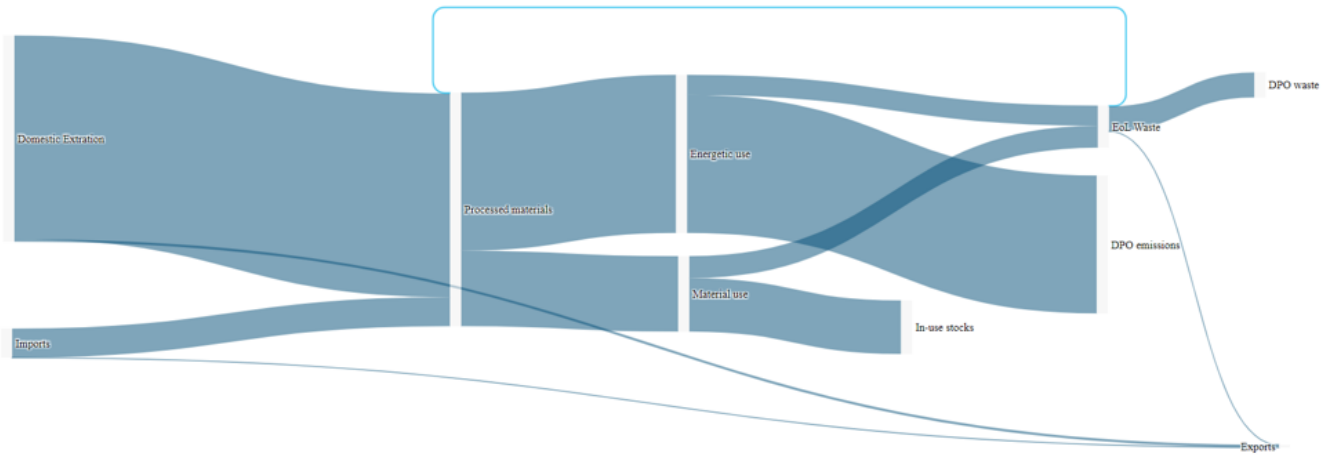
URBAN CIRCULARITY ASSESSMENT MIKKELI

Deliverable 7.7

Metabolism of Cities



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Abstract	This report on the Urban Circularity Assessment for Mikkeli presents the gathered information and main findings on the material flows of the local economy for 2015 and 2019, as well as the building stock accounting. It provides contextual information of the city and the local economy under study and then illustrates the quantities of flows in the single parts of the supply chain, summarised by a Sankey diagram. The accounted materials are evaluated in the form of circularity indicators and their data quality. Finally, the results are analysed and interpreted to determine a status quo, considering limitations of the data used, before recommendations are offered on how to achieve greater material circularity in the municipality of Mikkeli.
Keywords	Urban circularity assessment; Material flow accounting; Building stock; Circularity indicators; Urban metabolism; Circular city;
License	

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Summary

The Urban Circularity Assessment (UCA) was carried out for the municipality of Mikkeli in 2022 for the years 2015 and 2019. The Finnish municipality, located in the province of South-Savonia has a population of 53134 (2019) people that are spread over an area of 3229 km2.

The most significant employment sectors in Mikkeli are human health and social work activities (23%), manufacturing (12%) and wholesale and retail trade; repair of motor vehicles and motorcycles (10%). The construction sector employs 6% of employees in Mikkeli, which is at the same level as the corresponding percentage for the whole country (7%).

By applying the developed method, it is possible to illustrate that Mikkeli is a very linear city in its material flows (figure 1). However most of its materials consumption is of its own extraction, so very little material is imported or exported. Most of the imported materials are of fossil energy carriers (84%) when exports are mainly of biomass materials (71%) such as timber, wood based materials and cereals. Domestic material consumption is high, which indicates city-self-sufficiency and therefore less GHG emissions through the need of material transportations.

