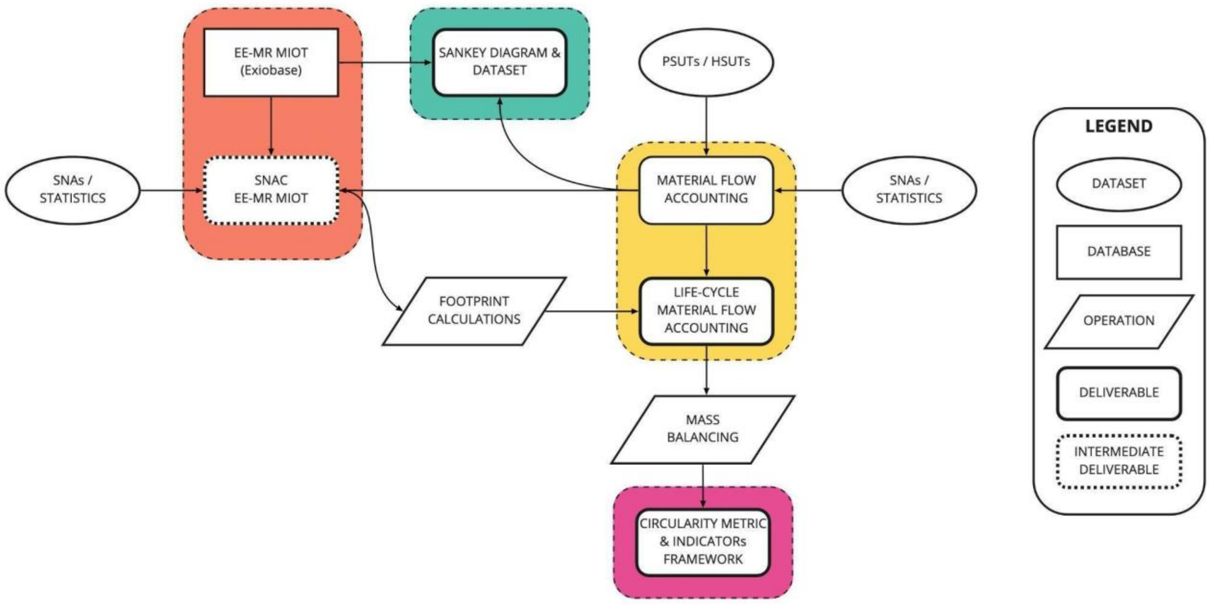
Circular strategies: a means to an end. While the strategies explored across these four sectors will serve to boost Croatia's Circularity Metric and slash its material consumption, they will also provide numerous other environmental and social co-benefits: the circular economy is the means to reach the end goal of life lived within planetary boundaries. This study provides a first glimpse into the intricacies of Croatia's economy—and highlights how circular strategies can contribute to a cleaner, more just, and more circular nation.

1. Circle Economy’s Socioeconomic Metabolism Approach

Most countries operate within the linear economy: ‘take-make-waste’ processes that lead to the over consumption of resources and emission of greenhouse gases (GHGs), where materials are used to satisfy citizens' needs and wants and then quickly disposed of. The alternative is a circular economy: a system where waste and pollution are designed out, materials are kept in use as long as possible, and natural systems are regenerated. A circular economy allows us to reimagine humanity's current way of living in a way that ensures an ecologically safe and socially just space for all.

Measurements are critical to understanding the world around us. As adapting the current economic system, to become more circular, becomes increasingly urgent, it is crucial to provide a tactical approach to understanding and measuring the intricacies of advancing the transition. This section explains how Croatia’s circularity was assessed using the Circularity Metric, by mapping the material flows and stocks that characterise Croatia’s Socioeconomic Metabolism (SEM) and complementing it with a life-cycle and consumption-based perspective on the country’s material footprint. As shown in Figure 1, Circle Economy’s SEM approach is organised around three elements which also constitute the key analytical deliverables of this study, namely: Material Flow Accounting (MFAc), the Circularity Metric and Indicators Framework (IF) and Sankey Diagram.

FIGURE 1 - Flowchart of data and deliverables for the SEM analysis



SOURCE - Own elaboration

The Material Flow Analysis (MFA) gives a high-level overview and understanding of Croatia’s SEM and at the same time constitutes the input to update the Environmental Extension (EE) of the Multi-Regional Input-Output Tables (MR-IOT). These tables are the engine of a technique known as Input-Output Analysis (IOA) and are used to calculate production- and consumption-based accounts, also known as 'footprints'. Footprints are fed back into the MFA to develop an experimental Life-Cycle MFAc which constitutes the basis for the calculation of the Circularity Metric and to the larger IF. Finally, for communicating the insights of the SEM analysis more intuitively, an infographic of material flows in the form of a sankey diagram is produced. A peculiarity of the sankey is its ability to clearly link and map any environmental impact (for instance, resource extraction, greenhouse gas emissions, freshwater consumption, etcetera) to the demand of products and services thereby unravelling the global footprints (for instance material, carbon, water, etcetera) behind satisfying societal needs.

Determining the Circularity Metric of the global economy is relatively simple, largely because there are no exchanges of materials in and outside of planet earth. For countries, however, trade dynamics introduce complexities for which the Metric must be adapted, resulting in certain methodological choices.[1] In assessing a country or region, it is possible to either take a production or consumption perspective. From a production perspective, all the materials involved in any processing or production activity are considered, regardless of whether they are exported or consumed domestically. In a consumption perspective, only the materials that are consumed domestically are considered, regardless of where they are produced. Whether the Metric is applied based on a consumption or production perspective will yield different results.

Concerning the baseline year of this analysis, it is important to note that due to the very heterogeneous nature of the different data sources employed in this assessment, no single baseline year can be identified as the decision was made to use the most recent year available for each dataset/database:

- Macroeconomic monetary data for the Input-Output Tables are for the year 2016;
- Domestic extraction data for all regions are for the year 2019;
- Waste generation and treatment data are for the year 2018;
- Air emissions data by NACE sectors are for the year 2018.

Because the most influential data in the determination of material and carbon footprints are material extraction and air emissions, this study will refer to 2019 and 2018 as the baseline years for the two sets of indicators, respectively.

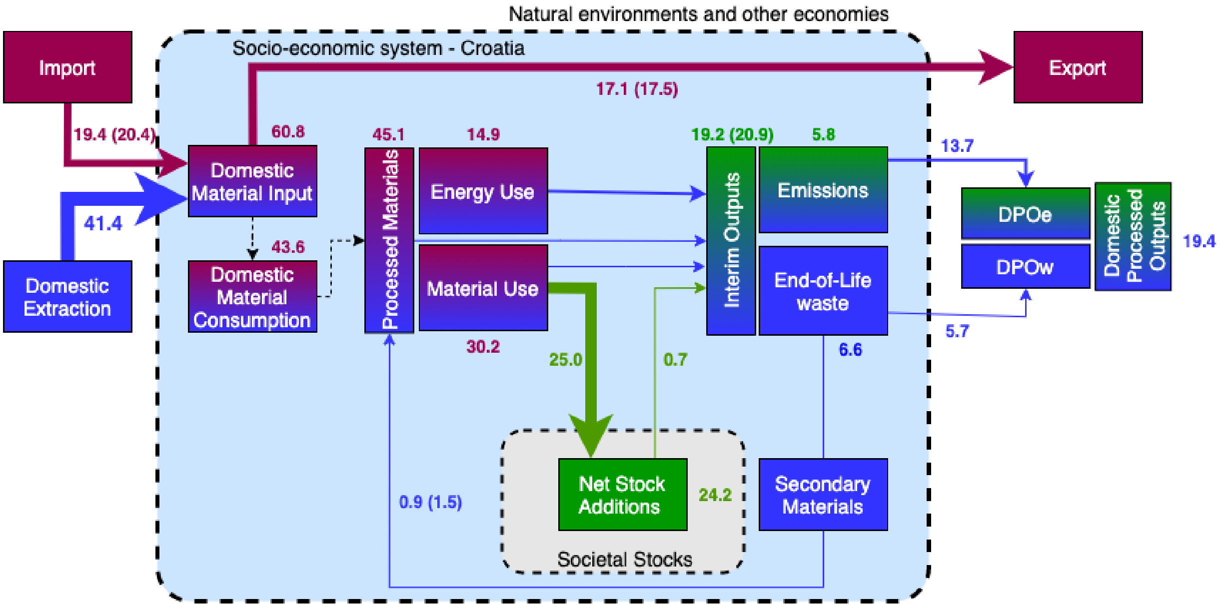
[1] Statistics Netherlands. (CBS). (2020). Notitie circulair materiaalgebruik in Nederland [Press release]. Retrieved from CBS Website

2. Assessment of Croatia's Socioeconomic Metabolism

2.1 Material Flow Accounting of Croatia's economy

Figure 2 is a schematic depiction of the main flows, stocks and related indicators of the Croatian economy for the year 2019. This overview only includes direct physical flows and not raw material equivalent (RME) flows. Domestic Extraction (DE) is the largest flow in the system with a volume of **41.4 million tonnes** of materials and, along with **19.4 million tonnes** of direct physical imported products (excluding secondary materials), brings Croatia's Domestic Material Input (DMI) to **60.8 million tonnes.** Subtracting **17.1 million tonnes** of direct physical exported products (secondary materials excluded), Croatia's Domestic Material Consumption (DMC) amounts to **43.6 million tonnes**, only slightly higher than its DE.

FIGURE 2 - Material flow analysis of Croatia's economy



NOTE - The size of the arrow is roughly proportional to the volume of the flow. For a detailed description of the flows, stocks and indicators please refer to Appendix A.6. Figures between parentheses show the total of primary and secondary imports/exports.
SOURCE - Own elaboration according to the framework of Mayer et al. (2018)[2].

According to this study's estimates, the net number of secondary materials consumed in Croatia amounted to about **1.5 million tonnes** and can be broken down as follows: **0.9 million tonnes** were secondary materials of domestic origin, **1 million tonnes** were imported (including both waste destined for recycling and secondary materials embodied in imports) and **0.4 million tonnes** were exported. In other terms, net cycled materials (1.5 million tonnes) equals domestic secondary materials (0.9 million tonnes) plus imported secondary materials (1 million tonnes) minus exported secondary materials (0.4 million tonnes).

This totals **45.1 million tonnes** of direct physical Processed Materials (PM), split as follows: **14.9 million tonnes** for energy use and **30.2 million tonnes** for material use. Emissions, excluding O2 and H2O, are estimated in between **4.7 and 4.4 million tonnes**, roughly a 10% difference with reported statistics (5.2 million tonnes) (see Appendix A.5 for more details). Solid and liquid waste from energy use, which also

[2] Mayer, A., Haas, W., Wiedenhofer, D., Krausmann, F., Nuss, P. & Blengini, G.A. (2018). Measuring Progress towards a Circular Economy: A Monitoring Framework for Economy-wide Material Loop Closing in the EU28. doi:10.1111/jiec.12809

includes food waste, is estimated at **10.6 million tonnes** while throughput materials from material use, for instance, materials with a lifespan of less than one year, amount to **4.7 million tonnes**. Materials that are added to stocks, for instance, materials with a lifespan longer than one year, represent the majority of those that are extracted (**25 million tonnes**) while the amount of demolished and discarded materials is as low as **0.7 million tonnes**. This is an extremely low figure for a flow that usually includes the major source of waste by volume, Construction and Demolition Waste (C&DW), suggesting that consistent underreporting is occurring. Finally, the total amount of Domestic Processed Output (DPO), representing all the outflows from the economy to the environment, stands at **19.4 million tonnes**. The complete mass balance table can be found in Appendix B.2.

2.2 The material footprint behind satisfying Croatia's societal needs

As previously mentioned, in 2019, Croatia extracted **41.5 million tonnes** of resources, the equivalent of about **9.9 tonnes of resources per capita per year**. Approximately two thirds (**5.8 tonnes per capita per year**) of this extraction consisted of Non-metallic Minerals, while the remaining third (**3.7 tonnes per capita per year**) consisted of biomass-related resources. Small extraction of fossil fuels (**0.4 tonnes per capita per year**) also occurred. In the Exiobase 49 regions framework (for the details of the regions, please see Appendix C.1), this places Croatia at the lower-mid end of the ranking—in 34th place, closer to countries like Belgium and Estonia (for more details please see Appendix C.2). Non-metallic Mineral extraction is calculated to be **24.4 million tonnes** and is the dominant resource group for sectors including construction, with the quarrying of sand and clay representing the lion's share of 58% (for more details please see Appendix B.4). Of the total Croatian DE, 58% is used within the country's borders while the remaining 42% is exported mainly to European countries, especially Italy and Germany. Croatia exports products based on Biomass and Non-metallic minerals almost exclusively, with the only exception being exports to Italy which also include small amounts of Fossil Fuels (Appendix C.4).

The weight of Croatia's direct physical imports stands at **19.4 million tonnes**. When accounting for the RME of direct physical imports, which make up the material footprint of Croatian imports, the figure increases by roughly 50% to **30.1 million tonnes**. This is a 1.55 RME to direct imports ratio, meaning that for every tonne of commodities imported into Croatia, 1.55 tonnes of resources were extracted elsewhere in the world to produce them. Again, Croatia ranks 34th in terms of per capita material footprint of imports with **7.2 tonnes per capita per year**, close to countries such as Portugal and Poland.

The weight of Croatia's direct physical exports stands at **17.1 million tonnes**. When accounting for the RME of direct physical exports, which make up the material footprint of Croatian exports, the figure increases slightly to **17.4 million tonnes**. This adds up to an almost 1:1 RME to direct exports ratio, meaning that Croatia mostly exports raw materials or products with very low embodied resources. Croatia ranks 31st in terms of its per capita material footprint of exports with **4.1 tonnes per capita per year**, close to countries such as China and Slovakia.

Bringing all this together, Croatia's material consumption footprint totals **54.1 million tonnes**, corresponding to **12.9 tonnes per capita per year,** making it the 9th country with the lowest per capita material consumption footprint and close to countries such as Portugal, Mexico and Romania (for more details please see Appendix C.2, Figure 15). With a consumption footprint higher than the domestic extraction, Croatia is still an 'importer of impacts': more resources are needed than are extracted. This extraction—and its related impacts—are occuring abroad to satisfy Croatia's final demand. Construction stands out as especially responsible for the material footprint, accounting for **4 million tonnes,** although its contribution compared to other sectors (7.5%) is not nearly as large as the average in the rest of the world

(RoW) (24.3%). Conversely, activities related to the quarrying of sand and clay are much more impactful than the global average in terms of material footprint. It must be mentioned, however, that economic data for the Croatian 'Quarrying of Sand and Clay' sector represents an extreme outlier in the overall Input-Output framework that can distort the interpretation of the results (for instance, part of the economic output of 'Construction'' may have been ascribed to the 'Quarrying of Sand and Clay' sector). The food processing and hospitality industries come in second and third with a footprint dominated by Biomass. The public sector—including public administration, health and social works, and recreational, cultural and sport activities—comes next and is characterised by a 'mixed' footprint consisting of Biomass and Fossil Fuels as well as Non-metallic Minerals. From a resource group perspective, Non-metallic Minerals dominate the footprint's composition with 43%, followed by Biomass with 34.5%, Fossil Fuels with 18.6% and finally Metal Ores with 3.4%. Regarding the region of origin, 45% percent (24.5 million tonnes) of the total consumption is satisfied by Croatian resources while the remaining 55% relies on foreign economies with the Rest of Europe, the United States and China ranking on top (for more details please see Appendix B.5, Figure 11). Interestingly, most of the Metal Ores are imported from the East European region, most of the Fossil Fuels from the United States (as well as Romania) while most of the Non-Metallic Minerals come from China. Table 1 summarises the key results in absolute figures.

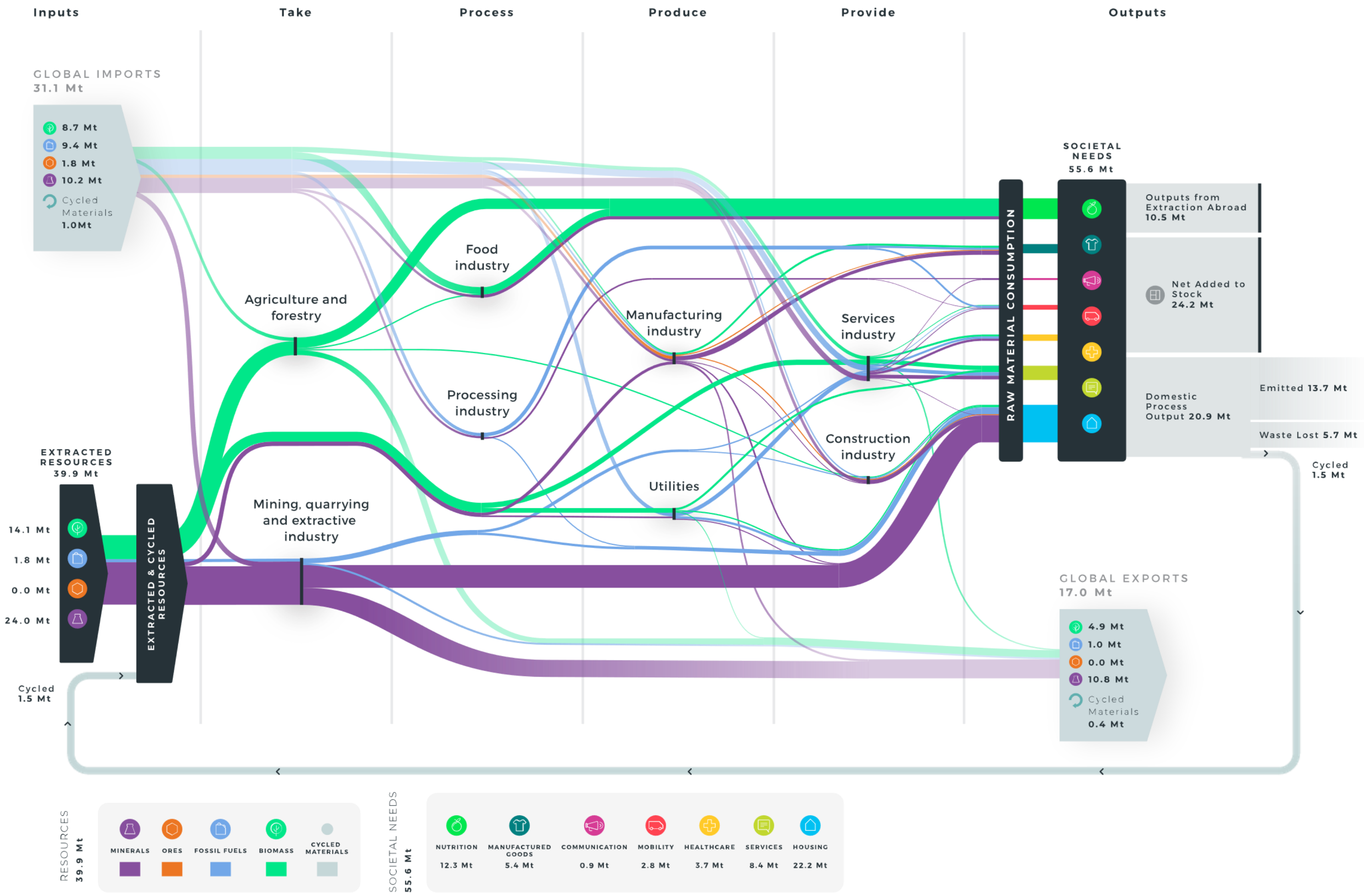
TABLE 1 - Summary of absolute footprint results by raw material category

Raw material category	Domestic Extraction (million tonnes)	Imports (RME) (million tonnes)	Ex ports (RME) (million tonnes)	Raw material consumption (million tonnes)
Biomass	15.6	8.7	5.5	18.8
Metal Ores	0.0	1.9	0.0	1.9
Non-metallic Minerals	24.2	10.2	11.0	23.4
Fossil Fuels	1.6	9.4	0.9	10.1
Total	**41.5**	**30.1**	**17.4**	**54.1**

SOURCE - Circle Economy Analysis, Exiobase v3.8 + HR resource extraction data 2016-2019

Assigning industries' outputs to selected societal needs and mapping the RME flows throughout the supply chain allows us to estimate the material footprint behind satisfying the societal need for Communication at 2% of the material footprint. The sankey diagram (Figure 3) shows that the societal need Housing dominates the material footprint at 40%, primarily using Non-metallic Minerals. Nutrition is the second largest end use for domestic material flows in Croatia, making up 23% of the total material footprint, consisting mostly of Biomass materials. Services ranks third, with 15% of the total share and approximately half of the materials consisting of Biomass and the remainder almost equally consisting of Non-metallic Minerals and Fossil Fuels. The remaining societal needs make up a smaller fraction of the total material footprint, with Manufactured Goods amounting to 10%, Healthcare to 7% and Mobility to 5% through the different sectors of the economy (Appendix B.3).

FIGURE 3 - Sankey diagram visualising the material footprint behind satisfying Croatia's societal needs and link with the four key resource groups



SOURCE - Circle Economy Analysis, Exiobase v3.8 + HR resource extraction data 2016-2019.

The consumption-based carbon footprint of Croatia amounts to around **22 million tonnes of CO2e**, with industries such as construction, milk production and hotels and restaurants being the top contributors (Appendix B.5, Figure 12). Exactly half of it is related to activities located within the Croatian borders, while the other half is related to imported products from foreign industries, in particular from the Rest of Europe, the United States, Romania and the Middle East (Appendix B.5, Figure 11). The production-based carbon, *id est,* the direct emissions from Croatian industries (excluding households), amounts instead to **18.2 million tonnes of CO2e** (Table 2), of which roughly 38% is exported to other countries (see Appendix B.5, Figure 13). Generation of electricity by coal, the production of raw milk, construction, petroleum refining and cement production are most responsible for the direct production of GHG emissions in Croatia (Appendix B.5, Figure 14).

TABLE 2 - Global Warming Potential by import, export, production and consumption

Unit: Million tonnes CO2e	Production-based	Imports	Exports	Consumption-based
Global Warming Potential (GWP)	18.2	11.0	7.0	22.2

SOURCE - Circle Economy Analysis, Exiobase v3.8 + HR resource extraction data 2016-2019.

2.3 Croatia's Circularity Metric

With a total consumption of raw plus secondary materials (also termed Processed Materials) of **55.6 million tonnes**, Croatia's circularity stands at **2.7%**, leaving a Circularity Gap of **97.3%**. The Circularity Gap can be broken down into a set of additional indicators that help to shed more light on the dynamics behind measuring circularity and the circular economy as a whole.[3]

Socioeconomic Cycling (SC): 2.7 % in Croatia. This refers to the share of secondary materials in the total consumption of an economy: the Circularity Metric. These materials are items that were formerly waste, but now are cycled back into use, and includes recycled materials from both the technical (such recycled cement and metals) and biological cycles (such as wood but excluding animals and waste). In Croatia, this number, 2.7%, is well below the global average of 8.6%.

Ecological Cycling Potential (EC): 23.2% in Croatia. This refers to the share of renewable primary biomass (for example, food crops, agricultural residues and wood but excluding those already included in the socioeconomic cycling) in the total consumption of an economy. To be considered circular, primary biomass must at the very least guarantee full nutrient cycling and be carbon neutral. Because detailed data on the sustainability of primary biomass is not available, the estimation of the ecological cycling potential needs to rely on a broader approach: if the amount of elemental carbon from land use, land-use change and forestry (LULUCF) emissions is at least the same as the carbon content of primary biomass in the domestic consumption of an economy, then all the consumed biomass can be considered carbon neutral. The considerable volume of forested area in Croatia provides a significant basin for carbon sequestration, meaning that Croatian LULUCF emissions are negative (-0.35 million tonnes), and the biomass consumed within its borders can be considered carbon neutral. However, while carbon neutrality is a necessary condition for biomass to be considered sustainable—it is not the only condition: nutrients (including both mineral and organic fertilisers) must be fully circular as well. As of yet, there are methodological limitations in determining nutrient cycling, and therefore, this study has not included ecological cycling in its calculation of Croatia's Circularity Metric—even though this would boost the province's circularity rate to

[3] Please see Appendix A.2, Table 7 for the definition of each indicator.

an impressive 23.2%. This study takes a precautionary stance with its exclusion, with the knowledge that its impact on the Metric may not be totally accurate.

Non-Circular Inputs (NCI): 10.7% in Croatia. This refers to fossil-based energy carriers, such as gasoline, diesel and natural gas that are burned for energy purposes and emitted into the atmosphere, and are inherently non-circular: the loop cannot be closed on fossil fuels.

Additions to Reserves and Stocks (NAS): 43.6% in Croatia. This refers to the vast majority of materials that are 'added' to the reserves of an economy as 'net additions to stock'. Countries are continually investing in new buildings and infrastructure, in order to provide Housing and Mobility, as well as renewable energy. This stock build-up is not inherently bad; many countries need to invest to ensure that the local populations have access to basic services, as well as build up infrastructure globally to support renewable energy generation, distribution, and storage capacity. These resources do, however, remain locked away and are not available for cycling, and therefore weigh down the Circularity Metric.

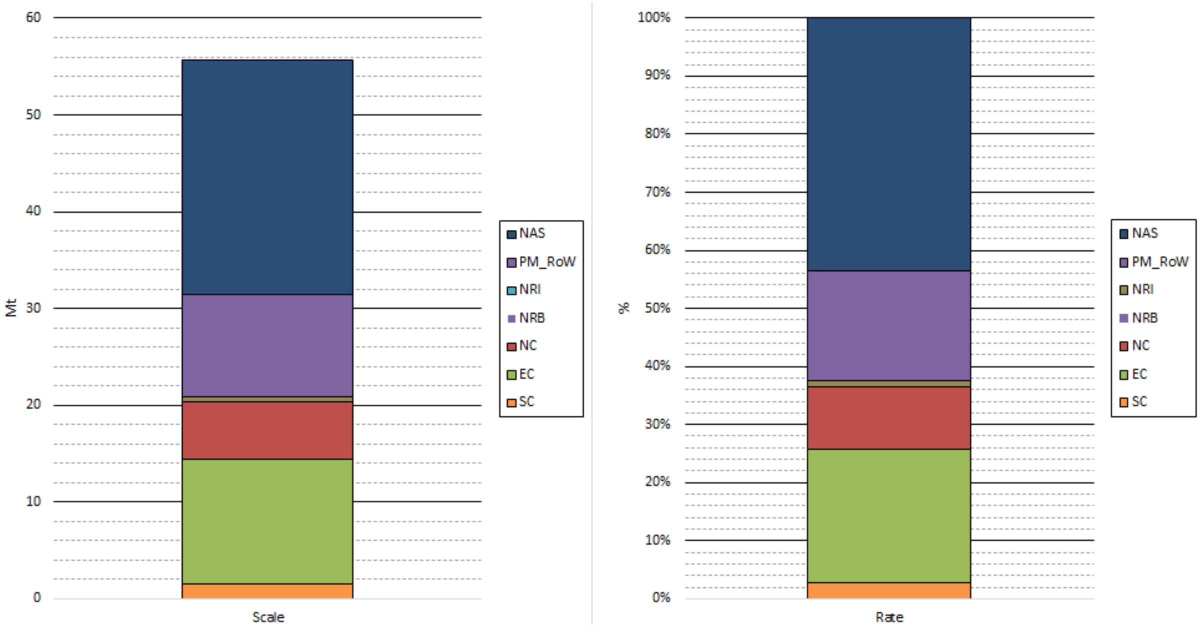
Non-Renewable Inputs (NRI): 1.1% in Croatia. This refers to inputs into the economy that are neither fossil fuels nor ecologically cycled including non-cycled materials such as metals, plastics and glass. These are often embodied in consumer products, ranging from furniture and sports goods to aircraft components and machinery for a variety of sectors. Although these inputs into the economy are not inherently non-circular and can, in principle, be cycled, they are being lost to the environment by means of landfilling or incineration. This figure is much lower than expected and this is thought to be due to underreporting of waste fractions belonging to the Net Depletion from Stocks which are reported to be as low as 0.7 million tonnes. As a reflection, the 'Additions to Reserves and Stocks' flow is found to be much higher than expected.

Non-Renewable Biomass (NRB): 0% in Croatia. This refers to the opposite of the ecological cycling potential and it is equal to zero due to Croatia's negative LULUCF emissions.

Net Extraction Abroad (NEA): 18.9% in Croatia. This refers to the net share of resources that are consumed in Croatia but were originally extracted abroad. Part of these resources end up either being emitted or wasted abroad or, alternatively, being added to Croatian stocks. Because the model is not yet able to trace the fate of these resources and to assign them to one of the other indicators, this share of consumption is accounted for separately.

Visualised scale and percentage indicators are shown in Figure 4.

Figure 4 - Visual representation of Croatia's circularity



NOTE - Left column shows absolute values, right column indicates the percentage.
SOURCE - *own elaboration based on Mayer et al. (2018).*[4]

2.4 Comparison of Croatia's circularity with other countries

A thorough comparison of Croatia’s Circularity Metric with that of other countries, especially countries with similar economic make-up, is not possible as these countries have not yet been investigated by Circle Economy and a full investigation of other countries’ profiles lies outside of the scope of this study. Previous country scans, however, have shown a wide range for the Circularity Metric: Norway's Metric stands at **2.4%**, Austria's at **9.7%**, and the Netherlands' at **24.5%**, while the global Circularity Metric in 2020 was found to be **8.6%**. It should be noted that the methodology between these studies and the current one has been improved, resulting in somewhat reduced direct comparability of the Metric. Instead, it is an interesting case to compare the readily available Circular Material Use Rate (CMUR) from Eurostat (see Appendix C.4). See the following textbox.

[4] Mayer, A., Haas, W., Wiedenhofer, D., Krausmann, F., Nuss, P. & Blengini, G.A. (2018). Measuring Progress towards a Circular Economy: A Monitoring Framework for Economy-wide Material Loop Closing in the EU28. doi:10.1111/jiec.12809

Comparison between Eurostat's Circular Material Use Rate (CMUR) and Circle Economys Circularity Metric. Since recently, Eurostat publishes the CMUR, a consumption-based life-cycle indicator representing the headline metric for circularity. While our position paper written in collaboration with Netherlands Environmental Assessment Agency (PBL) and Statistics Netherlands (CBS) notes the differences between the two indicators in more detail, here it was interesting to compare the two once the two main dissimilarities were eliminated. As a form of sanity check, the Circularity Metric was therefore re-calculated using the DMC rather than RMC and including animal and vegetal waste in the number of secondary materials (previously accounted for in the Ecological Cycling potential), thus leaving the method of estimation of imported and exported secondary materials as the difference between the two metrics. Croatia's CMUR amounted to **5.0%** in 2018, rising from 1.6% in 2010. As outlined above, this value is comparable but slightly higher than the re-calculated Circularity Metric of 4.7% from our analysis. Ranked 18th of the 27 EU Member States, the CMUR of Croatia is similar to that of Latvia (4.7%), Slovakia (4.9%) and Finland (5.9%), but below the EU27 average of 11.5% (see Appendix C.4). The neighbouring countries Hungary and Slovenia had a CMUR of 7% and 10% in 2018, respectively.

2.5 Waste generation and treatment in Croatia

Determining what happens to products and materials after their functional use in the present economy (**End-of-Use**) is essential to identifying and addressing opportunities for a more circular economy. In Croatia, the total amount of waste generated amounted to in **between 5.5** (waste generation reported on Eurostat) and **6.6 million tonnes** (mass-balanced End-of-Life waste estimated by Circle Economy), of which **3.8 million tonnes** are **treated domestically** (the mismatch between waste generation and treatment has multiple reasons that can be consulted on Eurostat). Of the total waste being treated, a reported **2.2 million tonnes (58%)** are either recycled, backfilled or reused for energy purposes. The other **1.6 million tonnes (42%)** are mostly sent to landfill. Specifically, the distribution of different waste recovery routes can be seen in Table 3 below. Important considerations on the difference between the waste statistics reported by Eurostat and their inclusion and allocation in the Economy-Wide Material Flow Analysis (EW-MFA) for the calculation of the circularity indicator are reported in Appendix A.3.

TABLE 3 - Volume breakdown by waste management route and corresponding percentage

Waste Management Route	Volume (tonnes)	Percentage
Disposal—landfill (D1, D5, D12)	1581549	42.0%
Disposal—incineration (D10)	0	0.0%
Disposal—other (D2-D4, D6-D7)	8843	0.2%
Recovery—energy recovery (R1)	73880	1.96%
Recovery—recycling	1971229	52.3%
Recovery—backfilling	131084	3.5%

SOURCE - Eurostat, please see Appendix A.3

By coupling up-to-date and reported waste generation data from Eurostat with high resolution breakdowns by sector from the hybrid version of the Exiobase supply and use tables, a granular breakdown of waste generation by 33 waste fractions and 163 industries was produced. An overview of the top fifteen waste generation sectors (including households) is presented in Appendix B.1.

Households are the main source of waste production with a share of 23.3% of the total when considered as a waste generation activity similar to an industry. About 80% of household waste is composed of a mix of materials which mainly include mixed municipal waste, bulky waste, street cleaning waste, kitchen waste and household equipment. The remaining 20% is mainly composed of paper and cardboard (4.7%), metal waste (3.8%), discarded equipment (2.8%), vegetable waste (1.8%) and plastic waste (1.4%). With 22.7% of the total, construction is the second sector by waste generation volume producing mainly C&DW, soils and metal waste. The aluminium mining industry comes in third place (11.8%) producing almost exclusively 'Other mineral waste', a broad category also including alumina and casting cores and moulds. The presence of aluminium mining in contrast to aluminium production is interesting given that no metal ores extraction is recorded in Eurostat ew-MF categories. This may be interpreted as an imprecision in the data from the hybrid IOT used for the waste disaggregation. The manufacturing of basic iron and steel and of ferro-alloys is also an important waste producer (8.5% of the total). In total, more than 20% of Croatian waste is related to metal manufacturing industries. Industries related to agriculture, namely 'Raw milk production', 'Pig farming' and 'Poultry farming' in combination are responsible for 9% of the total waste generation, almost entirely in the form of 'Animal faeces, urine and manure'. Other considerable sources of industrial waste are the hospitality industry (4.3%) with an extremely diverse waste generation profile, the paper industry (3.5%) and the public health and administration sector (2.8%). From the perspective of the individual waste streams, it is important to highlight once again the considerably low incidence of C&DW which only contributes 9% of total waste generation, strongly suggesting the possibility of considerable underreporting.

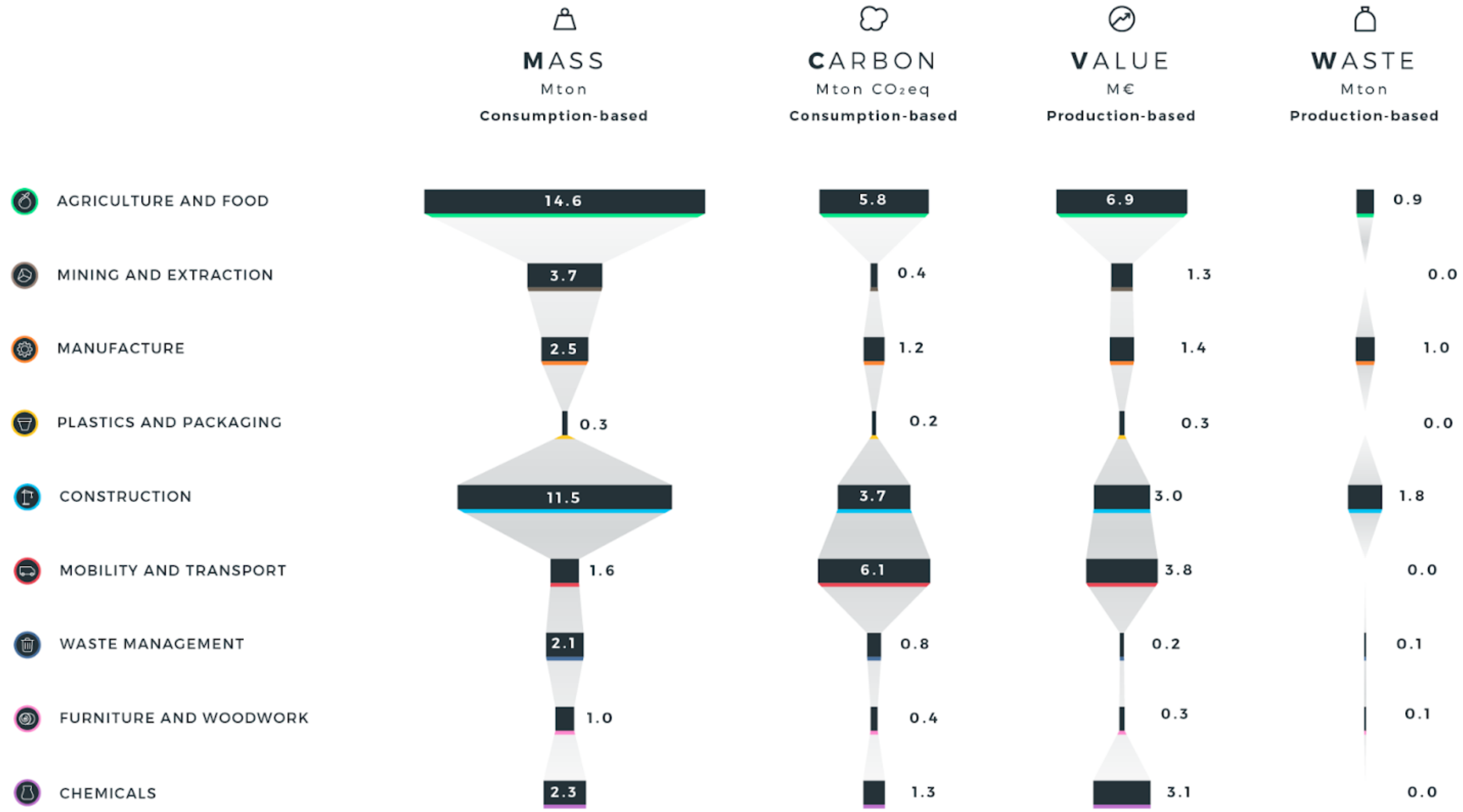
3. Priorities in the Croatian Material Metabolism: the MCV-W Nexus

In exploring opportunities for increasing circularity and reducing the total consumption footprint of Croatia, it is important to have a clear understanding of where the key leverage points for change lie. To have this, it is necessary to comprehensively evaluate which sectors and value chains have the most significant material resource consumption, and generate the largest socioeconomic and environmental impacts. This information begins to give us a clearer sense of which sectors and value chains could have the highest transformation potential.

The metabolism analysis allows us to zoom into the specific material consumption (Mass) and waste generation (Waste) flows associated with different areas of the economy. In addition to these data points, additional sectoral information on financial value creation (Value) and emissions (Carbon) was introduced. All of the aforementioned data points make up the Mass-Carbon-Value-Waste (MCV-W) nexus. The results of the MVC-W nexus are summarised in Figure 5 below.

The MVC-W nexus is a helpful tool for pinpointing key levers in the economy where significant mitigation potential lies through introducing circular strategies. Ultimately, it is important to keep in mind that circular economy approaches are a means to reducing environmental pressures, while continuing to deliver economic and social benefits. A closer look at each of the footprint categories is helpful to better grasp each of the elements that make the MCV-W nexus. Firstly, **Mass** is consumption-based, shown in million tonnes, and represents the material footprint of each sector. It indicates where the most significant material consumption is taking place in the economy and thus where reducing consumption should be prioritised. Secondly, **Carbon** is consumption-based, shown in million tonnes of CO2e, and gives us perspective on where the largest emissions mitigation potential may lie. Thirdly, **Value** is production-based, shown in millions of euros, and gives us information from an economic perspective. It indicates gross value added (GVA) per activity for each sector. Finally, **Waste** is production-based, shown in million tonnes, and provides an overview of the most significant waste sources. It, therefore, indicates the priority sources to reduce waste. It is important to note that for the waste category, household waste was not included in the figures due to the impossibility of distinguishing between different waste streams. Considering the high volumes of household waste generated, this has a large impact on waste figures for sectors such as food and plastics.

FIGURE 5 - Visualisation of the MCV-W Nexus



From the first initial categorisation of nine macro-sectors, four sectors have been prioritised: (1) food, (2) construction, (3) plastics and (4) textiles (see Appendix A.4 to see the aggregation of activities). This prioritisation is based on stakeholder and workshop consultation between the Ministry of Economy and Sustainable Development of Croatia (MoESD), the Environment Agency Austria (UBA), which performed the policy landscape assessment, the World Bank, and Circle Economy, which performed the quantitative analysis.

The difference between the initial macro-sectors identified and the final four selected ones is as follows. Food was disaggregated from 'Agriculture and Food', Textiles from 'Manufacture', and Plastics from 'Plastics and Packaging' (see Appendix A.4 for all details). 'Construction' was kept the same, with the addition of some activities previously grouped under 'Mining and Extraction' (for instance, quarrying of sand, clay and stone); these are major providers of the primary raw materials necessary for construction operations, thus allowing us to consider the whole value chain.

Before analysing each of these sectors individually, it is also helpful to analyse their combined footprint to develop an understanding of their magnitude in relation to the rest of the Croatian economy. The mass of these four sectors amounts to a total of 19.4 million tonnes, accounting for roughly 35% of total material consumption in Croatia. Their carbon footprint amounts to 6.3 million tonnes CO_2e, representing about 23% of total greenhouse gas (GHG) emissions in Croatia. Their value amounts to €4,826 million, or about 11% of total GVA. Finally, these four sectors generate 1.93 million tonnes of waste: about 35% of total waste generated (excluding households).

The analysis below concerns the individual footprint of each of the four sectors.