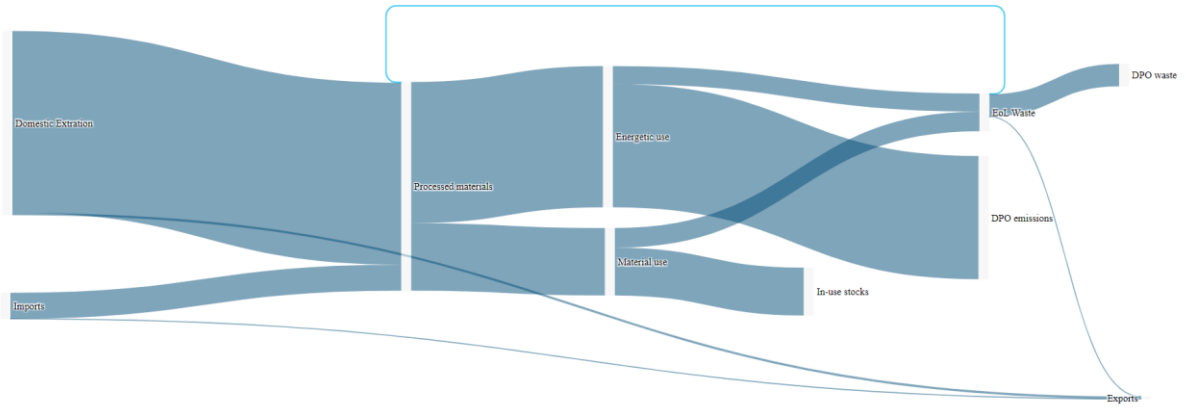


Figure 1 - Mikkeli Sankey diagram (interactive diagram in online report)

Biomaterial

Given the land use of Mikkeli which is mostly of mature forest and water bodies, this provides an opportunity to develop the circular bioeconomy of the city. For instance, a significant share of biomass demands of Mikkeli is already covered by local extraction of foods and wood-based fuels. However, a large part of this wood is used for energetic use, which could be replaced by green energy such as solar energy, since wind turbines cannot be used in most parts of Eastern Finland due to the country's defence systems. A new biorefinery in Mikkeli has further promoted the circularity of the biomaterial, but there is still a significant amount of unused

biomass (crop residue) in the rural areas through cultivation on the lands. If the unused biomass was to be produced into methane and thereafter biofuel and heat, it would have a more positive change in the circularity of the city.

CDW material

By applying the developed method, it is possible to illustrate that Mikkeli is a linear and carbon-rich city (90-95% linear), processing yearly approximately 1300 kt of materials, adding 10-20 kt in the building stock and recycling just 4 kt of secondary materials in their economy. From these numbers, the magnitude of the efforts becomes visible. In addition, the “weight” of Mikkeli can be illustrated through its building stock which amounts to 15.000 kt (or 290 t per capita), which requires continuous flows for both its operation and construction.

Data quality

A great amount of datasets were collected and processed for the UCA work. These datasets are enclosed in several spreadsheets that are interconnected. Should anyone have more interest in understanding the data or intention of replicating the process, they should reach out to Metabolism of Cities (info@metabolismofcities.org). By browsing the online version of the UCA report, the embedded charts, Sankey diagram can be interacted with: https://cityloops.metabolismofcities.org/city/mikkeli/uca-report/

1. Introduction

The EU Horizon 2020 funded CityLoops project focuses on closing the material loops of cities in terms of material flows, societal needs and employment. Cities, depending on their magnitude and types of economic activities, possess considerable opportunities and various levers to transform their metabolism and economy towards a more environmentally sustainable and circular state.

Within this project, seven European cities, amongst those also the city of Apeldoorn are (planning to) implement demonstration actions to kickstart their circularity journey. To better understand what the current circularity status quo is, as well as the impact of these actions, and the efforts needed to transform their cities, an Urban Circularity Assessment (UCA) method was developed. The method consists of urban material flow and stock accounting that paired with system-wide indicators assesses the material circularity of a city.

The material flows are accounted economy-wide for two separate years, applying a city-level adjusted Mayer et al. (2019) framework, which in itself builds on the EW-MFA method, including a wide material scope (specified below), while optimised for a circular economy assessment. The material stock accounting is limited to the buildings of the municipality, with the exact material scope depending on data availability in each city. Finally, the mass-based, "circularity" indicators cover the entire system and enable the assessment of a city's circularity. As such, a balance between comprehensiveness and scientific rigour on the one hand, and operability by urban policy makers and practitioners on the other is sought by the UCA method.