3.1 Food

The food sector has the second-highest material footprint of the four selected sectors, amounting to 5.65 million tonnes (about 10% of total material consumption in Croatia). It is also a substantial source of waste, producing 0.11 million tonnes (about 2% of total waste, excluding households), particularly destined for landfilling. However, it is noteworthy to clarify that, given data availability, it is difficult to measure food waste accurately and pinpoint leakages in the system. For example, a large share of waste categorised under 'Hotels and Restaurants' likely corresponds to food waste. A lack of data granularity and low rates of separate collection prevents more detailed analysis of different waste streams. However, it is certain that diverting food waste to lower value channels is relatively common, given the high volume of edible food waste in high-income countries. Valorisation of these waste streams, however, provides an opportunity to address crucial social issues such as food poverty, food insecurity, and lack of access to affordable, nutritious food.

The sector's carbon footprint is quite significant: 1.65 million tonnes of CO_2e, representing about 6% of total GHG emissions in Croatia. In particular, the three main subsectors, 1) processing of food products not elsewhere classified (nec), 2) processing of dairy products, and 3) manufacturing of beverages (see Appendix A.4) make up about 73% of the sector's total emissions, and 2.6%, 1.1% and 0.6%, respectively, of total GHG emissions in Croatia. However, since the food sector is closely linked to agriculture, a land-intensive sector, its indirect impact is much higher: an additional 11% share of total GHG emissions in Croatia. It is also important to note that, globally, the impact of food production and food waste is becoming more relevant in the public and policymaking spheres, not only given its climate impact but also due to its massive consequences for biodiversity, animal welfare and human health.

Moreover, the economic dimension of the food sector is also significant, amounting to €1,128 million, about 2.5% of total national GVA. Notably, the processing of high-value products such as food products nec, meat products, and vegetable oils and fats (see Appendix A.4) amount to 77% of the total GVA of the sector, and 0.9%, 0.4% and 0.4%, respectively, of the total GVA of the national economy.

Finally, it is also important to highlight the relevance of the food sector from a policy perspective. *The Farm to Fork Strategy*[5], the *Updated Bioeconomy Strategy*[6], and the *2020 Circular Economy Action Plan*[7] are all EU policy instruments with a strong focus on preventing, reducing and better managing food waste across the entire value chain. Similarly, by aiming to reduce the environmental and health impact of food production, the EU *Chemicals Strategy for Sustainability* also indirectly, albeit crucially, influences the food sector. On a national level, Croatia is also taking several measures that target the food sector. Notably, the *Food Waste Prevention Plan 2019–2022*[8], the *Waste Prevention Plan (2015–2021)* and a range of new legislation on food waste aims to tackle primary waste sources and advance circularity in the food sector.

3.2 Construction

Among the four selected sectors, construction maintains the biggest footprint overall, particularly regarding material use and waste. The sector's material consumption amounts to 11.5 million tonnes, making up 21% of the total material consumption across the whole Croatian economy. It is also very significant in terms of waste, generating 1.77 million tonnes, or 32% of total waste generated in the nation (in line with the EU average[9]). However, it is noteworthy to highlight that recycling and material recovery rates for construction and demolition waste (C&DW) in Croatia (78%) sit below the EU average (88%) and that much of this waste is being disposed of in low-value channels.[10,11] The downcycling of construction waste is not unique to Croatia and remains a prevalent problem across the EU.[12]

The construction sector is also characterised by a large carbon footprint, producing 3.64 million tonnes of CO_2e, accounting for about 13% of Croatia's total GHG emissions. This issue is also not unique to Croatia: the construction sector holds one of the largest carbon footprints on a global scale, with cement alone contributing as much as 8% of total CO_2 emissions.[13] At the same time, it is important to note how construction methods and practices also directly impact GHG emissions. Steps can be taken that impact the energy efficiency of buildings, the reusability of construction materials and components, and the actual (passive) usage of buildings and infrastructure.

From a socioeconomic perspective, construction is also a highly relevant sector. Despite taking a big hit in the aftermath of the 2008 financial crisis, construction is a high added-value sector for Croatia, accounting for €2,930 million (6.5% of total national GVA).[14] Moreover, it is also a very labour-intensive sector: it has high potential for job creation in repair, maintenance and renovation in addition to jobs in material

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[5] European Commission. (2020). Farm to Fork Strategy. Retrieved from: EC website

[6] European Commission. (2018). Updated Bioeconomy Strategy. Retrieved from: Publications Office of the EU website

[7] European Commission. (2020). Circular Economy Action Plan. Retrieved from: EC website

[8] Government of Croatia. (2019). Food Waste Prevention Plan 2019 - 2022. Retrieved from: EC website

[9] European Commission. (n.d.). Construction and demolition waste.Retrieved from: EC website

[10] Eurostat. (2021). Recovery rate of construction and demolition waste. Retrieved from: Eurostat

[11] Bedekovic, G. et al. (2018). Construction and demolition waste management in Croatia with recycling overview. doi:10.31025/2611-4135/2018.13733

[12] Di Maria, A., Eyckmans, J., & Van Acker, K. (2018). Downcycling versus recycling of construction and demolition waste: Combining LCA and LCC to support sustainable policy making. doi:10.1016/j.wasman.2018.01.028

[13] Timperley, J. (2018). Why cement emissions matter for climate change. Retrieved from: Carbon Brief website

[14] Excludes real estate services.

manufacturing, handling and building. While the sector tends to stick to the *status quo* and is relatively traditional in its practices, opportunities for circular intervention are plentiful. Design for reuse and disassembly, for example, could spur the creation of new business models in the sector.

Finally, due to the arguments mentioned above, the policy landscape has a strong focus on construction. For instance, at the EU level, the *2020 Circular Economy Action Plan*[15] prioritises 'construction and buildings' and cement, under the high-impact intermediary materials category. Similarly, given the relevance of construction to public procurement in Croatia, EU Green Public Procurement (GPP)[16] could also have a high steering effect on the sector at the national level. Moreover, national policies such as the *Waste Management Plan 2017–2022* focus on improving the CDW management system to reduce waste and increase recycling. Additionally, the *Low-Carbon Development Strategy* incorporates more ambitious circular measures and principles into building design criteria to, among other goals, improve resource efficiency and energy performance.

3.3 Plastics

The plastic material stream has a low material footprint: 0.21 million tonnes, about 0.5% of total material consumption. Plastics are lightweight and have a low density despite being ubiquitous in society, accounting for their relatively low footprint. However, plastics usually have a relatively large waste footprint, amounting to 0.04 million tonnes (0.8% of total waste generated, excluding households). Studies have found that total plastic waste figures (from 2015) amount to ten times more: 0.4 million tonnes, of which 0.36 million tonnes (86% of total) is collected. Three-quarters of this (0.3 million tonnes) undergoes linear waste management (landfill and incineration) while one quarter (0.1 million tonnes) is actually recycled.[17]

From an environmental perspective, plastics constitute a significant global challenge. The plastic sector produces 0.21 million tonnes of CO2e, about 0.75% of the total GHG emissions of Croatia. However, these figures do not capture the whole picture: they fail to take into account emissions related to the extraction of the fossil fuels required to produce plastics in the first place. For example, globally, plastics account for roughly 6% of oil production and produce approximately 390 million tonnes of CO2.[18] Moreover, the environmental problems associated with plastics transcend emissions. For Croatia, a Mediterranean country with a long coastline and a touristic sector central to its economy, marine litter and plastic pollution are also crucial challenges that threaten ecosystems and biodiversity in general, with consequences for core economic assets such as fisheries, beaches and islands.[19] Within this context, it is essential to emphasise that the environmental problems that plastics create require a consumption-based, waste management approach.

Moreover, despite its massive environmental impact, the plastics sector does not provide much value to the Croatian economy. Since most plastics are produced elsewhere and then imported, the financial value of the sector amounts to €320 million, about 0.72% of total GVA.

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[15] European Commission. (2020). Circular Economy Action Plan. Retrieved from: EC website

[16] European Commission. (n.d.). Green Public Procurement. Retrieved from: EC website

[17] World Wildlife Fund (WWF). (2019). Stop the flood of plastic. A guide for policymakers in Croatia. Retrieved from: WWF website

[18] Ellen MacArthur Foundation (EMF). (2016). New plastics economy - Rethinking the future of plastics. Retrieved from: EMF website

[19] Ibidem.

Plastics are in the public spotlight and are under increasingly intense scrutiny and concern from a policy perspective. The EU's *Strategy for Plastics in a Circular Economy*[20], the *2020 Circular Economy Action Plan*[21], and the revision of EU waste legislation[22], all aim to tackle plastic pollution, prevent and reduce plastic waste, and increase and improve the recyclability and reusability of plastic products through various measures. Nationally, the *Integrated National Energy and Climate Plan 2021–2030* promotes a shift towards bioplastics. There is also an official intention to establish a Register of Extended Accountability for manufacturers of plastic packaging for implementing Extended Producer Responsibility (EPR) and transposing EU legislation into national law. From the 1st of July 2021, the new *Waste Management Law* bans single-use plastics, including light plastic bags, q-tips, cutlery, plates and straws as well as other products made of expanded polystyrene such as plastic food containers and lids.

3.4 Textiles

The textiles manufacturing sector has a relatively high material footprint, amounting to 1.6 million tonnes, about 2.9% of total material consumption. A closer look into each of the three sub-sectors, 1) Manufacturing of textiles, 2) Manufacturing of apparel; dressing and dyeing of fur, and 3) Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harnesses and footwear (see Appendix A.4), are all divided rather evenly in terms of their material footprint, amounting to, respectively, 1%, 0.9% and 1% of total material consumption in Croatia.

Textiles manufacturing also has a substantial environmental footprint. The sector produces 0.80 million tonnes of CO_2e, accounting for about 2.8% of Croatia's total GHG emissions. However, it is important to highlight that these figures exclude further pollution from substances directly related to the production of textiles, for example: chemicals, dyes and other hazardous substances. It is worth remembering that globally, textiles manufacturing is one of the most heavily polluting industries, it is extremely water-intensive, and produces high amounts of waste.[23]

The financial value of the Croatian textile sector has diminished substantially over the last two decades. Still, it amounts to €450 million: about 1% of Croatia's total GVA. It is worth noting that export orientation, foreign ownership, and wide geographical distribution of factories across the country are some of the core features of Croatia's textile manufacturing sector.[24] Questionable labour practices, which negatively affect workers', is also a prevalent trend across labour-intensive industries such as textile manufacturing.[25]

The 2020 *Circular Economy Action Plan*[26], along with the upcoming EU *Strategy for Sustainable Textiles*[27], which plans to make the separate collection of textiles obligatory by 2025, seek to strengthen the competitiveness and innovation capacity of the sector while simultaneously boosting the textile reuse market. The EU's *Ecolabel*[28] also promotes resource efficiency, the reduction of waste and pollution, and increases in resource productivity in the production of a wide range of product groups, including textiles.

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[20] European Commission. (2018). A European Strategy for Plastics in a Circular Economy. Retrieved from: EUR-Lex website

[21] European Commission. (2020). Circular Economy Action Plan. Retrieved from: EC website

[22] Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste. Retrieved from: EUR-Lex website

[23] European Parliament. (2021). The impact of textile production and waste on the environment. Retrieved from: EP website

[24] Flanders Investment & Trade Market Survey. (2015). The Croatian textile market. Retrieved from: Flanders investment and trade

[25] European Parliament. (2014). Workers' conditions in the textile and clothing sector: just an Asian affair? [Briefing]. Retrieved from: EP website

[26] European Commission. (2020). Circular Economy Action Plan. Retrieved from: EC website

[27] European Commission. (2021). EU strategy for sustainable textiles. Retrieved from: EC website

[28] European Commission. (n.d.). EU Ecolabel. Retrieved from: EC website

Additionally, *REACH*[29] regulation and the EU *Chemicals Strategy for Sustainability*[30] also directly impact the textile sector given the heavy use of (hazardous) chemical substances used in textile manufacturing.[31] There is a lesser focus on the sector on a national level, with plans to establish a separate collection system for waste textiles and waste footwear.

[29] European Chemicals Agency (ECHA). (n.d.). REACH Legislation. Retrieved from: ECHA website

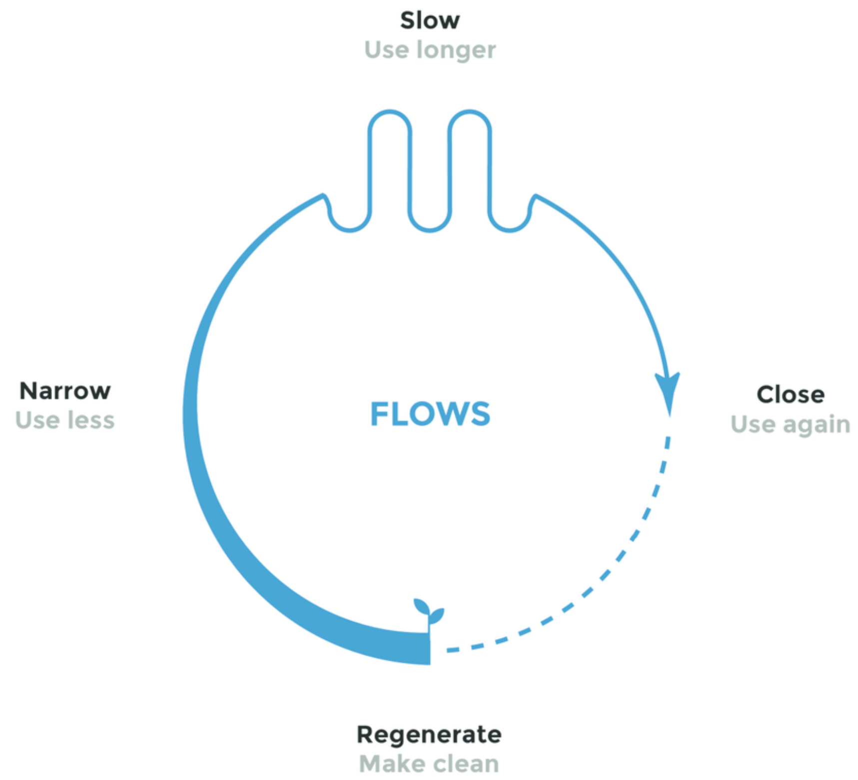
[30] European Commission. (2020). Chemicals Strategy for Sustainability. Retrieved from: EC website

[31] Dutch National Institute for Public Health and the Environment (RIVM). (2014). Hazardous substances in textile products. Retrieved from: RIVM website

4. Croatia Circular Transition Pathways

Contrary to the current linear economic model based on a take-make-use-waste approach, the circular economy aims to maximise resource efficiency and prevent or minimise leakages (waste, greenhouse gas (GHG) emissions and pollution) at a systems level. Value is also to be maintained or increased to the largest extent possible at each stage of use. To this end, strategies and pathways to transition economic activities and advance circularity focus on four core principles: narrow, slow, close and regenerate material and energy flows (see Figure 6).[32]

FIGURE 6 - A circular economy: narrow, slow, close and regenerate material and energy flows



SOURCE - Circular ecosystem innovation: An initial set of principles[33]

Narrow flows—use less: The amount of materials and/or energy used in the making of a product or in the delivery of a service are reduced. This is through circular design or increasing the usage rates of materials and products. In practice: Sharing and rental models, material lightweighting, multifunctional products or buildings, energy efficiency, digitisation.

Slow flows—use longer: Resource use is optimised as the functional lifetime of goods is extended. Durable design, materials and service loops that extend lifetimes, such as repair and remanufacturing, both

[32] Konietzko, J., Bocken, N.M.P., & Hultink, E.J. (2020). Circular ecosystem innovation: An initial set of principles. doi:10.1016/j.jclepro.2019.119942

[33] Konietzko, J., Bocken, N.M.P., & Hultink, E.J. (2020). Circular ecosystem innovation: An initial set of principles. doi:10.1016/j.jclepro.2019.119942

contribute to slowing rates of extraction and use. In practice: Durable material use, modular design and design for disassembly, repair, remanufacturing, refurbishing, renovation, remodelling.

Close flows—use again: The reuse of materials, components or products at end-of-life is optimised, facilitating a circular flow of resources. This is enhanced by improved collection and reprocessing of materials and optimal cascading (recycling, upcycling, collaborative production) by creating value in each stage of reuse. In practice: Design for recyclability (both technical and biological), design for disassembly, recycling, biomass waste-to-energy.

Regenerate flows—make clean: Fossil fuels, pollutants, hazardous substances and toxic materials are replaced with regenerative sources, thereby increasing and maintaining value in natural ecosystems. In practice: Regenerative material use, renewable energy, regenerative agriculture.

Based on these four principles, for Croatia to advance circularity, a total of 15 strategies were identified within the four prioritised sectors. These are distributed as follows: Food (4), Construction (4), Plastics (3), and Textiles (4). The strategies were prioritised from a long-list based on the impact reduction potential from a material, GHG emissions, economic, waste and policy perspective. This assessment was conducted qualitatively by experts within Circle Economy, drawing on previous research conducted in national *Circularity Gap Reports*, which have previously quantified the impacts of similar strategies using input-output modelling.[34] The strategies are organised by sector and classified in Table 4 below:

TABLE 4 - Key strategies per prioritised sector and core principles behind each strategy

Sector	Strategy	Core principle behind strategy			
		Narrow	Slow	Close	Regenerate
Food	Procure fresh, local produce and animal products for consumption.	■			■
	Implement surplus food distribution networks linked to food retail, hotels and restaurants.	■	■		
	Develop effective separate collection and processing of organic waste.			■	
	Scale up the production of biofuels from organic waste.	■		■	
	Harvest and reuse valuable building materials and components.	■	■	■	
	Design buildings using circular principles: disassembly, adaptability, flexible reuse.	■	■		

[34] This study uses Input-Output analysis to understand the impact of different strategies. However, it is impossible to pinpoint specific material leakages or efficiency losses along a given value chain due to a lacking data granularity at a national level. Therefore, to understand the relative strength of interventions or key levers of change, this report models and changes the modelling variables. This qualitative approach was followed due to the limited scope to conduct a full modelling and quantification exercise. However, expert scoring and previous *Circularity Gap Report* work was drawn on. Please see: Circularity Gap Report website

Construction	Design for reduced energy consumption over the lifetime of the use of the building.				
	Practise spatial design and new area development with the aim of maximising resource efficiency, reducing environmental footprints and generating social benefits.				
Plastics	Substitute plastic packaging with 100% recyclable, bio-based alternatives.				
	Develop take-back schemes for plastic packaging (supermarkets and households).				
	Invest in modern and efficient waste treatment and plastic recycling plants.				
Textiles	Design textile products to be recyclable and reusable.				
	Encourage household collection of textiles.				
	Implement chemical and mechanical recycling strategies to recover textiles from waste streams.				
	Stimulate second hand clothing and repair/renewal services in attractive retail environments.				

Moreover, a table has also been included for each strategy with 'barriers' and 'drivers' divided over four categories: (1) Legal and regulatory, (2) Cultural, (3) Economic and financial, and (4) Technological and capacity-based.[35] The strategies identified for each of the prioritised sectors are described in the sections below.

4.1 Food

The food sector has a significant footprint, as shown in the MCV-W nexus. When the whole value chain is considered and combined with the agricultural sector, the overall footprint becomes even bigger (see Figure 5). To reduce the carbon footprint and volumes of waste generated as well as increase the value created by the food sector, strategies to increase circularity fundamentally focus on minimising waste and implementing the EU's food waste hierarchy (prioritise food surplus, by-products and food waste). The four proposed strategies build on one another and follow this food waste recovery hierarchy. Strategy 4.1.1 aims to reduce surplus food and food waste by shortening supply chains and thus reducing environmental impact. Strategies 4.1.2 and 4.1.3 aim to, on one hand, minimise food waste by redirecting surplus food to feed people, and on the other hand, when food waste is unavoidable, ensure it is properly collected and sorted, supporting its valorisation and utilisation. Finally, partially building on strategy 4.1.3, strategy 4.1.4 suggests utilising organic waste from agricultural and industrial residues and food waste for energy generation uses, such as biogas production. Furthermore, these four strategies are 'low-hanging fruits' for Croatia since the conditions are already in place to quickly implement them and advance circularity.

[35] Desk research has been carried out to reflect the Croatian context in the barriers and enablers section. However, given the limited time and lack of local knowledge, many of the findings reflect more general barriers and enablers that nations face around the world.

4.1.1 Procure fresh, local produce and animal products for consumption.

Description: This strategy aims to narrow resource flows, especially material and energy consumption, by ensuring that local food production supports consumption to the highest degree possible. It can also regenerate natural ecosystems when integrated with regenerative agriculture and organic food farming.

Impact: Shorter supply chains, if carefully managed and underpinned with the necessary logistics and supply chain infrastructure, can have positive environmental and socioeconomic impacts.[36][37] Economically, the main outcomes of this strategy are local economic value creation for farmers and food producers, improved market access for small producers, and higher profit margins due to lower intermediaries. Additionally, from a governance and social perspective, the procurement of local fresh produce and animal products can revitalise local communities and rural economies, as well as contribute to food security and potentially (agro)tourism.[38] The potential environmental impact of shorter food supply chains is also high. Besides reduced GHG emissions and less energy consumption (due to less transportation given the shortened distance between production and consumption), higher production standards, better management of natural resources and reduced pressure on biodiversity are other possible positive environmental impacts.[39]

Stakeholders: Farmers, distributors, food processing companies and public authorities.