The material scope of the flow accounting aims to cover the entire local economy and is divided into a total of six material groups. These material groups are depicted as icons here and were studied each with more specific materials in sub-categories and along the supply chain of domestic extraction, imports & exports, domestic material consumption and waste. When studying these materials and the entire supply chain, together, these elements help to set a solid knowledge and analytical foundation to develop future circularity roadmaps and action plans.

Within the CityLoops project, the Urban Circularity Assessment was carried out by three of the seven cities (Mikkeli, Porto and Sevilla) themselves after having previously successfully completed their Sector-wide Circularity Assessments and Reports. They could build on extensive training that they had received in the form of courses on data collection for the

construction and biomass sectors and data processing. The cities were accompanied and supported in their work by the Metabolism of Cities team, who conducted the UCA for two further cities (Apeldoorn and Bodø). Numerous additional insights can be found in the individual Data Hubs of each city.

This current Urban Circularity Assessment report presents the gathered information in seven sections:

- *Urban Context*
- *Economic Context of Mikkeli*
- *Material Flows in Mikkeli*
- *Material Stock in Mikkeli*
- *Analysis of Flows and Stocks: Measuring Indicators*
- *Data Quality Assessment*
- *Analysis of Data and Indicators: Assessing Circularity*

It provides contextual information of the city and the local economy under study. It then illustrates the quantities of flows in the single parts of the supply chain, summarised by a Sankey diagram, followed by a map of the material stock. Both of the accounted materials are evaluated in the form of circularity indicators and their data quality. Finally, the results are analysed and interpreted to determine a status quo, taking into account limitations of the data used, before recommendations are offered on how to achieve greater material circularity in the municipality of Mikkeli.

(The italic texts in this report were written by Metabolism of Cities' Aristide Athanassiadis and Carolin Bellstedt. They provide relevant general information and serve as connecting elements of the single report parts.)*

2. Urban Context

To contextualise the results of the Urban Circularity Assessment, this section provides population and land use information data for Mikkeli. In addition, population numbers and area size of the city under study, as well as its corresponding NUTS3, NUTS2 and country were included, as can be seen to the right of the Mikkeli map. Data for these scales were added to better understand how relevant and important the approximations are when downscaling data from these scales to the city level.

Mikkeli
53,134
3,229 km^2

Etelä-Savo
144,615
19,130 km^2

Pohjois- ja Itä-Suomi
1,278,237
236,450 km^2

Finland
5,525,292
390,908 km^2

2.1. Population of Mikkeli

In 2019, there were 53 134 inhabitants in the city of Mikkeli, of which 13.9% were aged 0-14, 60.2% were aged 15-64 and 25.7% were over 65 years old. The population of the city of Mikkeli has been slightly declining in the 21st century, but since 2016 the population change has clearly accelerated, and the city lost almost 1 400 people between 2016 and 2019. After the year 2019 the decline is still evident, since in 2020 the population was 52583 and in the year 2021 it was 52121. The negative demographic development of the city of Mikkeli is largely the result of two components: natural demographic change has accelerated slightly, but especially outward migration (particularly emigration of young adults) has increased considerably in the years 2016-2019. (Kumpusalo 2020).