	Barriers	Enablers
Legal and regulatory	• Existing trade relationships and agreements[40] • Legal limitations influencing food importers (supermarkets, food processors)	• Green Public Procurement, an effective instrument for public authorities to stimulate demand for local, sustainable food production
Cultural	• Unwillingness and lack of demand to prioritise local, seasonal sources of nutrition • High demand for imported goods, especially high value commodities (tropical fruit, tea, coffee, chocolate)	• Growing culture and interest in local, organic, seasonal and sustainable food • Promotion of and awareness raising for the agritourism industry, rural specialisation, and benefits of local and seasonal diets
Economic and financial	• Low cost imported goods	• Financial incentives to support diverse and specialised rural communities and the agricultural sector[41]
Technological and capacity-based	• Lack of agricultural infrastructure (greenhouses, food processing facilities) to satisfy dietary needs year-round	• Local transport networks for food distribution

[36] Malak-Rawlikowska, A. et al. (2019). Measuring the Economic, Environmental, and Social Sustainability of Short Food Supply Chains. doi:10.3390/su11154004

[37] United Nations Industrial Development Organization. (2020). Short food supply chains for promoting local food on local markets. Retrieved from: UNIDO website

[38] Food and Agriculture Organization (FAO). (n.d.). Sustainable local procurement. Retrieved from: FAO website

[39] Vittersø, G. et al. Short Food Supply Chains and Their Contributions to Sustainability: Participants' Views and Perceptions from 12 European Cases. doi:10.3390/su11174800

[40] United States Department of Agriculture (USDA). (2010). Local food systems: concepts, impacts, and issues. Retrieved from: USDA website

[41] World Economic Forum (WEF). (2020). Incentivizing Food Systems Transformation. Retrieved from: WEF website

4.1.2 Implement surplus food distribution networks linked to food retail, hotels and restaurants.

Description: This strategy aims to narrow and slow resource flows by better matching excess food supply and points of demand, thus maximising the prevention of food waste and loss. The strategy focuses on ensuring that human consumption is prioritised for edible food that would otherwise be discarded or wasted, for example, by facilitating increased donation or last-minute sale of unsold goods from markets and supermarkets. The implementation of this strategy can be structured through a (digital) system or platform that ensures an effective network for food distribution is built and sustained.

Impact: The outcomes of improving supply and demand for food are multifaceted. Utilising and reducing food waste and loss can result in reductions in GHG emissions and pressure on land and water. While the economic benefits are perceived to have high potential in well functioning systems, the main source of benefits are related to social outcomes such as increased food accessibility and utilisation.[42]

Stakeholders: Retailers, restaurants, local authorities and food banks.

	Barriers	Enablers
Legal and regulatory	• Food safety and quality regulations[43]	• Food waste prevention regulations
Cultural	• Perceptions of 'ugly' or less fresh food as waste	• Awareness of importance of food waste minimisation
Economic and financial	• Dependencies on surplus food • Cost and coverage of logistics solutions for food collection[44]	• Cost reductions/elimination of food procurement for business or private individuals
Technological and capacity-based	• Resources to separate and prepare food for distribution at source	• Digital apps, platforms, decentralised communication channels • Volunteer logistics for localised food waste pick-up and drop-off

4.1.3 Develop effective separate collection and processing of organic waste.

Description: This strategy aims to increase and improve the separate collection and processing of organic waste from households and commercial sources to support their valorisation, and prevent landfilling and incineration which are key contributors to GHG emissions. A crucial factor at play for this strategy is the importance of having the necessary infrastructure to ensure effective and efficient separate collection and processing of organic waste for its further valorisation and utilisation.

Impact: Similarly to the previous strategy (see 4.1.2), benefits would primarily be achieved from an environmental perspective, namely reduced GHG emissions due to diversion from landfills or incineration. As higher value processing options become more prominent, aside from employment creation, the

[42] Giuseppe, A. et al. (2014). Economic benefits from food recovery at the retail stage: An application to Italian food chains. doi:10.1016/j.wasman.2014.02.018

[43] Hermsdorf, D. et al. (2017). Food waste reduction practices in German food retail. doi:10.1108/BFJ-06-2017-0338

[44] Hermsdorf, D. et al. (2017). Food waste reduction practices in German food retail. doi:10.1108/BFJ-06-2017-0338

economic benefits of high value organic waste processing, such as biogas production (strategy 4.1.4) or use as a feedstock for bioplastics (strategy 4.3.1), become more attractive.[45]

Stakeholders: Restaurants (owners, managers and workers), households, municipal authorities and waste management companies.

	Barriers	Enablers
Legal and regulatory	• Incineration targets that compete with higher value reuse of organic waste	• Organic waste collection or biogas production targets • Landfill and waste management emissions reduction targets
Cultural	• Behavioural barriers to waste management • Education about best practices	• Influential restaurants, hotel chains, supermarkets and government run organisations implement pilot projects • Education and information campaigns
Economic and financial	• Extra cost implications of separate waste collection	
Technological and capacity-based	• Processing plants can detract from public spaces (smell, hygiene) especially for markets placed in or near popular / attractive city centres	• Dedicated waste collection and transportation infrastructure for organics • Processing infrastructure to minimise contamination

4.1.4 Scale up the production of biofuels from organic waste.

Description: This strategy aims to narrow and close resource flows by valorising previously discarded organic waste. Croatia has high potential for biogas/biomethane production currently underexploited.[46] This strategy thus relates to the more systematic and organised utilisation of 1) biodegradable content of municipal solid waste (for instance, from households, markets and supermarkets, and leftover food and solid kitchen waste), 2) agricultural organic waste and by-products, such as olive or grape waste and animal excrement (for instance,cow manure and pig slurry), and 3) industrial food processing residues (for instance, fruit and chicken).[47][48] The implementation of the previous strategy (4.1.3) is crucial for the success of this one.

Impact: When carefully managed, using organic waste to produce biogas and other biofuels can have important environmental benefits: reduced waste and sewage disposal, for example due to the utilisation of manure, and potentially a reduction in GHG emissions. From a socioeconomic perspective, decentralised energy production for rural communities can contribute to their sustainable development and revitalisation.[49] Closed-loop energy production also results in economic savings from a reduction in disposal costs for slurry and/or a reduction in the management costs of a farm from digestate substituting chemical

[45] Slorach, P. C. et al. (2019). Environmental and economic implications of recovering resources from food waste in a circular economy. doi:10.1016/j.scitotenv.2019.07.322
[46] Petravić-Tominac, V. et al. (2020). Current state of biogas production in Croatia. doi:10.1186/s13705-020-0243-y
[47] Girotto, F. et al. (2015). Food waste generation and industrial uses: A review. doi:10.1016/j.wasman.2015.06.008
[48] Petravić-Tominac, V. et al. (2020). Current state of biogas production in Croatia. doi:10.1186/s13705-020-0243-y
[49] Perez, I. et al. (2014). Technical, economic and environmental assessment of household biogas digesters for rural communities. doi:10.1016/j.renene.2013.07.017

fertilisers.[50] Furthermore, if the electricity generated with biogas can be sold externally, it can also become an additional revenue source for farmers and other industries, such as waste management companies.

Stakeholders: Farmers, local authorities, utilities companies, and regulators and policymakers.

	Barriers	Enablers
Legal and regulatory	● Complex regulatory and administrative procedures in the management of organic waste streams ● Zoning or permitting restricting the placement of biofuel processing facilities	● Bioenergy policy and targets, with supportive regulatory mechanisms (Feed in Tariff and market quota)[51] ● Comprehensive and supportive national regulatory framework[52] ● EU regulatory and policy framework supporting renewable energy sources
Cultural	● NIMBY ('not in my back yard') attitudes to biogas and organic waste processing locations ● Lack of knowledge and expertise by key stakeholders (for instance, farmers)	● Education and cooperation between groups of smallholder farmers ● Influential restaurants, hotel chains, supermarkets and government run organisations implementing pilot projects
Economic and financial	● Increasing price of fossil fuel alternatives ● Price of switching and retrofitting existing systems	● Tax incentives and targets for 'green' public transport fuels ● Clear communication of economic returns ● Incentives offered to potential consumers of biogas (so that they switch over from current options)
Technological and capacity-based	● Single waste producers do not produce at scale, therefore must potentially cooperate with other small producers or are potentially unable to procure required technology ● Scarcity of 'manufacturers' who consumer waste products to produce biogas ● Complex logistics and packaging for waste producers to distribute gas ● Lack of large-scale infrastructure	● Analysis of hotspots for the production of specific wastes ● Support and management for effective, affordable and efficient technology

4.2 Construction

The MFA and the MCV-W Nexus revealed the resource-intensity of the construction sector: it requires large volumes of inputs and produces considerable GHG emissions and volumes of waste. The MFA does not show, however, that building-related energy consumption (related to heating and cooling) over the lifetime of buildings is very significant - often multiple times the resource demand in the construction phase. This is clearly linked to the material and carbon footprints of the sector. The ultimate goal of making construction circular is to reduce the life cycle material footprint that the sector has, as well as energy and water

[50] Salerno, M. et al. (2017). Costs-benefits analysis of a small-scale biogas plant and electric energy production. Retrieved from: Researchgate

[51] IEA Bioenergy. (2018). Country reports. Croatia - 2018 update. Retrieved from: IEA bioenergy website

[52] European Technology and Innovation Platform (ETIP). (2020). Bioenergy in Croatia. Retrieved from: ETIP website

consumption, GHG emissions, and waste generation.[53] It is therefore important to use materials and building and demolition techniques that are circular (strategy 4.2.1), but also that the building use phase enables resource efficiency (strategy 4.2.2), environmental and social co-benefits over the long term (strategies 4.2.3 and 4.2.4).

4.2.1 Harvest and reuse valuable building materials and components.

Description: This strategy aims to narrow, slow and close resource flows in the built environment. The recovery of existing valuable resources from the built environment is an opportunity to offset the use of virgin materials for new buildings or infrastructure. The objective is thus to improve collection rates and maximise recoverability and reusability. For instance, this can be done by gathering detailed building information to support the identification and localisation of valuable resources (*id est,* materials and components) and create a geological map (*id est,* of the city of Zagreb) showing the location and availability of previously selected resources.[54]

Impact: Implementing this strategy can have substantial environmental benefits, through increased resource efficiency, reduction in virgin material demand, and lower GHG emissions. Moreover, by retaining and reusing valuable building materials and components, the value of these resources is retained instead of destroyed or downcycled when turned into C&DW. Moreover, these activities are labour-intensive and thus have a high potential for job creation.[55]

Stakeholders: Local authorities, researchers, digital designers, architects and engineers, urban planners and miners, and construction companies.

	Barriers	Enablers
Legal and regulatory	• Material quality standards in construction projects • Material safety standards • Lack of standardisation for reuse and recycling	• Stricter sustainability standards for building • Circular economy policies for material reuse
Cultural	• (Quality) perceptions of recycled material use • Lack of knowledge and skills in construction companies • Relationships with preferred suppliers	• Demonstrated business case for the use of circular materials over the lifetime of the building • Make trainings available and stimulate knowledge sharing networks • Create a showcase circular neighbourhood or building with influential partners
Economic and financial	• Total Cost of Ownership of secondary materials • Inexpensive virgin materials	• Set a premium on virgin or high impact materials so as to encourage the use of secondary / low impact materials

[53] As a reference, in the Netherlands, the construction industry is responsible for around 50% of all material consumption in the country, 40% of the total energy consumption, 30% of the total water consumption, and about 35% of the CO2 emissions. Source: Government of the Netherlands. (2016). A Circular Economy in the Netherlands by 2050. Retrieved from: Government of the Netherlands website

[54] Madaster. (n.d.). Material passport. Retrieved from: Madaster website

[55] Organisation for Economic Co-operation and Development (OECD). (2020). Labour market consequences of a transition to a circular economy: a review paper. Retrieved from: OECD website

Technological and capacity-based	• Limited access to high quality, volumes, consistency for building projects • Secondary material processing infrastructure • Skilled labour and process management systems	• Material storage facilities • Release information about local available materials and their impacts for instance stone versus brick etc. • Research and create a detailed stock model - prioritising buildings planned to be demolished and in earthquake-prone areas

4.2.2 Design buildings using circular principles: disassembly, adaptability, flexible reuse.

Description: This strategy aims to slow and narrow resource flows by introducing circularity upstream in the construction value chain through the incorporation of circular design principles in buildings. New buildings will thus be designed from their early stages in ways that facilitate their assembly/disassembly, adaptability and flexible reuse over multiple use phases.

Impact: Environmental benefits through circular design strategies include reduced material use and total carbon footprint over a building's life cycle. These impact savings can obviously vary significantly depending on the building's intended use and the overall design (ie. insulation) approaches that are utilised. Depending on how buildings are designed and used, there are potentially social and economic benefits of using buildings in a more flexible and adaptive manner, reflecting the current demands of building occupants.[56]

Stakeholders: Designers, architects, urban planners, and contractors.

	Barriers	Enablers
Legal and regulatory	• Zoning that limits building function, adaptability, modularity	• Sustainability requirements for buildings integrated into Green Public Procurement standards • Social, heritage, and community requirements for buildings
Cultural	• Preference and attitudes toward new build • Lack of skills and knowledge in construction companies for retrofitting & circular design methods	• Increasing preferences for retrofitting of heritage and industrial buildings, spaces
Economic and financial	• Cost of labour for advanced design practices (modularity, adaptability)	• Total Cost of Ownership savings • Material and building maintenance savings • New business models (i..e take-back, remanufacturing)[57]
Technological and capacity-based	• Lack of capacity, training, or equipment to implement such building systems and methods	• Training and capacity building in collaborative urban planning and building design practices

[56] Nichols, A. (2020). Making the social impacts of adaptive reuse projects in Copenhagen visible. Retrieved from: Aalborg University website

[57] Cheshire, D. (2016). Building Revolutions: Applying the Circular Economy to the Built Environment. doi:10.4324/9780429346712

4.2.3 Design for reduced energy consumption over the lifetime of the use of the building.

Description: This strategy aims to narrow resource flows by means of design and building methods that dramatically reduce life cycle energy efficiency, such as passive house, BREEAM and LEED standards. While these strategies call for typically more materials to be used in the construction phase, when combined with circular design principles (see strategy 4.2.2) they can achieve significant material and energy savings over the course of a building's life cycle.

Impact: The key benefit to be achieved with this approach is environmental. A reduction of energy consumption, life cycle emissions and material use is expected, particularly when taken into account that energy use represents a third of direct physical processed materials for Croatia (see Material Flow Accounting). Globally, roughly 30% of global energy consumption and energy-related CO2 emissions are linked to the use of buildings, mainly due to space heating.[58] Passive house building designs are well known to reduce total building energy use by up to 90%.[59] This can considerably decrease the energy use of Croatia and thus its mass and carbon footprint, while increasing value. Considering that many buildings in Croatia may need to be renovated to fulfill energy and emissions targets, there are potentially socioeconomic benefits (employment, training and upskilling) due to large scale retrofitting, renovation and upgrade programs[60] like enerPHIT.[61]

Stakeholders: Designers, builders, contractors, and architects, building energy specialists and assessment agencies.

	Barriers	Enablers
Legal and regulatory	• Regulations governing aesthetic appeal of buildings (ie. no exterior insulation, solar panels, etc)	• Energy efficiency standards for buildings (ie. passive house)[62] • National climate change targets (ie. NDCs)[63]
Cultural	• Reluctant attitudes of homeowners or municipalities to change historical or heritage identity	• Increased awareness of importance of emissions and energy reductions, cost savings • Desire for increased indoor comfort
Economic and financial	• Cost-intensive process to retrofit, build, and certify[64]	• Rising (fossil) energy prices • Falling (renewable) energy prices • Direct or indirect subsidies from national, regional, municipal sources

[58] United Nations Environment Programme. (2017). Towards a zero-emission, efficient, and resilient buildings and construction sector. Global status report 2017. Retrieved from: World Green Building Council website

[59] Jiang, W. (2019). The benefits of passive house buildings. Retrieved from: Energy post website

[60] Ellen MacArthur Foundation (EMF). (2020). The built environment. Two circular investment opportunities for a low-carbon and prosperous recovery. Retrieved from: EMF website

[61] Theumer, S. (2015). Step-by-step towards EnerPHit-Standard retrofit. Retrieved from: EuroPHit website

[62] BRE Group. (n.d.). The passivhaus standard. Retrieved from: BRE Group website

[63] United Nations Climate Change. (n.d.). Nationally Determined Contributions (NDCs). Retrieved from: UNFCCC website

[64] Plebankiewicz, E. et al. (2019). Trends, Costs, and Benefits of Green Certification of Office Buildings: A Polish Perspective. doi:10.3390/su11082359

Technological and capacity-based	• Supply of skilled and knowledgeable companies to conduct retrofits or construction	• Distributed training and capacity building programs

4.2.4 Practise spatial design and new area development with the aim of maximising resource efficiency, reducing environmental footprints and generating social benefits.

Description: This strategy aims to narrow, slow and generate flows by including circular economy principles in spatial design and urban planning decision making.[65] These assess the physical, social and environmental factors, determine the allocation, development and usage of physical structures (*id est*, buildings, infrastructure), and impact the extent to which materials and components can be reused. It also influences long-term matters related to housing, mobility and social behaviour. Hence, this strategy explores a systemic approach to spatial design and urban planning that reduces sprawl, maximises walkable accessibility to services, aggressively promotes public and human-powered transport methods, optimises low-carbon mobility between rural and urban areas.

Impact: The main benefit of such a strategy is a substantial reduction in material input given the maximisation of resource efficiency and the increase in recoverability and reusability. Also a reduction in terms of GHG emissions and energy consumption for mobility, and the more efficient use of space for residential, commercial, and possibility for re-naturalisation and better integration of green space in the urban fabric. The social benefits are also significant, ensuring greater livability and quality of life, namely through greater connectivity to basic services and human-centric design, promoting local business and tourism.[66]

Stakeholders: Urban planners, local authorities, contractors, architects, and representatives of civil society and local communities.

	Barriers	Enablers
Legal and regulatory	• Zoning regulations and requirements for buildings and space	• Sustainability requirements of urban and building design (ie. car-free policies, bike lanes)
Cultural	• Perceived impact or displacement of area redevelopment	• Public demand for human-centric urban design • Increased property value
Economic and financial	• Price to develop near urban centres	• Maintenance cost reductions of cyclable and walkable • Increased access to foot traffic and business
Technological and capacity-based	• Lack of technical skills and research capacity	• Digital technologies for better urban planning (geodesign approach)

[65] Remøy, H., Wandl, A., Ceric, D., & Timmeren, A. v. (2019). Facilitating Circular Economy in Urban Planning. doi:10.17645/up.v4i3.2484

[66] Zapata-Diomedi, B. et al. (2019). Physical activity-related health and economic benefits of building walkable neighbourhoods: a modelled comparison between brownfield and greenfield developments. doi:10.1186/s12966-019-0775-8

4.3 Plastics

Increasing the circularity of plastics requires a systemic approach. Three core factors largely determine the effectiveness of this: eco-design, collection and recycling capacity, and sustained demand for recycled plastic. Interventions focusing on eco-design that prioritise single-material, fully recyclable and easy-to-separate plastic products (strategy 4. 3.1) are key to enable high-quality recovery and end-of-use. Eco-design will, in turn, enable new business models that replace single-use products with reusable and/or recyclable alternatives (strategy 4.3.2), reducing the overall material consumption of plastics. Adequate infrastructure is vital to manage the increasing amounts of plastic waste in circular and sustainable means. Increasing homogeneity and harmonisation of plastic materials (strategy 4.3.1) combined with effective collection and sorting (strategy 4.3.2) and modern waste management infrastructure (strategy 4.3.3) greatly improves the efficiency of recycling processes and the quality of recycled plastic, supporting its cost competitiveness vis-a-vis virgin plastic and thus demand for recycled plastics.

4.3.1 Substitute plastic packaging with 100% recyclable, bio-based alternatives.

Description: This strategy aims to narrow material and energy flows associated with plastics packaging by promoting monomaterial 100% recyclable, bio-based alternatives. The valorisation of plastic waste is crucial[67] for the fulfilment of this strategy, hence its close link to the other two strategies (4.3.2 and 4.3.3).

Impact: The potential environmental and socioeconomic impacts of having fully recyclable plastics packaging are high and widespread. Firstly, monomaterial, 100% recyclable alternatives can reduce the ecological impact of packaging, especially in terms of GHG emissions.[68] Moreover, ensuring plastics' recyclability can also reduce (marine) litter and pollution and protect biodiversity and human health. Secondly, from a macroeconomic perspective, an overall reduction in plastic consumption and fossil fuel demand can reduce Croatia's import bill. Increased recycling can also result in local value and job creation in labour-intensive waste management and recycling activities. Furthermore, given its high potential for bioeconomy development[69], Croatia is well-placed to benefit from an increasing share of 100% bio-based recyclable packaging alternatives[70], revitalising rural communities in the country's interior and strengthening its competitiveness.

Stakeholders: Producers, investors, manufacturers, recyclers, waste management companies, and local authorities.

	Barriers	Enablers
Legal and regulatory	• Legal and regulatory environment supporting the status quo[71]	• EPR scheme with ecomodualted fee • Fiscal incentives (*id est,* reduced VAT) for 100% recyclable, bio-based packaging • Virgin Materials Tax (VMT)

[67] Beltran, M. et al. (2021). Food Plastic Packaging Transition towards Circular Bioeconomy: A Systematic Review of Literature. doi:10.3390/su13073896

[68] EuRIC. (2020). Plastic Recycling Factsheet. Retrieved from: European Circular Economy Stakeholder Platform website

[69] CELEBio. (2020). Country report: Croatia. Retrieved from: CELEBio website

[70] Dartford, K. & Gómez, J. L. (2019). How companies across Europe are creating sustainable products using no fossil fuels. Retrieved from: Euronews website

[71] Friedrich, D. (2020). How regulatory measures towards biobased packaging influence the strategic behaviour of the retail industry: A micro empirical study. doi:10.1016/j.jclepro.2020.121128

		• Green Public Procurement (GPP)
Cultural	• Lack of awareness	• Demand for more sustainable (recyclable and reusable) alternatives to plastic packaging[72]
Economic and financial	• Alternatives may be more expensive and consumers might not be willing to pay or may not afford the premium	• Potential savings on mixed waste disposal tax, municipal fees
Technological and capacity-based	• Alternatives may not have the same qualities (durability, waterproof, lightweight etc)	

4.3.2 Develop take-back schemes for plastic packaging (supermarkets and households).

Description: This strategy aims to slow and cycle material flows by maximising the reuse of plastic packaging. By introducing take-back schemes, such as deposits and reverse logistics based on product return and reuse, plastic packaging products can retain their value by optimising their reusability and recyclability to the maximum extent possible. This would be applicable to PET and HDPE bottles, as well as Fast Moving Consumer Goods (FMCGs).

Impact: Environmental benefits range from a reduced material footprint—and thus reduced emissions—to reductions in plastic litter and pollution. From a strictly economic perspective, take-back schemes can also reduce expenditures related to energy use and collection as well as optimise operations for businesses (both producers and retailers). Increased recovery and reutilisation could also provide new job opportunities.[73]

Stakeholders: Brand owners, packaging manufacturers, retailers (supermarkets), waste management companies and consumers.

	Barriers	Enablers
Legal and regulatory	• Ineffective mix of common and individual compliance schemes	• Ambitious regulatory pressure • Effective EPR for plastic
Cultural	• The inconvenience of having to transport bottles or other packaging back to the shop	• Education and information campaigns raising environmental awareness and promoting 'green consumption'
Economic and financial	• Additional labour and operational costs to operate take-back schemes • Inability of retail locations to invest in necessary infrastructure or space	• Clear benefits for businesses (for instance, optimised business operations and lower energy and collection expenditures) • Potential cost savings incentives for refilled bottles passed along to the customer

72 Herbes, C. et al. (2018). Consumer attitudes towards biobased packaging – A cross-cultural comparative study. doi:10.1016/j.jclepro.2018.05.106

73 Mwanza, B. G. (2017). The significance of reverse logistics to plastic solid waste recycling in developing economies. Retrieved from: Researchgate

Technological and capacity-based	• Lack of staff or adequate space in store to operate such systems • Supply chain difficulties • Lack of latest technologies and technical skills among personnel	• Bottle Collection System • Bottle Refilling System

4.3.3 Invest in advanced waste management infrastructure (to ramp up plastic recycling).

Description: Building on the previous two strategies (see 4.3.1 and 4.3.2), this strategy aims to close resource flows by improving and expanding the degree to which plastics are diverted, collected and processed by means of advanced waste management infrastructure. Modern recycling facilities equipped with new technologies, such as effective sorting and cleaning, are key to increasing the efficiency and competitiveness of recycling methods and minimising resource input (energy and water). It is also key in determining the quality and price of secondary materials, and thus their market attractiveness. There are investments being made in new waste management centres.[74] Still, ensuring sufficient investment in advanced PET/E and HDPE mechanical biological treatment recycling facilities is fundamental to growing and developing the market for recycled plastic and ensuring that Croatia has the necessary, effective in-house capacity to treat plastic waste volumes domestically, particularly for packaging.

Impact: The economic potential of plastic recycling systems is significant, especially in terms of formal job creation in collection, sorting and recycling activities.[75][76] However, the economic case is strengthened when considering indirect effects and externalities, such as marine litter and pollution, and their impacts on the tourism industry, for instance. Environmental benefits are varied and widespread, ranging from energy and GHG emissions savings and decreased use of natural resources, to curtailed plastic pollution and health benefits.[77][78]

Stakeholders: Central government, municipal authorities, waste management companies and plastic packaging manufacturers.

	Barriers	Enablers
Legal and regulatory	• Plastic waste exports	• Supportive taxation and regulation ensuring cost-competitiveness of recycling plants • EU targets for plastic waste recycling • Standards & Certifications
Cultural	• Consumer convenience and habits	• Increased awareness resulting in higher separate collection rates
Economic and financial	• Cheaper waste treatment alternatives (for instance, incineration) • Lack of funding	• Making alternatives easily available (not necessarily cheaper) (see Strategy 3.2) • Growing demand for recycled materials

[74] Flanders Investment & Trade. (2018). Waste and water management in Croatia. Retrieved from: Flanders Investment & Trade website

[75] Phung, C. G. (2019). Implications of the circular economy and digital transition on skills and green jobs in the plastics industry. Retrieved from: Open Edition Journals website

[76] Platform for Accelerating the Circular Economy (PACE). (2021). Circular Economy Action Agenda for Plastics. Retrieved from: PACE website

[77] Circle Economy. (2020). Will you be my partner? Retrieved from: Circle Economy website

[78] EuRIC. (2020). Plastic recycling factsheet. Retrieved from: European Circular Economy Stakeholder Platform website

	• High acquisition costs for new technologies	
Technological and capacity-based	• Quality of recycled plastic may be lower and not suitable for certain products	• Introduction of 100% recyclable plastic packaging and implementation of take-back schemes (Strategies 3.1 & 3.2) • Effective waste collection and separation systems

4.4 Textiles

The textile manufacturing sector has a relatively minor yet still significant overall footprint, particularly in terms of material consumption and GHG emissions. Similar to plastics, eco-design, collection rates, and adequate infrastructure are essential to advance circularity in the sector and across the whole value chain. The four proposed strategies build upon one another and aim to tackle these three major factors. Eco-design (strategy 4.4.1) is fundamental for expanding the use of fabrics and fibres made from recycled feedstock and thus enable their use in high-quality applications. It is also a fundamental enabler for advancing circularity across the whole value chain. Adequate collection of textiles (strategy 4.4.2) is crucial to effectively sort, recycle and reuse textile products (strategy 4.4.3), and thus increase material recovery by preventing landfilling or incineration (and the high carbon footprint associated with these disposal options). Modern recycling infrastructure is key to overcoming challenges related to textiles recycling (for example, inadequate quality and cleanliness) and ensure the effective recycling of textiles and direct reuse of quality secondary materials. Finally, extending the lifespan of textile products, such as clothing and footwear (strategy 4.4.4), is critical for reducing the mass, carbon and waste footprints of the sector, particularly given how 'fast fashion' has dramatically increased the volume of virgin fabrics used, the speed at which textile products are disposed of, and thus the volumes of textile waste generated.

4.4.1 Design textile products to be recyclable and reusable.

Description: This strategy aims to slow material and energy flows by introducing circular practices, through their design or material selection, into textile manufacturing processes. Eco-design approaches are beneficial upstream approaches that then trickle down and ease downstream activities such as recycling (Strategy 4.4.3) and repair and reuse (Strategy 4.4.4).

Impact: Designing for disassembly, recyclability and reuse can result in reduced material and resource inputs, namely water, chemicals and energy. These strategies could also reduce the carbon footprint of textiles and clothing manufacturing.[79] Moreover, they present an opportunity to add value to domestic production, particularly to promote local SMEs that can specialise in these activities, strengthening their competitiveness and potentially creating new job opportunities.

Stakeholders: Clothing designers, textile manufacturers, municipalities and waste management companies.

	Barriers	Enablers
Legal and regulatory	• Lack of legal requirements (for instance, compulsory obligations and norms) • Lack of standards	• EPR scheme for textiles • Fiscal incentives (for instance, reduced VAT) for eco-design of textiles

[79] Muthu, S.S. et al. (2012). Carbon footprint reduction in the textile process chain: Recycling of textile materials. doi:10.1007/s12221-012-1065-0

Cultural	• Higher prices than alternatives • Lack of commitment and vision by senior management	• Increased awareness and demand for recycled/recyclable products
Economic and financial	• Disassembly and reuse of materials and fibres can be more expensive than producing from virgin fibres	• Clear communication of the economic benefits
Technological and capacity-based	• Lack of control over design, material selection and processes	

4.4.2 Encourage household collection of textiles.

Description: This strategy aims to close material flows by enabling citizens to sort and drop off their household textiles conveniently, and for them to then be transported and further processed for reuse. This strategy builds on the previous Strategy (4.4.1) and relates strongly to the next two Strategies (4.4.3 and 4.4.4), as effective collection is fundamental to recycling and reusing textiles.

Impact: Increased household collection rates can reduce the landfilling and incineration of textiles, thus reducing GHG emissions. More importantly, collection is fundamental to the valorisation and further reuse of textiles, which results in the prevention of new textile production, and thus reduced material inputs (water, chemicals, fibres) and energy consumption (GHG emissions). The social impact of this strategy is also substantial, as it can increase awareness about sustainability and (excess) household textile consumption. There are also economic and employment opportunities to be derived from the collection, sorting, storage and transport of textiles to recycling and other facilities.

Stakeholders: Municipalities, households, logistics and waste management companies, and textiles recycling facilities.

	Barriers	Enablers
Legal and regulatory		• Mandatory collection
Cultural	• Lack of consumer awareness	• Abundant placement of textile bins and signage
Economic and financial	• Value may not be recoverable from waste streams • Collection, sorting and storing costs	• Appropriate location of textile facilities to enable processing (see Strategy 4.3) • Tendering textile collection to a private third party
Technological and capacity-based	• Implementing more bins in the public space alongside an efficient collection system	• Distributing textile bags (protective with drawstrings) • Making textile bins visible and conveniently located

4.4.3 Implement chemical and mechanical recycling strategies to recover textiles from waste streams.

Description: This strategy partly builds on the previous two (4.4.1 and 4.4.2), and aims to close resource flows for materials and energy by maximising the recovery of materials from textile waste streams and their transformation into new materials. Bringing this strategy to life could involve, for example, flexible/hybrid recycling plants where both mechanical and chemical recycling can take place in a cost efficient manner and deliver secondary raw materials.

Impact: Environmentally speaking, recycling textiles reduces material and energy consumption, and can also lower water, chemicals and energy consumption across the production chain. It can also cut GHG emissions by reducing the overall use of new textile products, and thus demand for primary raw materials.[80][81] A fully integrated advanced textiles recycling system is also projected to result in local economic development and job creation due to the labour intensiveness of the processes, and through locally retaining the value of clothing and other textile products.[82]

Stakeholders: Recycling companies, local authorities, waste management companies, researchers and experts.

	Barriers	Enablers
Legal and regulatory	• Regulatory uncertainty and overcomplexity for combined recycling activities	• EPR scheme for textiles to promote eco-design and hence ease recycling • Fiscal incentives (for instance, reduced VAT) for recycling activities • Prohibition of incineration and landfilling • Strict regulations for separate collection
Cultural	• Lack of consumer awareness	• Clear communication about the benefits of recycling
Economic and financial	• Lower prices for virgin fibres • Immature, small market	
Technological and capacity-based	• Lack of necessary equipment and machinery, particularly in SMEs • Difficult to ensure quality of recycled fibres	• Investment in necessary infrastructure (collection, sorting, storage, transport, *etcetera*)

4.4.4 Stimulate second-hand clothing and repair/renewal services in attractive retail environments.

Description: This strategy aims to slow resource flows for materials and energy by extending the lifetime of textile products. Second-hand clothing shops or markets, clothing libraries, and repair cafés or shops are all avenues that can stimulate the repair and use of second-hand clothing, particularly when placed in attractive retail environments.

Impact: Economic, job and value creation through the sourcing, laundering and retail of second-hand clothes, as well as in labour-intensive services to repair and maintain clothing.[83] From an environmental perspective, extending the lifetime of clothing and textile products is more beneficial than recycling, given that it prevents or reduces new textiles and clothing production.[84] In this sense, environmental benefits are

[80] Muthu, S.S., Li, et al. (2012). Carbon footprint reduction in the textile process chain: Recycling of textile materials. doi:10.1007/s12221-012-1065-0

[81] Zamani, B. (2014). Towards Understanding Sustainable Textile Waste Management: Environmental impacts and social indicators. Retrieved from: Chalmers University website

[82] Ellen MacArthur Foundation (EMF). (2017). A New Textiles Economy: Redesigning fashion's future. Retrieved from: EMF website

[83] Ellen MacArthur Foundation (EMF). (2017). A New Textiles Economy: Redesigning fashion's future. Retrieved from: EMF website

[84] Gustav, S. & Peters, G. M. (2018). Environmental impact of textile reuse and recycling – A review. doi: 10.1016/j.jclepro.2018.02.266

greater upstream in the value chain, for example, by lowering demand for cotton, chemicals and dyes, and transportation.[85]

Stakeholders: Public authorities, logistic and waste management companies, second hand clothing shops, repair cafés and consumers.

	Barriers	Enablers
Legal and regulatory		• Fiscal incentives (for instance, reduced VAT) for minor repair services and second-hand sales • Legal and regulatory ease of opening second-hand clothing shops and repair cafés
Cultural	• Hunger for fast fashion • Perceived hygiene or status of second-hand or repaired clothes	• Increased awareness and clear communication on the benefits of recycling • Making high quality second-hand clothing available
Economic and financial	• Ease of access of first-hand clothes and convenience (for instance, sizing, variety, *etcetera*) • Price to repair items may be high relative to new purchase • Lower remuneration and market demand for services prevents entrepreneurial action	
Technological and capacity-based	• Lacking logistics and infrastructure	• Repair workshops and training in schools • Digital platforms and apps for second-hand clothing and accessories

85 Niinimäki, K. et al. (2020). The environmental price of fast fashion. doi:10.1038/s43017-020-0039-9

Appendices

Appendix A: Methodology

A.1: Methodological note on IO-based footprints

Typical for highly industrialised, service-oriented economies, Croatia is a net importer of resources: more resources are imported than exported. In this study, a consumption-based perspective has therefore been taken in a bid to generate actionable insights for production and consumption on the ground. This has also been the approach in previous *Circularity Gap Report* studies. Demand-based indicators applied in this analysis allow for a re-allocation of environmental stressors from producers in Croatia and the Rest of the World (RoW) to final consumers in Croatia. In terms of footprinting, this means all the products and materials that went into meeting final demand in Croatia were accounted for, excluding those extracted or processed domestically but consumed elsewhere.

In the application of Input-Output Analysis (IOA) to materials, *id est* material footprinting, it is important to make a distinction between so-called direct physical flows and flows of Raw Material Equivalents (RME). Direct physical flows, namely Domestic Extraction (DE), imports and exports are not the main scope of IOA. Only DE is accounted for and used for the calculation of flows in RMEs. One key difference between, for instance, direct imports and RME imports is that, while the former measures the physical weight of imported commodities, the latter measures the volume of resources (DE) embodied in the direct imports. Footprint accounts are calculated through the following set of standard Input-Output formulas. The definition of each symbol can be found in Table 5.

$$D_{cba}^{i} = D_{pba}^{i} + D_{imp}^{i} - D_{exp}^{i}$$
$$D_{pba} = Fe + Ge$$
$$D_{imp} = MY_t$$
$$D_{exp} = \widehat{MY_t}e$$

TABLE 5 - Definition and symbol of Input-Output formulas

Variable name	Symbol	Description
Consumption-based accounts	D_{cba}^{i}	Footprint of consumption
Production-based accounts	D_{pba}^{i}	Footprint of production or territorial accounts
Imports accounts	D_{imp}^{i}	Footprint of imports or factors of production occurring abroad (embodied in imports) to satisfy domestic final demand
Exports accounts	D_{exp}^{i}	Footprint of exports or factors of production occurring domestically (embodied in exports) to satisfy final demand abroad
Factor production	F_e	Factors of production: extension plus value added block
Final demand factors	G_e	Factors of production: extension of final demand
Multipliers	$M = SL$	–

Leontief inverse	$L = (I - Z\widehat{x^{-1}})^{-1}$	Total requirements matrix
Factor production coefficients	$S = F\widehat{x^{-1}}$	–
Gross output	$x = Z_e + Y_e$	–
Transaction matrix	Z_e	Matrix of interindustry flows or intermediate transaction matrix
Final demand matrix	Y_e	–
Final demand matrix to satisfy factors of production abroad	$Y_t = Y - Y_{i,j} \| i = j$	Final demand matrix with domestically satisfied final demand set to zero

Note: the $\widehat{\ }$ symbol represents the diagonalised vector, the e symbol represents a summation vector of 1s.

A.2: Croatia's Circularity Metric and Indicator Framework

The Circularity Metric is an economy-wide indicator of the state of circularity of an economy having the following characteristics:

- It is an input-side indicator (as opposed to output-side such as recycling), thus measuring the share of secondary material consumption of the total material consumption of an economy;
- It takes a consumption-based perspective, and it allocates the merits of imported secondary materials (both waste destined to recycling and recycled materials embodied in imports) to the importing country[86];
- It takes a life-cycle perspective and is therefore based on the Raw Material Consumption (RMC) rather than the Domestic Material Consumption (DMC) of a country.

In mathematical terms, the metric and the assumptions behind it are condensed in the following equations set, with the variable definitions listed in Table 6. The technical details of the framework can be found in Appendix A.6.

$$NCM = \frac{smc_i + wu_i}{RMC_i + smc_i + wu_i}$$

$$\text{with } \frac{smc_i}{RMC_i} = \frac{smi_i}{RMI_i}$$

$$smc_i = \frac{RMC_i}{RMI_i} * smi_i$$

$$smi_i = sm_i + (imp_i * GCM_i)$$

TABLE 6 - NCM-related variable definitions

Variable	Definition
sm_i	Secondary materials of resource group i deployed domestically
smi_i	Secondary materials of resource group i deployed domestically and imported (the latter include imported waste for recycling and share of secondary materials in imported products)
smc_i	Secondary materials of resource group i consumed domestically

[86] This allocation principle is one of the main differences with the Circular Material Use Rate (CMUR) calculated by Eurostat (see *Comparison between Eurostat's Circular Material Use Rate (CMUR) and CE's Circularity Metric* in section two, below Figure four for more information).

wu_i	Waste of resource group i reused domestically without (or with minimal) pre-processing
imp_i	Direct physical imports of physical products of resource group i
RMI_i	Raw Material Input of resource group i
RMC_i	Raw Material Consumption of resource group i
GCM	Global Circularity Metric[87] of resource group i
NCM_i	National Circularity Metric of resource group i

With a total consumption of raw plus secondary materials (also termed Processed Materials) of **55.6 million tonnes**, Croatia's circularity stands at **2.7%**, leaving a Circularity Gap of **97.3%**. The Circularity Gap can be broken down into a set of additional indicators that help to shed more light on the dynamics behind measuring circularity and the circular economy as a whole. The definitions for each indicator are listed in the following table.

TABLE 7 - Definition of key variables and indicators of the framework

	Dimension	Code	Input-side Indicator
Scale indicators (t/yr)	*Inflow*	–	*Secondary Material Consumption* ***(SMC)***
	Inflow	–	*Domestic Material Consumption* ***(DMC)***
	Inflow	–	*Raw Material Consumption* ***(RMC)***
	Outflow	–	*Net Extraction Abroad* ***(NEA)*** *= RMC - DMC*
	Interim flows	–	*Processed Materials* ***(PM)*** *= RMC + SMC*
Rate Indicators (%)	*Socioeconomic cycling*	*SC*	*Input socioeconomic cycling rate* ***(ISCr):*** *Share of SMC in PM*
	Ecological Cycling potential	*ECp*	*Input ecological cycling potential* ***(IECrp)****: Share of renewable primary biomass inputs in DMC (so excluding SM)*
	Non-Renewable Biomass	*NRB*	*All non-renewable biomass inputs (**NRBI)** defined as the ratio of net C in DMC biomass (dry content) to the net C in LULUCF*
	Non-Circular Inputs	*NCI*	*Input non-circularity rate* ***(INCr)****: Share of eUse of fossil energy carriers in PM*

[87] Due to the absence of extensive data on the trade and consumption of secondary materials, these have been estimated by introducing two assumptions:

1. To estimate the volume of secondary materials imported, the average Global Circularity Metric (GCM) calculated per resource group was applied to the country-specific direct physical imports aggregated by resource group. Because the GCM includes waste for recycling and partially also secondary materials, it is assumed to be a good proxy for the estimation of the total amount of imported secondary materials.
2. In order to understand the amount of secondary materials that are consumed domestically, rather than exported, it was assumed that the share of secondary materials in the total consumption of raw materials is equal to the share of imported and domestically cycled secondary materials in the total input of raw materials. This assumption is applied at the level of single resource groups (Non-Metallic Minerals, Metal Ores, Fossil Fuels and Biomass). For example: if the share of secondary biomass, say recycled paper, in the total input of biomass is 1%, then the share of recycled paper consumed in the total consumption of biomass will also be 1%.