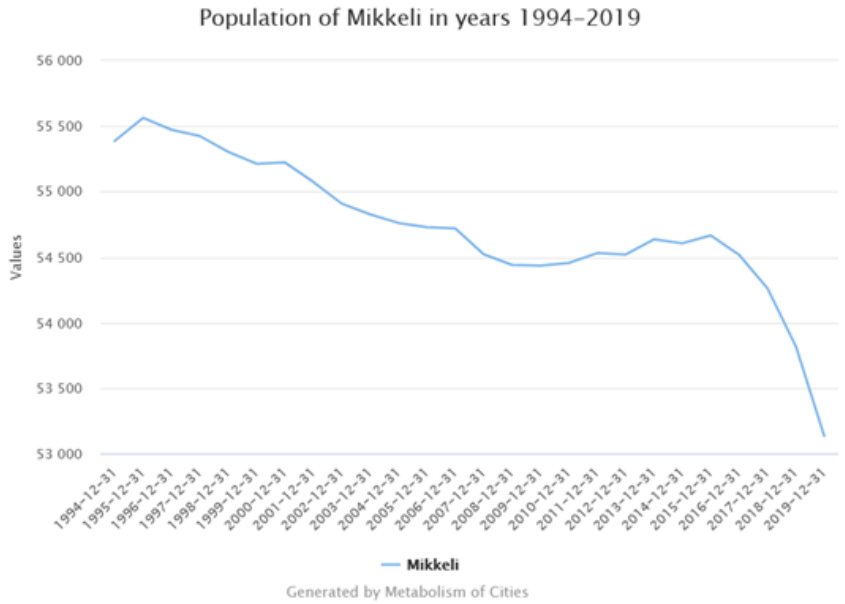


Figure 2 - Population of Mikkeli (interactive graphic)

The rapid decline in the population of Mikkeli has been considerably steep in the years 2016-2019 (Figure 2). In 2019, Statistics Finland published a new population forecast for the city of Mikkeli. The city's population is predicted to further decline by 11 % by 2040.

2.2. Land Use

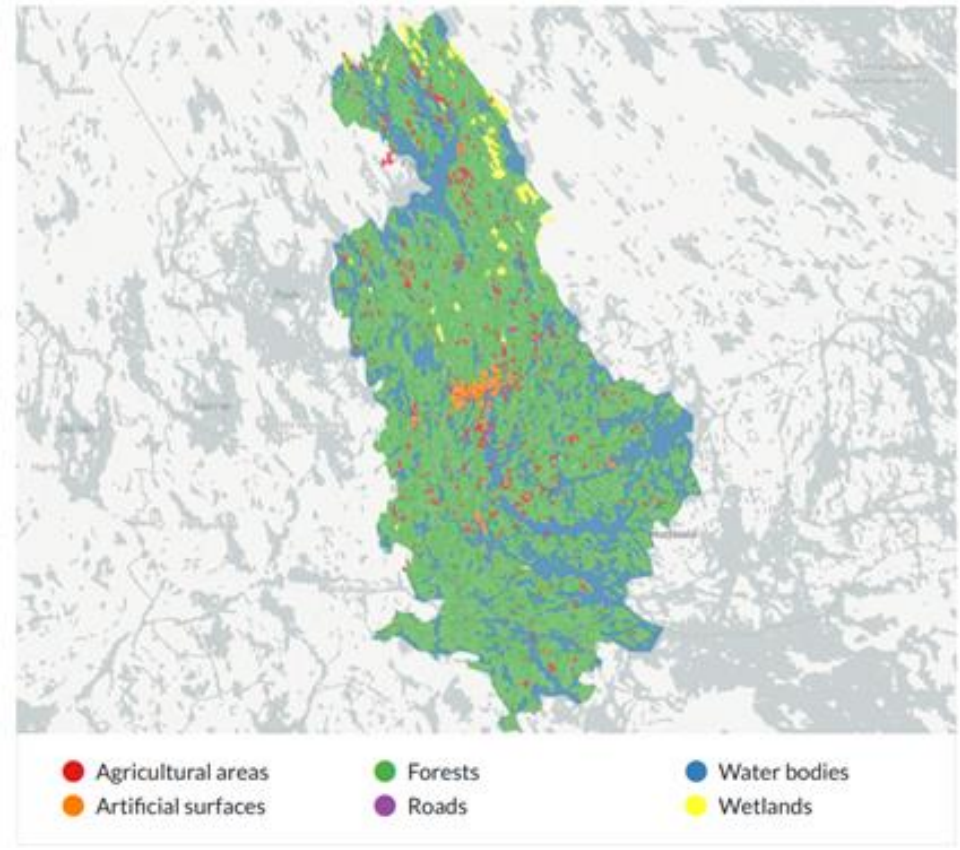


Figure 2 - Land use map (interactive graphic)

There are various living environments in Mikkeli (Figure 2). These include a growing downtown area, developing agglomerations and the quiet of the rural area. Living in Mikkeli is divided into two main area types: city/agglomerations and dispersed habitat/rural areas (Riihelä et al. 2015). There are 10558 summer cottages by the lake shores of the rural areas of Mikkeli. This makes the city one of the most popular summer cottage areas in Finland. In Mikkeli, there are around 700 lakes and ponds, and water covers 424.7 km2 of the city. In 2019 there was 12,747 ha of agricultural land in Mikkeli and 479 farms in total.

A more accurate description of the land use in Mikkeli can be seen in the figure 3 below. The areas of mature forest and lakes are dominant, following this, the use of land for cultivating mixed crops and raising livestock. Mikkeli may be seen as a city of forests and lakes.

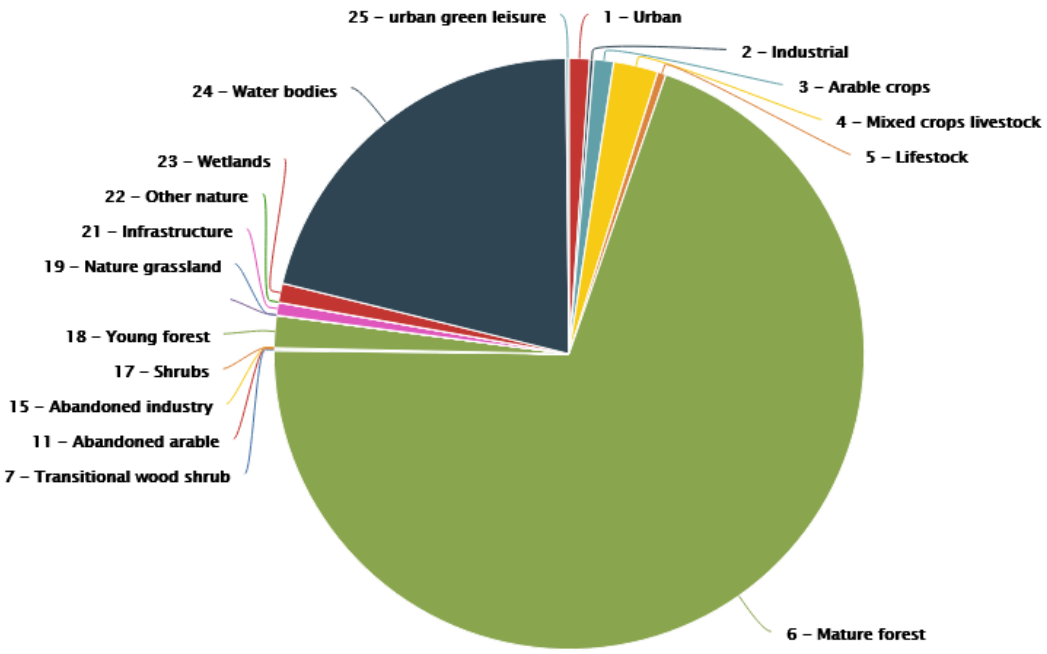


Figure 3 - Land use chart of Mikkeli (European Commission, Urban Data Platform Plus, 2023)

3. Economic Context of Mikkeli

This section puts into perspective the economic context of the city under study. It describes its significance in terms of GDP or GVA and provides information on the number of people employed, as well as the main economic activities. Main actors that play a significant importance may also be highlighted.

AREA	GDP AT MARKET PRICES MILLIONS OF EUROS, 2019	EMPLOYEES (2019)
Mikkeli	2499.9	21938
South Savonia	4510.9	57000
Finland	239858	2533000

Table 1 – The Gross domestic product of area at current market prices (Statistics Finland)

The GDP has been steadily rising in Mikkeli throughout the years 2015-2018, but since the year 2019 has been falling (figure 5). Compared to other cities with inhabitants of around

50000, GDP is a little below average (Table 1). (Statistics Finland, Income, and production by area, annually 2019)