	Non-Renewable Inputs	*NRI*	*All non-renewable inputs excluding NRB and NC*
	Net Additions to Stock	*NAS*	*Share of NAS in PM*
	Net Extraction Abroad	*NEA*	*Share of NEA in PM*

SOURCE - own elaboration based on Mayer et al. (2018)

A.3: Waste flow codes (W-Code) for NACE waste categories as reported by Eurostat and allocation to main ew-MFA categories and material or energetic use.

The conceptual gap between waste statistics and ew-MFA is based on different reporting classifications, and waste flows have been allocated to ew-MFA categories based on the main material components of waste flows. This was only feasible at the level of the main material groups distinguished in ew-MFA: biomass, fossil energy carriers, industrial minerals, construction minerals, metal ores.[88]

Table 8 shows detailed allocations of each waste flow to the aforementioned ew-MFA main material categories, and whether waste flows stem from eUse or mUse. Expert informed assumptions were necessary to judge whether waste flows reported in statistics result from energetic or material use. Most waste flows could unambiguously be allocated to wastes from material use. Among the waste flows originating from energetic use were animal and vegetal wastes (W09) and combustion wastes (W124). A few flows recorded in waste statistics were excluded, since they are following a different system boundary and thus are not recorded as extraction in ew-MFA statistics. The most important flows quantitatively that were excluded were soils (W126) and dredging spoils (W127). For a detailed allocation of waste flows to ew-MFA categories, see the Table eight below (based on Mayer et al. 2018).

[88] The differences between this categorisation and the one from the sankey is as follows. 'Biomass' is the same as in the sankey. 'Fossil energy carriers' include 'fossil fuels' from sankey. 'Metal ores' equal 'ores' from sankey. 'Industrial minerals' and 'construction minerals' are added together to 'non-metallic minerals', called 'minerals' in sankey.

TABLE 8 - Allocations of each waste flow to the aforementioned ew-MFA main material categories, and whether waste flows stem from eUse or mUse

WST_OPER (Labels)	Exclude from calculation	Biomass	Metals	Industrial Minerals	Fossils	Construction Minerals	Total	Material Use	Energetic Use	Reference
WASTE (Labels)										
Total waste	Aggregate	-	-	-	-	-	0	-	-	-
Chemical and medical wastes (subtotal)	**Aggregate**	-	-	-	-	-	**0**	**-**	**-**	-
Spent solvents	–	-	-	-	1.00	-	1	1	-	Eurostat
Acid, alkaline or saline wastes	–	-	-	1.00	-	-	1	1	-	Eurostat
Used oils	–	-	-	-	1.00	-	1	1	-	Eurostat
Chemical wastes	–	0.07	0.16	0.18	0.59	-	1	1	-	Eurostat
Industrial effluent sludges	–	0.42	0.08	0.43	0.06	-	1	1	-	Eurostat
Sludges and liquid wastes from waste treatment	Double-counting	-	-	-	-	-	0	-	-	-
Health care and biological wastes	–	0.62	0.01	0.03	0.35	-	1	1	-	Eurostat
Recyclable wastes (subtotal, W06+W07 except W077)	**Aggregate**	-	-	-	-	-	**0**	**-**	**-**	-
Metal wastes, ferrous	Included in W06	-	-	-	-	-	0	-	-	-
Metal wastes, non-ferrous	Included in W06	-	-	-	-	-	0	-	-	-
Metal wastes, mixed ferrous and non-ferrous	Included in W06	-	-	-	-	-	0	-	-	-
Glass wastes	–	-	-	1.00	-	-	1	1	-	Eurostat
Paper and cardboard wastes	–	1.00	-	-	-	-	1	1	-	Eurostat
Rubber wastes	–	0.06	0.20	-	0.75	-	1	1	-	Mayer
Plastic wastes	–	-	-	-	1.00	-	1	1	-	Eurostat
Wood wastes	–	1.00	-	-	-	-	1	1	-	Eurostat
Textile wastes	–	0.30	-	-	0.70	-	1	1	-	Eurostat
Equipment (subtotal, W077+W08A+W081+W0841)	**Aggregate**	-	-	-	-	-	**0**	**-**	**-**	-
Waste containing PCB	–	-	0.50	0.50	-	-	1	1	-	Mayer
Discarded equipment (except discarded vehicles and batteries	–	-	1.00	-	-	-	1	1	-	Mayer
Discarded vehicles	–	-	1.00	-	-	-	1	1	-	Mayer
Batteries and accumulators wastes	–	-	1.00	-	-	-	1	1	-	Mayer
Animal and vegetal wastes (subtotal, W091+W092+W093)	**Aggregate**	-	-	-	-	-	**0**	**-**	**-**	-
Animal and mixed food waste	Included in W091_092	-	-	-	-	-	0	-	-	-
Vegetal wastes	Included in W091_092	-	-	-	-	-	0	-	-	-
Animal faeces, urine and manure	Double-counting	-	-	-	-	-	0	-	-	-
Mixed ordinary wastes (subtotal, W101+W102+W103)	**Aggregate**	-	-	-	-	-	**0**	**-**	**-**	-
Household and similar wastes	Country-specific	0.64	0.07	0.01	0.16	0.12	1	1	-	Eurostat
Mixed and undifferentiated materials	–	0.31	0.11	0.01	0.48	0.09	1	1	-	Eurostat
Sorting residues	–	0.49	0.10	0.30	0.11	-	1	1	-	Eurostat
Common sludges	–	1.00	-	-	-	-	1	-	1	Eurostat
Mineral and solidified wastes (subtotal)	**Aggregate**	-	-	-	-	-	**0**	**-**	**-**	-
Mineral waste from construction and demolition	–	0.01	-	-	0.03	0.96	1	1	-	Eurostat
Other mineral wastes (W122+W123+W125)	–	-	-	-	-	1.00	1	1	-	Eurostat
Combustion wastes	–	-	-	-	1.00	-	1	-	1	-
Soils	Exclude	-	-	-	-	-	0	-	-	-
Dredging spoils	Exclude	-	-	-	-	-	0	-	-	-
Mineral wastes from waste treatment and stabilised wastes	Double-counting	-	-	-	-	-	0	-	-	-
Metallic wastes (W061+W062+W063)	**–**	-	1.00	-	-	-	**1**	**1**	**-**	Mayer
Animal and mixed food waste; vegetal wastes (W091+W092)	–	1.00	-	-	-	-	1	-	1	Mayer

SOURCE - env_wastrt accounts (Eurostat, 2018)

Legend: WASTE/WST_OPER = Waste category, Exclude from calculations = Exclusion of individual categories to eliminate double-counting, aggregated categories, and alignment with ew-MFA system boundaries, Biomass, Metals, Industrial minerals, Fossils, Construction = Share of individual waste flow categories in ew-MFA main material category, Total = Sum of shares, Material use = Share of waste stemming from material use, Energetic use = share of waste stemming from energetic use.

A.4: Category aggregation of sectors in MVC-W nexus

Sector	Initial Category	Revised Category
Cultivation of paddy rice	Agrifood	Agri
Cultivation of wheat	Agrifood	Agri
Cultivation of cereal grains nec	Agrifood	Agri
Cultivation of vegetables, fruit, nuts	Agrifood	Agri
Cultivation of oil seeds	Agrifood	Agri
Cultivation of sugar cane, sugar beet	Agrifood	Agri
Cultivation of plant-based fibers	Agrifood	Agri
Cultivation of crops nec	Agrifood	Agri
Cattle farming	Agrifood	Agri
Pigs farming	Agrifood	Agri
Poultry farming	Agrifood	Agri
Meat animals nec	Agrifood	Agri
Animal products nec	Agrifood	Agri
Raw milk	Agrifood	Agri
Wool, silk-worm cocoons	Agrifood	Agri
Manure treatment (conventional), storage and land application	Agrifood	Agri
Manure treatment (biogas), storage and land application	Agrifood	Agri
Forestry, logging and related service activities (02)	Furniture and woodwork	Furniture and woodwork
Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing (05)	Agrifood	Agri
Mining of coal and lignite; extraction of peat (10)	Mining and extraction	Mining and extraction
Extraction of crude petroleum and services related to crude oil extraction, excluding surveying	Mining and extraction	Mining and extraction
Extraction of natural gas and services related to natural gas extraction, excluding surveying	Mining and extraction	Mining and extraction
Extraction, liquefaction, and regasification of other petroleum and gaseous materials	Mining and extraction	Mining and extraction

Mining of uranium and thorium ores (12)	Mining and extraction	Mining and extraction
Mining of iron ores	Mining and extraction	Mining and extraction
Mining of copper ores and concentrates	Mining and extraction	Mining and extraction
Mining of nickel ores and concentrates	Mining and extraction	Mining and extraction
Mining of aluminium ores and concentrates	Mining and extraction	Mining and extraction
Mining of precious metal ores and concentrates	Mining and extraction	Mining and extraction
Mining of lead, zinc and tin ores and concentrates	Mining and extraction	Mining and extraction
Mining of other non-ferrous metal ores and concentrates	Mining and extraction	Mining and extraction
Quarrying of stone	Mining and extraction	Construction
Quarrying of sand and clay	Mining and extraction	Construction
Mining of chemical and fertilizer minerals, production of salt, other mining and quarrying n.e.c.	Mining and extraction	Mining and extraction
Processing of meat cattle	Agrifood	Food
Processing of meat pigs	Agrifood	Food
Processing of meat poultry	Agrifood	Food
Production of meat products nec	Agrifood	Food
Processing vegetable oils and fats	Agrifood	Food
Processing of dairy products	Agrifood	Food
Processed rice	Agrifood	Food
Sugar refining	Agrifood	Food
Processing of Food products nec	Agrifood	Food
Manufacture of beverages	Agrifood	Food
Manufacture of fish products	Agrifood	Food
Manufacture of tobacco products (16)	Manufacture	Manufacture
Manufacture of textiles (17)	Manufacture	Textiles
Manufacture of wearing apparel; dressing and dyeing of fur (18)	Manufacture	Textiles
Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear (19)	Manufacture	Textiles

Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (20)	Furniture and woodwork	Furniture and woodwork
Re-processing of secondary wood material into new wood material	Furniture and woodwork	Furniture and woodwork
Pulp	Manufacture	Manufacture
Re-processing of secondary paper into new pulp	Manufacture	Manufacture
Paper	Manufacture	Manufacture
Publishing, printing and reproduction of recorded media (22)	Manufacture	Manufacture
Manufacture of coke oven products	Manufacture	Manufacture
Petroleum Refinery	Chemicals	Chemicals
Processing of nuclear fuel	Manufacture	Manufacture
Plastics, basic	Plastics & Packaging	Plastics
Re-processing of secondary plastic into new plastic	Plastics & Packaging	Plastics
N-fertiliser	Chemicals	Chemicals
P- and other fertiliser	Chemicals	Chemicals
Chemicals nec	Chemicals	Chemicals
Manufacture of rubber and plastic products (25)	Plastics & Packaging	Plastics
Manufacture of glass and glass products	Construction	Construction
Re-processing of secondary glass into new glass	Manufacture	Manufacture
Manufacture of ceramic goods	Manufacture	Manufacture
Manufacture of bricks, tiles and construction products, in baked clay	Construction	Construction
Manufacture of cement, lime and plaster	Manufacture	Construction
Re-processing of ash into clinker	Manufacture	Construction
Manufacture of other non-metallic mineral products n.e.c.	Manufacture	Manufacture
Manufacture of basic iron and steel and of ferro-alloys and first products thereof	Manufacture	Construction
Re-processing of secondary steel into new steel	Manufacture	Manufacture
Precious metals production	Manufacture	Manufacture
Re-processing of secondary precious metals into new precious metals	Manufacture	Manufacture

Aluminium production	Manufacture	Manufacture
Re-processing of secondary aluminium into new aluminium	Manufacture	Manufacture
Lead, zinc and tin production	Manufacture	Manufacture
Re-processing of secondary lead into new lead, zinc and tin	Manufacture	Manufacture
Copper production	Manufacture	Manufacture
Re-processing of secondary copper into new copper	Manufacture	Manufacture
Other non-ferrous metal production	Manufacture	Manufacture
Re-processing of secondary other non-ferrous metals into new other non-ferrous metals	Manufacture	Manufacture
Casting of metals	Manufacture	Manufacture
Manufacture of fabricated metal products, except machinery and equipment (28)	Manufacture	Manufacture
Manufacture of machinery and equipment n.e.c. (29)	Manufacture	Manufacture
Manufacture of office machinery and computers (30)	Manufacture	Manufacture
Manufacture of electrical machinery and apparatus n.e.c. (31)	Manufacture	Manufacture
Manufacture of radio, television and communication equipment and apparatus (32)	Manufacture	Manufacture
Manufacture of medical, precision and optical instruments, watches and clocks (33)	Manufacture	Manufacture
Manufacture of motor vehicles, trailers and semi-trailers (34)	Mobility and Transport	Mobility and Transport
Manufacture of other transport equipment (35)	Mobility and Transport	Mobility and Transport
Manufacture of furniture; manufacturing n.e.c. (36)	Furniture and woodwork	Furniture and woodwork
Recycling of waste and scrap	Waste management	Waste management
Recycling of bottles by direct reuse	Waste management	Waste management
Production of electricity by coal	Utilities	Utilities
Production of electricity by gas	Utilities	Utilities
Production of electricity by nuclear	Utilities	Utilities
Production of electricity by hydro	Utilities	Utilities
Production of electricity by wind	Utilities	Utilities
Production of electricity by petroleum and other oil derivatives	Utilities	Utilities

Production of electricity by biomass and waste	Utilities	Utilities
Production of electricity by solar photovoltaic	Utilities	Utilities
Production of electricity by solar thermal	Utilities	Utilities
Production of electricity by tide, wave, ocean	Utilities	Utilities
Production of electricity by Geothermal	Utilities	Utilities
Production of electricity nec	Utilities	Utilities
Transmission of electricity	Utilities	Utilities
Distribution and trade of electricity	Utilities	Utilities
Manufacture of gas; distribution of gaseous fuels through mains	Utilities	Utilities
Steam and hot water supply	Utilities	Utilities
Collection, purification and distribution of water (41)	Utilities	Utilities
Construction (45)	Construction	Construction
Re-processing of secondary construction material into aggregates	Construction	Construction
Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessories	Mobility and Transport	Mobility and Transport
Retail sale of automotive fuel	Wholesale and Retail	Wholesale and Retail
Wholesale trade and commission trade, except of motor vehicles and motorcycles (51)	Wholesale and Retail	Wholesale and Retail
Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods (52)	Wholesale and Retail	Wholesale and Retail
Hotels and restaurants (55)	Tourism	Tourism
Transport via railways	Mobility and Transport	Mobility and Transport
Other land transport	Mobility and Transport	Mobility and Transport
Transport via pipelines	Mobility and Transport	Mobility and Transport
Sea and coastal water transport	Mobility and Transport	Mobility and Transport
Inland water transport	Mobility and Transport	Mobility and Transport
Air transport (62)	Mobility and Transport	Mobility and Transport
Supporting and auxiliary transport activities; activities of travel agencies (63)	Mobility and Transport	Mobility and Transport
Post and telecommunications (64)	Other Services	Other Services

Financial intermediation, except insurance and pension funding (65)	Other Services	Other Services
Insurance and pension funding, except compulsory social security (66)	Other Services	Other Services
Activities auxiliary to financial intermediation (67)	Other Services	Other Services
Real estate activities (70)	Other Services	Other Services
Renting of machinery and equipment without operator and of personal and household goods (71)	Other Services	Other Services
Computer and related activities (72)	Other Services	Other Services
Research and development (73)	Other Services	Other Services
Other business activities (74)	Other Services	Other Services
Public administration and defence; compulsory social security (75)	Other Services	Other Services
Education (80)	Healthcare, education and recreation	Healthcare, education and recreation
Health and social work (85)	Healthcare, education and recreation	Healthcare, education and recreation
Incineration of waste: Food	Waste management	Waste management
Incineration of waste: Paper	Waste management	Waste management
Incineration of waste: Plastic	Waste management	Waste management
Incineration of waste: Metals and Inert materials	Waste management	Waste management
Incineration of waste: Textiles	Waste management	Waste management
Incineration of waste: Wood	Waste management	Waste management
Incineration of waste: Oil/Hazardous waste	Waste management	Waste management
Biogasification of food waste, incl. land application	Waste management	Waste management
Biogasification of paper, incl. land application	Waste management	Waste management
Biogasification of sewage slugde, incl. land application	Waste management	Waste management
Composting of food waste, incl. land application	Waste management	Waste management
Composting of paper and wood, incl. land application	Waste management	Waste management
Waste water treatment, food	Waste management	Waste management
Waste water treatment, other	Waste management	Waste management
Landfill of waste: Food	Waste management	Waste management

Landfill of waste: Paper	Waste management	Waste management
Landfill of waste: Plastic	Waste management	Waste management
Landfill of waste: Inert/metal/hazardous	Waste management	Waste management
Landfill of waste: Textiles	Waste management	Waste management
Landfill of waste: Wood	Waste management	Waste management
Activities of membership organisation n.e.c. (91)	Healthcare, education and recreation	Healthcare, education and recreation
Recreational, cultural and sporting activities (92)	Tourism	Tourism
Other service activities (93)	Other Services	Other Services
Private households with employed persons (95)	Other Services	Other Services
Extra-territorial organizations and bodies	Other Services	Other Services
Household transport	Mobility and Transport	Mobility and Transport
Residential heating and cooling	Utilities	Utilities

A.5: Comparison calculated emissions from fossil fuel combustion with data reported in emission statistics (Eurostat, 2018)

TABLE 9 - Comparison calculated emissions from fossil fuel combustion with data reported in emission statistics

Emission	Value (Mt)	molar mass molecule (g/mol)	molar mass element (g/mol)
Eurostat (2018)			
CO2	17.9	44	12
CH4	0.16	14	12
N2O	0.05	46	14
SO2	0.35	64	32
Sum excluding oxygen from air	5.26		
This study			
Fossil fuels (wet)	6.23		

Average vapor including vapor from combustion and excess H2 (%)	24%		
Fossil fuels (DM)	4.74		
Comparison			
Difference ew-MFA - emissions accounts (t)	-0.53		
Difference ew-MFA - emissions accounts (%)	10%		

SOURCE - Eurostat, 2018

The calculation includes all emissions to air from biomass including all gaseous outputs from humans and livestock which are only partly included in emission statistics. Therefore, the comparison was focused on emissions to air from fossil fuels. The following steps were performed (Mayer et al. 2018):

- The following emissions to air were extracted from Eurostat (2017c) for 2014.
    - Year 2014. All NACE branches plus households in tonnes for CO2, CH4, N2O and SO2.
- The emissions were converted into the chemical elements contained in the fuel at the point of extraction. Thus, CO2 was converted to C and SO2 to S. CH4 and N2O are emissions stemming from elements already included in fossil fuels.
- DMC fossil fuel data was extracted from the calculation files (originally from ew-MFA statistics) and used to deduce the vapour generated during combustion (H2O built from elements contained in fuel and excess H2). Standard moisture content was assumed for brown coal, hard coal, oil shale and tar sands, peat, crude oil, condensate and natural gas liquids, natural gas and fuel for land, water and air transport.
- Finally, fossil fuel emissions from dry matter (DM), derived from a calculation for emissions to air from emission accounts excluding oxygen from air, were examined. The table above (9) presents the results.
- The final calculation is about 5.7% higher than the emission accounts which seems to be a reasonable variation.

A.6: Technical details of Croatia's Material Flow Accounting

Model variable	Sources, calculation	Description
Domestic extraction	Material flow database (Eurostat, 2019)	Materials extracted from within the HR domestic environment
Imports	Material flow database (Eurostat, 2019)	Intra and Extra EU imports
Imported secondary materials	CE estimation	Includes both imported waste for recovery and secondary materials embodied in imports
Exports	Material flow database (Eurostat, 2019)	Intra and Extra EU exports
Exported secondary materials	CE estimation	Includes both exported waste for recovery and secondary materials embodied in exports

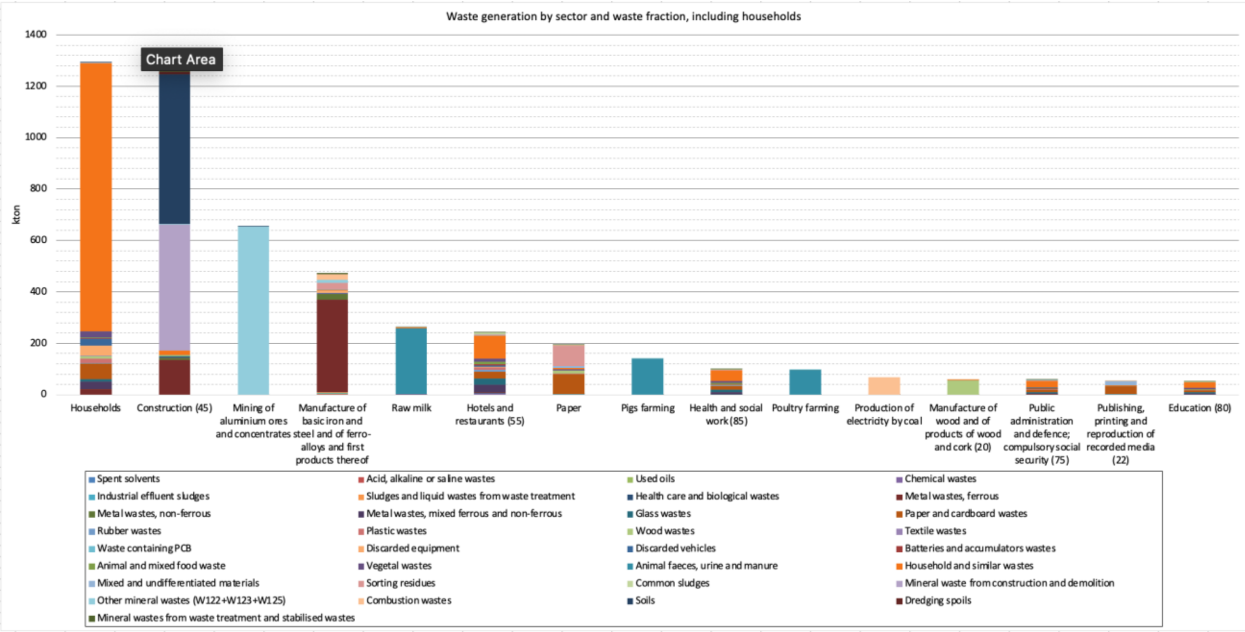
Domestic secondary materials	Waste statistics (Eurostat, 2018)	Re- and downcycling comprises flows reported as recycling or backfilling in waste statistics, where. recycling is defined as 'any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes' and backfilling as a recovery operation where waste is used in excavated areas (such as underground mines, gravel pits) and where the waste is substituting other non-waste materials which would have had to be used for the purpose. Materials that have been re- and downcycled are also referred to as secondary materials. Flows that are not consistent with ew-MFA system boundaries (*id est,* dredging spoils, soils) were excluded.
Throughput materials	MFA database, waste statistics and estimates	Short-lived products (life span of less than one year) and processing and manufacturing waste (recorded in waste statistics); wastage and deliberative dissipative uses (not recorded in waste statistics)
Mining waste	Calculated from DE of ores (Eurostat, 2019)	Waste rock from domestic mining
Emissions	Calculated and cross checked with Eurostat emission statistics	All gaseous outputs including vapor from combustion and human and animal respiration; oxygen input from air is excluded.
Solid and liquid waste from energetic use	Waste statistics (Eurostat, 2018) and calculated	Solid waste from combustion of fuels and excrements of humans and livestock at the water content of biomass intake (*id est,* excluding water uptake by humans and livestock)
EoL waste	Waste statistics (Eurostat, 2018) and calculated	Total end of life waste comprises all solid waste from eUse and mUse including throughput materials and extractive waste
Gross additions to stock	Calculated	Materials used to build up in-use stocks of materials (life span of less than one year)
Depletions from stock	Calculated based on waste statistics	Solid waste from discarded in-use stocks (comprises construction and demolition waste but also all other discarded long living products)
RME imports	Calculated from Exiobase v3.8, same as D_{imp}	Imports footprint
RME exports	Calculated from Exiobase v3.8, same as D_{exp}	Exports footprint
Direct material input	DE + imports	-
Direct material consumption	DMI - exports	-
Raw material input (RMI)	DE + RME imports	-
Raw material consumption (RMC)	Calculated from Exiobase v3.8, same as D_{cba}	Consumption-based material footprint
Processed materials (PM)	DMC + SMC	All primary and secondary materials consumed in the socioeconomic system
Processed materials (RME)	RMC + SMC	All primary and secondary materials consumed in the

		socioeconomic system in RME
Net extraction abroad (NEA)	RMC - DMC	Difference between consumption in direct and RME terms
Energetic use	Calculated from material flow database and information from (Mayer et al. 2018)	Fraction of PM that is used to provide energy. eUse comprises not only technical energy but also feed for livestock and food for humans.
Material use	Calculated from material flow database and information from (Mayer et al. 2018)	Fraction of PM that is used for material purposes. Comprises all metals and non metallic minerals, fractions of biomass and fossil energy carriers.
Interim outputs	Eol waste + emissions	All wastes and emissions after the use phase.
Net additions to stock	NAS = GAS - Depletions from stock	Net amount of materials that are added to the socioeconomic stocks
Domestic processed output from energy	DPOe = emissions + Liquid and solid waste	All DPO related to energy use
Domestic processed output from materials	DPOw = EoL waste - SM	All EoL waste excluding materials recovered for re- and downcycling. All liquid and solid outputs including moisture content as included in extracted material but excluding extra added water (for example, during industrial processes or drinking water).
Domestic processed output	DPOe + DPOw	Total domestic processed output to the environment (waste and emissions).

Appendix B: Croatia Results

B.1: Top 15 sectors (including households) by waste generation, split by waste fraction

FIGURE 7 - Waste generation by sector and waste fraction, including households



B.2: Mass balance of Croatia's Material Flow Accounting

Name	Edge Code	Value (million tonnes)				
		Biomass	Metal Ores	Non-metallic Minerals	Fossil Fuels	Total
Domestic extraction	1	15.56	0.00	24.22	1.62	**41.4**
Imports	2	5.01	2.43	4.50	7.42	**19.4**
Imported secondary materials	2.1	0.13	0.22	0.62	0.06	**1.0**
Exports	3	7.69	1.50	5.12	2.82	**17.1**
Exported secondary materials	3.1	0.10	0.00	0.30	0.02	**0.4**
Domestic secondary materials	4	0.30	0.09	0.33	0.18	**0.9**
Throughput materials	5	2.12	0.15	2.17	0.27	**4.7**
Mining waste	6	0.00	0.00	0.00	0.00	**0.0**
Emissions	7	0.00	0.00	0.00	5.79	**5.79**
Solid and liquid waste	8	7.93	0.00	0.00	0.00	**7.93**
EoL waste	9	3.21	0.19	2.74	0.43	**6.6**
Gross additions to stock	10	2.1	0.9	21.8	0.2	**25.0**

Depletions from stock	11	0.1	0.0	0.6	0.1	**0.7**
Name	**Node Code**	**Biomass**	**Metal Ores**	**Non-metallic Minerals**	**Fossil Fuels**	**Total**
RME imports	RIMP	8.69	1.86	10.20	9.36	**30.1**
RME exports	REXP	5.48	0	11.02	0.88	**17.4**
Direct material input	DMI	20.57	2.43	28.73	9.05	**60.8**
Direct material consumption	DMC	12.88	0.93	23.60	6.23	**43.6**
Raw material input	RMI	24.25	1.86	34.43	10.99	**71.5**
Raw material consumption	RMC	18.77	1.86	23.41	10.10	**54.1**
Processed materials	PM	13.21	1.24	24.25	6.44	**45.1**
Processed materials (RME)	PM_RME	19.10	2.16	24.06	10.32	**55.6**
Net extraction abroad (NEA)	NEA	5.89	0.93	-0.20	3.87	**10.5**
Energetic use	eUse	8.97	0.00	0.00	5.93	**14.9**
Material use	mUse	4.24	1.24	24.25	0.52	**30.2**
Interim outputs	IntOut	10.12	0.19	2.74	6.13	**19.2**
Net additions to stock	NAS	2.05	0.83	21.19	0.18	**24.2**
Secondary materials	SM	0.30	0.09	0.33	0.18	**0.9**
Domestic processed output from energy	DPOe	7.93	0.00	0.00	5.79	**13.7**
Domestic processed output from materials	DPOm	2.91	0.10	2.41	0.26	**5.7**
Domestic processed output	DPO	10.8	0.1	2.4	6.1	**19.4**

B.3: Material footprint behind satisfying Croatia's societal needs and link with the four key resource groups

Societal Need	Resource group	kton	Share
Communication	Non-Metallic Minerals	470.4	1.7%
	Biomass	144.0	
	Metal Ores	113.9	
	Fossil Fuels	207.6	
Healthcare	Non-Metallic Minerals	1344.8	6.6%
	Biomass	1158.7	
	Metal Ores	152.1	
	Fossil Fuels	996.5	
Housing	Non-Metallic Minerals	16050.2	39.8%
	Biomass	1456.2	
	Metal ores	591.5	
	Fossil Fuels	4059.7	
Manufactured goods	Non-Metallic Minerals	2457.6	9.7%
	Biomass	1228.2	
	Metal Ores	491.7	
	Fossil Fuels	1242.0	
Mobility	Non-Metallic Minerals	767.8	5.0%
	Biomass	472.8	
	Metal Ores	153.5	
	Fossil Fuels	1410.0	
Nutrition	Non-Metallic Minerals	1180.5	22.1%
	Biomass	10450.3	
	Metal Ores	143.1	
	Fossil Fuels	515.4	
Services	Non-Metallic Minerals	2111.3	15.1%
	Biomass	3832.5	
	Metal Ores	293.7	
	Fossil Fuels	2141.5	
Total (incl. SMC)	**All**	**55637**	**100%**

B.4: Croatia Material footprint and stressor

Figure 8 - Croatia's top 10 industries by material stressor

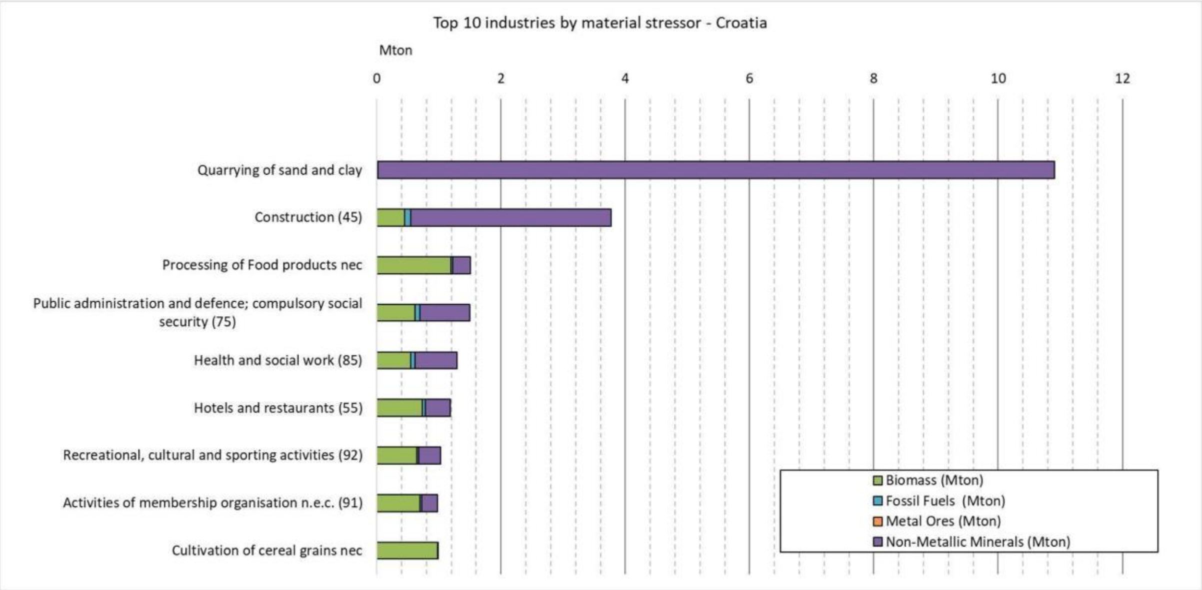


Figure 9 - Top 10 regions by material stressor for Croatia

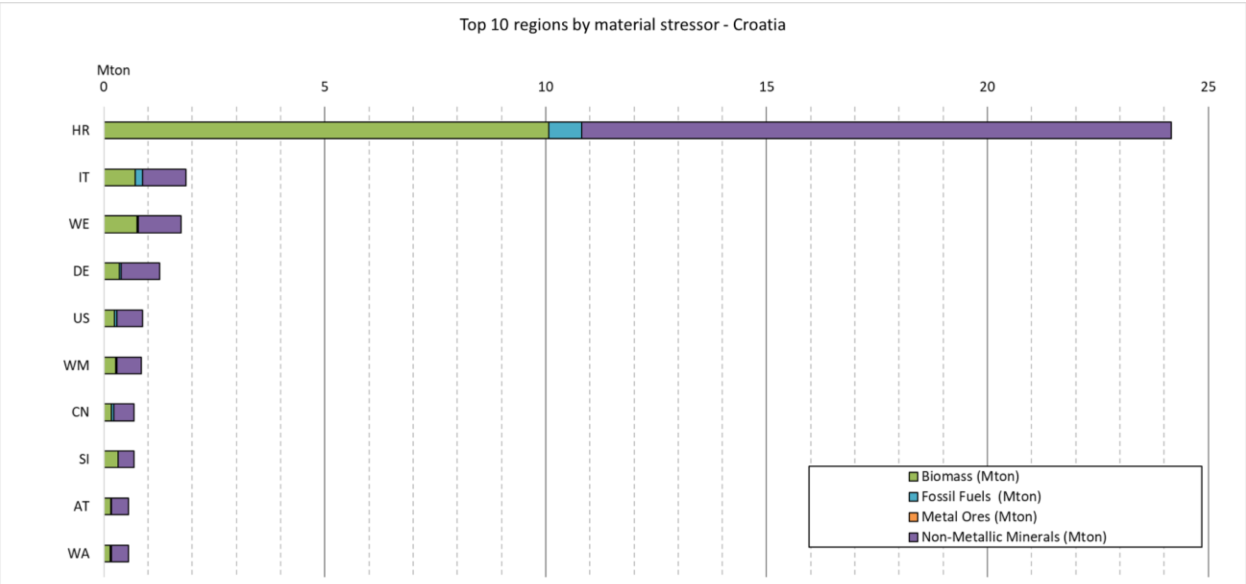
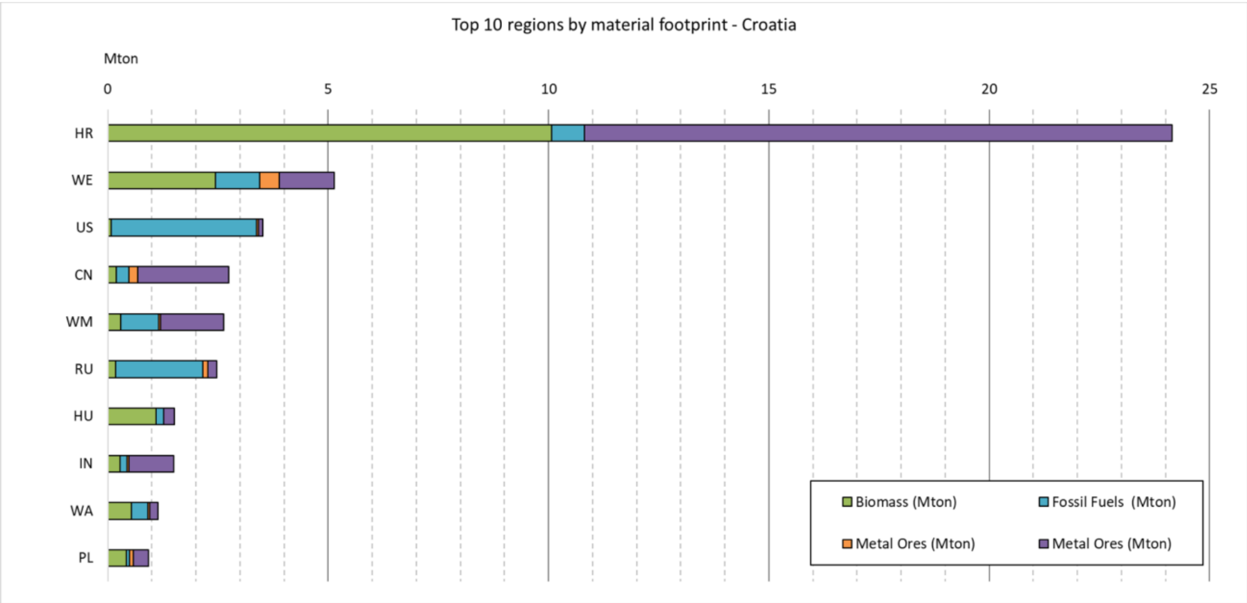


Figure 10 - Top 10 regions by material footprint



B.5: Croatia carbon footprint and stressor (GWP)

Figure 11 - Top 10 regions by carbon footprint (GWP), in Mt CO2e

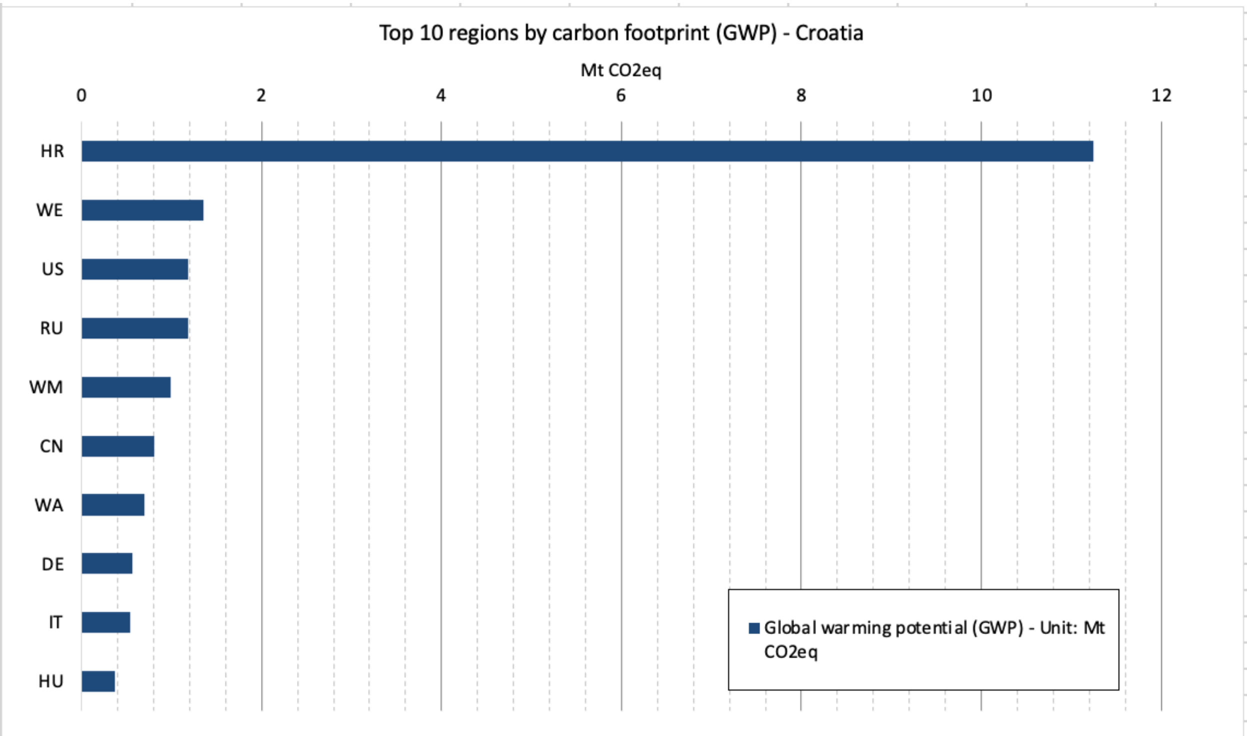


Figure 12 - Croatia's top ten industries by carbon footprint (GWP)

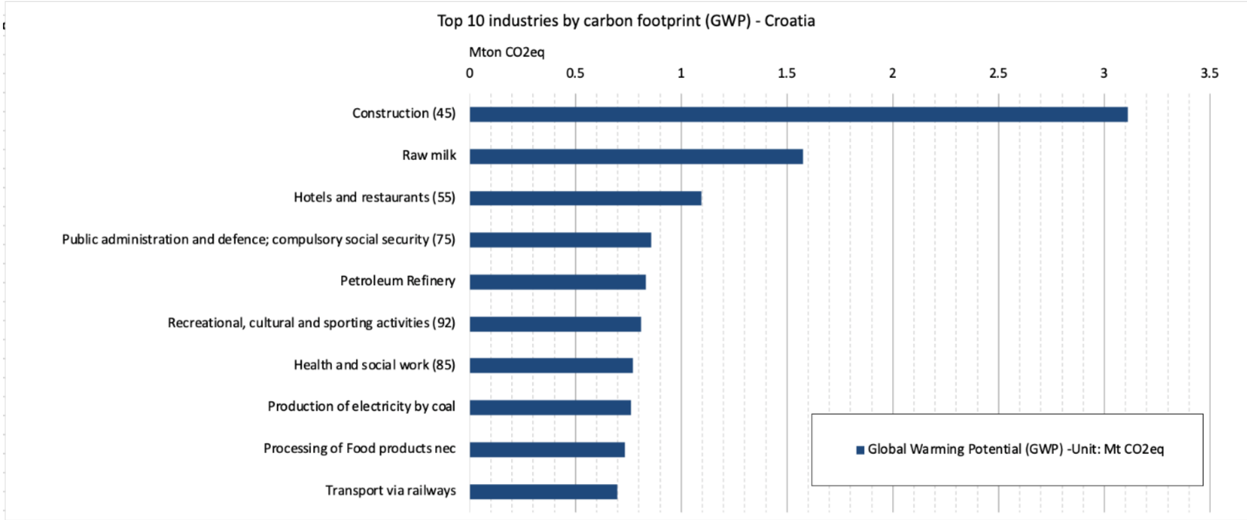


Figure 13 - Top ten regions by carbon stressor (GWP)

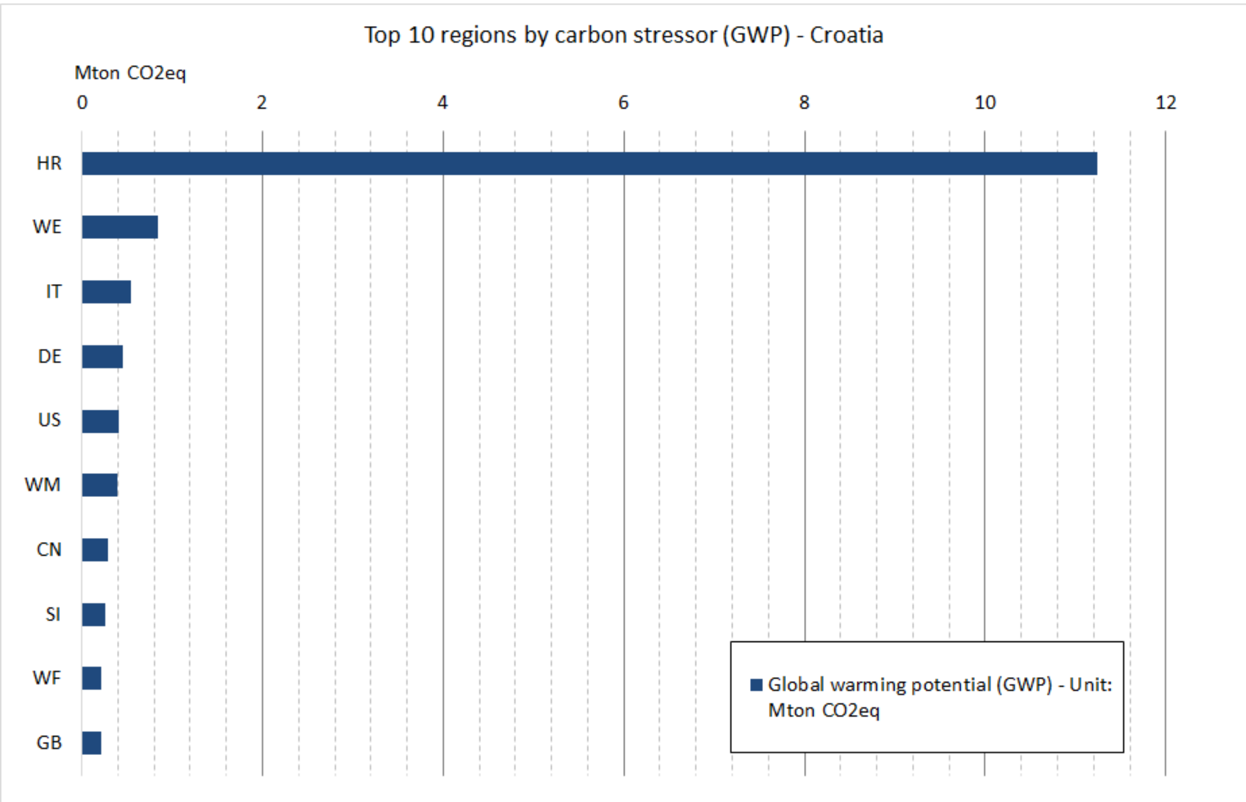
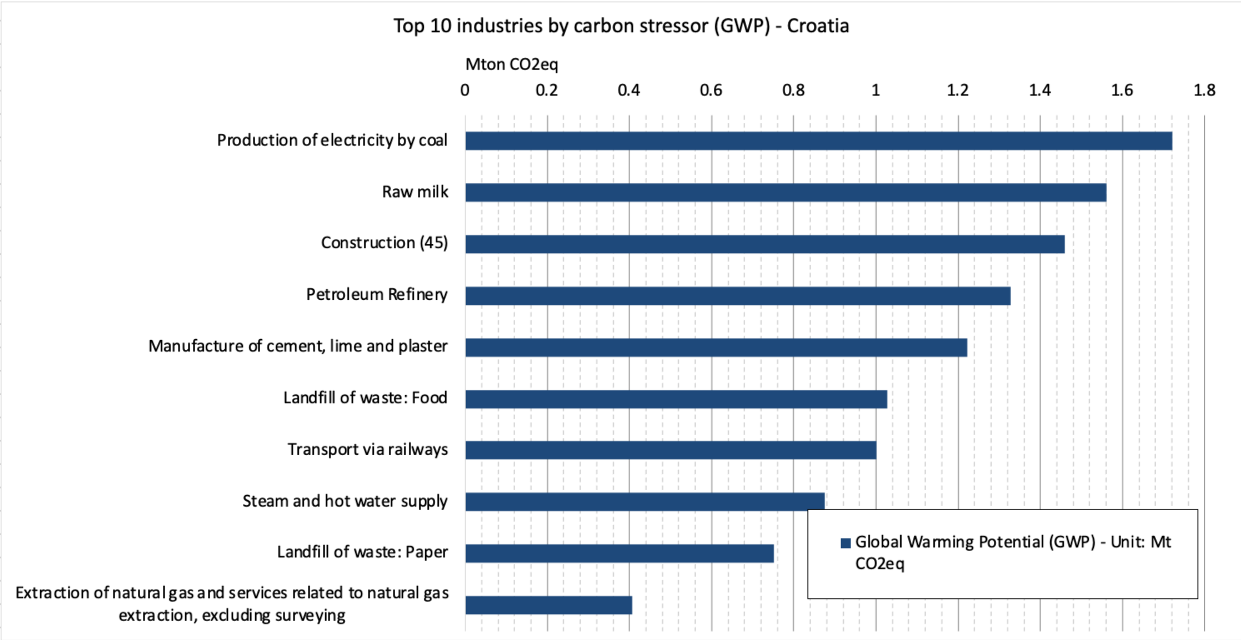


Figure 14 - Croatia's top ten industries by carbon stressor (GWP)



Appendix C: How does Croatia compare to other countries?

C.1: 44 and 5 Rest of the World regions

No.	DESIRE code	Name
1	AT	Austria
2	BE	Belgium
3	BG	Bulgaria
4	CY	Cyprus
5	CZ	Czech Republic
6	DE	Germany
7	DK	Denmark
8	EE	Estonia
9	ES	Spain
10	FI	Finland
11	FR	France
12	GR	Greece
13	HR	Croatia
14	HU	Hungary
15	IE	Ireland
16	IT	Italy
17	LT	Lithuania
18	LU	Luxembourg
19	LV	Latvia
20	MT	Malta
21	NL	Netherlands
22	PL	Poland
23	PT	Portugal
24	RO	Romania
25	SE	Sweden
26	SI	Slovenia
27	SK	Slovakia
28	GB	United Kingdom
29	US	United States
30	JP	Japan
31	CN	China
32	CA	Canada
33	KR	South Korea
34	BR	Brazil
35	IN	India
36	MX	Mexico
37	RU	Russia
38	AU	Australia
39	CH	Switzerland
40	TR	Turkey
41	TW	Taiwan
42	NO	Norway
43	ID	Indonesia
44	ZA	South Africa

45	WA	RoW Asia and Pacific
46	WL	RoW America
47	WE	RoW Europe
48	WF	RoW Africa
49	WM	RoW Middle East

C.2: Ranking of regions by per capita production-based and consumption-based material footprint

Figure 15 - Comparison of per capita consumption-based material footprint

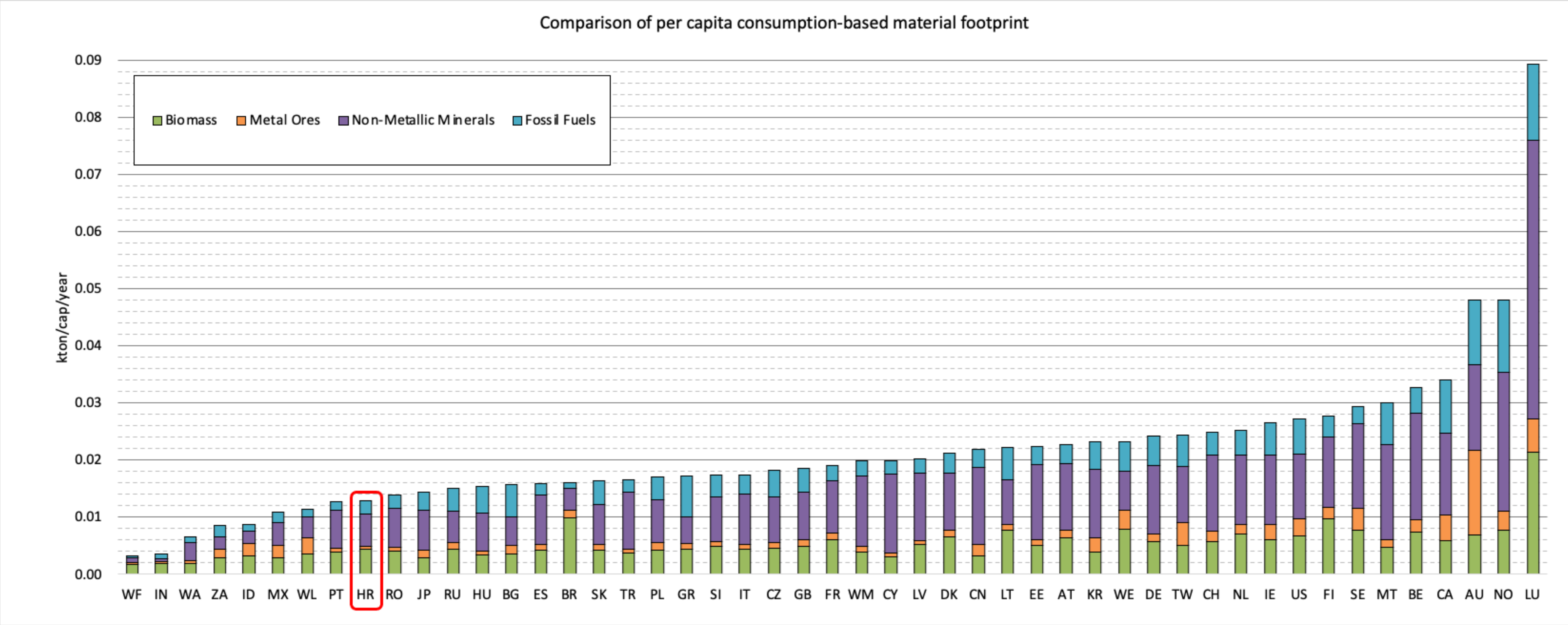
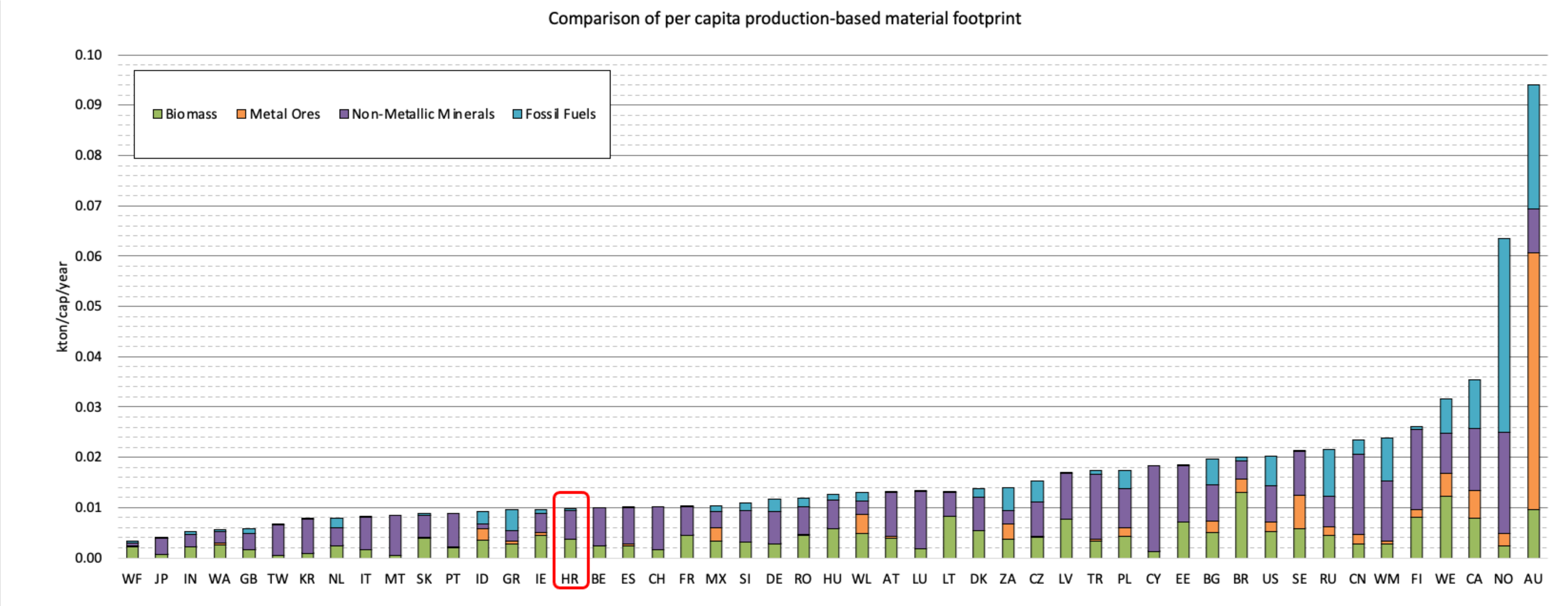


Figure 16 - Comparison of per capita production-based material footprint



C.3: Top 10 regions and sectors of material footprint or stressors

Figure 17 - Top 10 industries by material footprint, Rest of World (RoW)

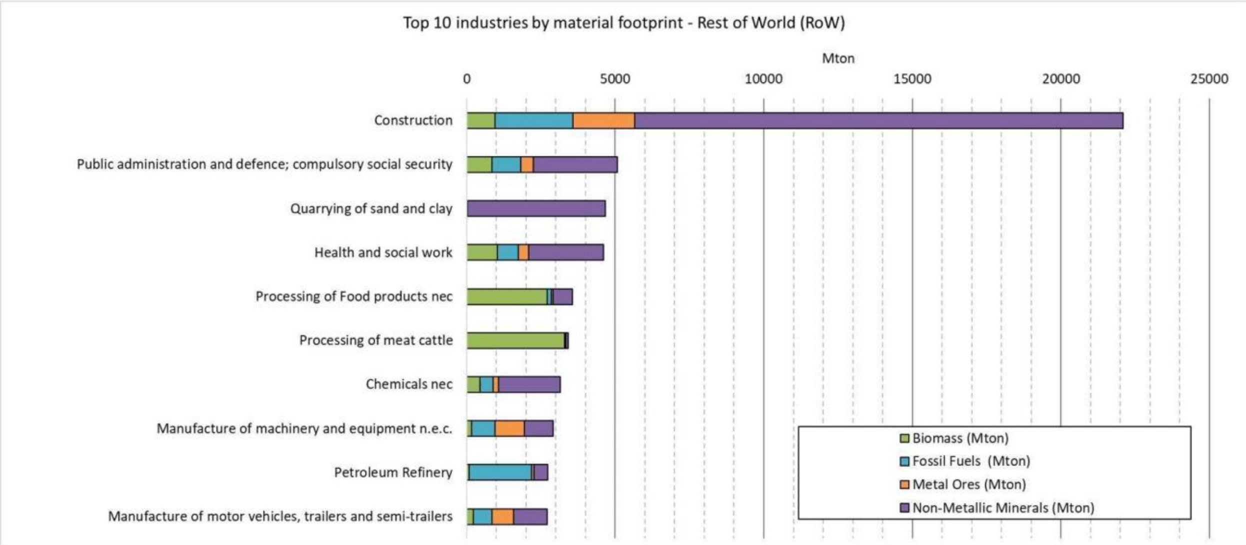
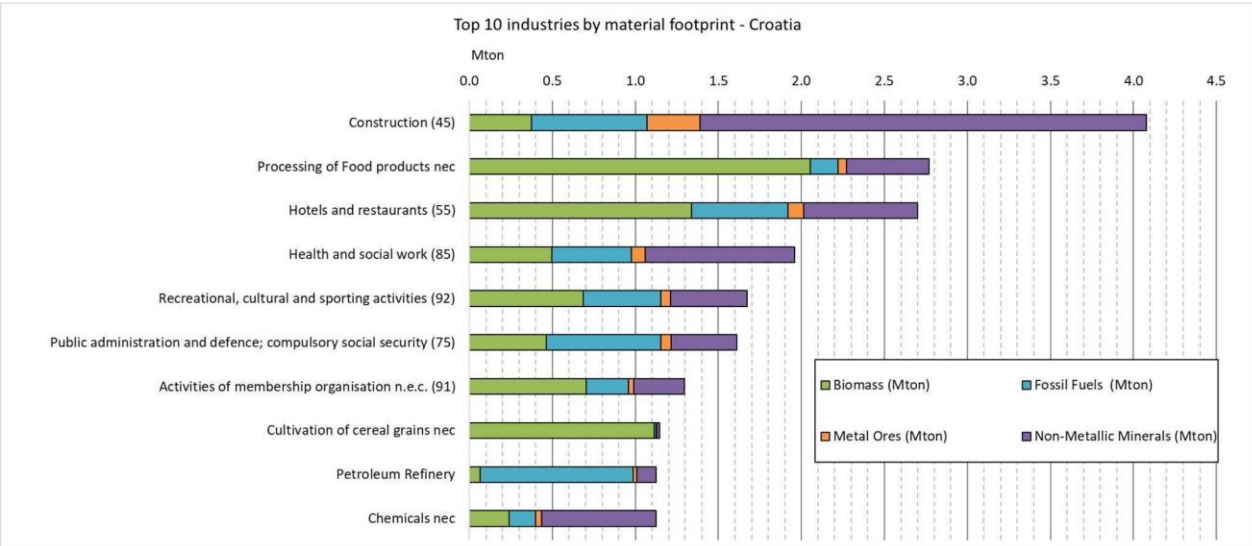
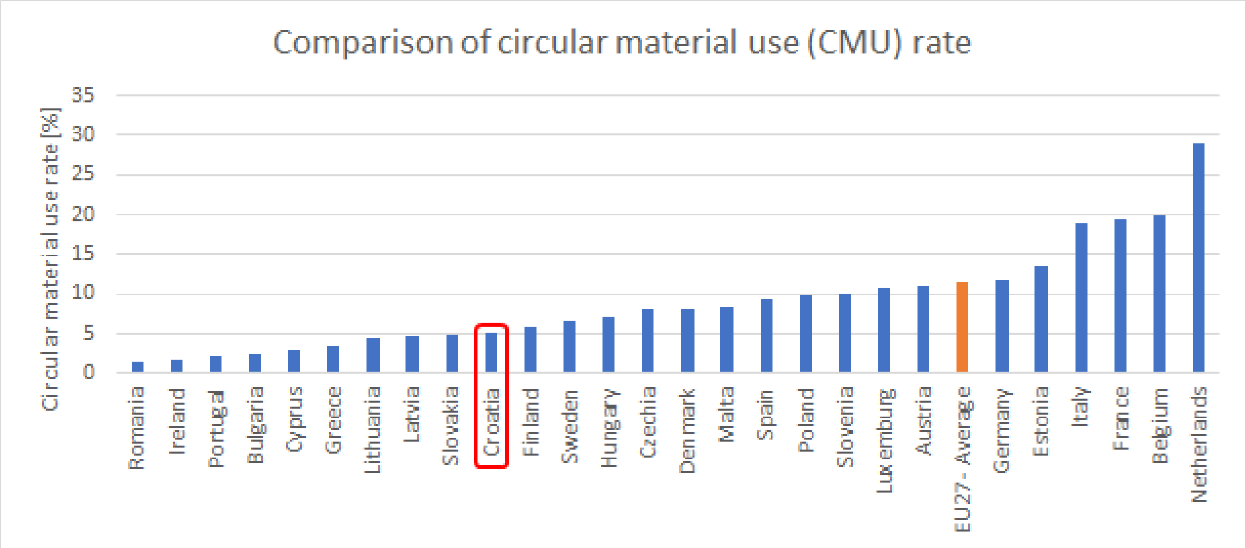


Figure 18 - Croatia's Top 10 industries by material footprint



C.4: Circular Material Use Rate of EU-27 countries in 2018 (Eurostat)



SOURCE - Eurostat, 2018