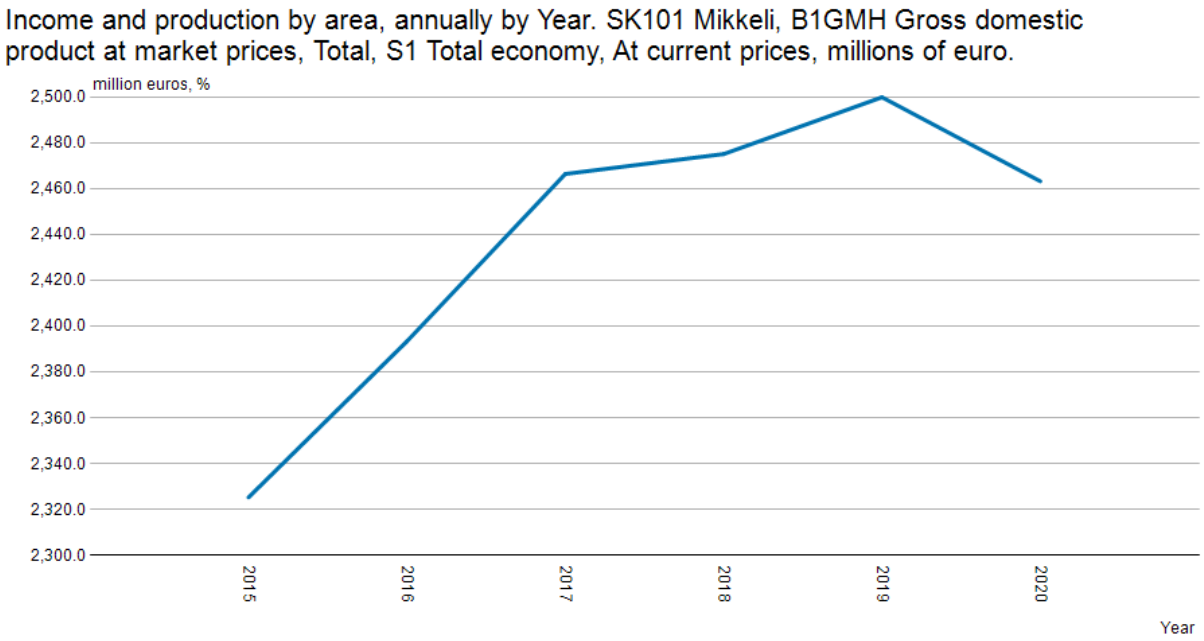


Figure 5 – The GDP of Mikkeli in years 2015-2020 (Statistics Finland)

Mikkeli is the regional centre of Southern Savonia. Mikkeli had 53134 inhabitants at the end of 2019. Statistics Finland's given data on employed persons in 2019 is 21938. The employment self-sufficiency rate of the city of Mikkeli is 103.5, meaning that there are more jobs than employed persons in the city area. This is explained by the fact that as a regional centre and the centre of its economic region, people from the surrounding municipalities come to work in Mikkeli. Correspondingly, one in ten of those employed in Mikkeli work elsewhere than Mikkeli.(Kumpusalo, 2020)

In 2019, 38.2% of Mikkeli's workforce worked in the public sector and 61.8% in the open sector (private sector + entrepreneurs). The public sector share was among the highest among the large cities, although it should be noted that Mikkeli is also a traditional state administrative city. However, in terms of sustainability of the regional economy, Mikkeli's share of open sector jobs could be improved.(Kumpusalo, 2020)

At the end of 2019, there were 3313 companies registered at Mikkeli and 4055 business establishments. There were 62 enterprises per every 1000 inhabitants. This number increased by five enterprises per 1000 inhabitants over the previous three years. In 2018, a total of 11,926 people were employed in enterprises operating in the city of Mikkeli. (Kumpusalo, 2020)

Despite the decrease in population and the number of employees in businesses, the number of businesses in Mikkeli increased by 2% between 2016 and 2018 and by 5% by the end of 2019. Entrepreneurship is increasingly becoming the work choice of more people. When looking at the size of enterprises, more than 95% are micro- and small enterprises. (Kumpusalo, 2020)

The smart specialisation platforms (S3) of the region as well as Mikkeli are focused on the main living environments of the area: water, forests, and agricultural areas (European Commission, Smart Specialisation platform, 2023) The thematic platforms are water smart territories and traceability and big data in the agri-food value chain. The S3 priorities of the region are:

- Food - Purity and safety of the food chain products
- Forest Processes - New Forest biomass products and production processes
- Water - Clean water technologies and environmental safety concepts

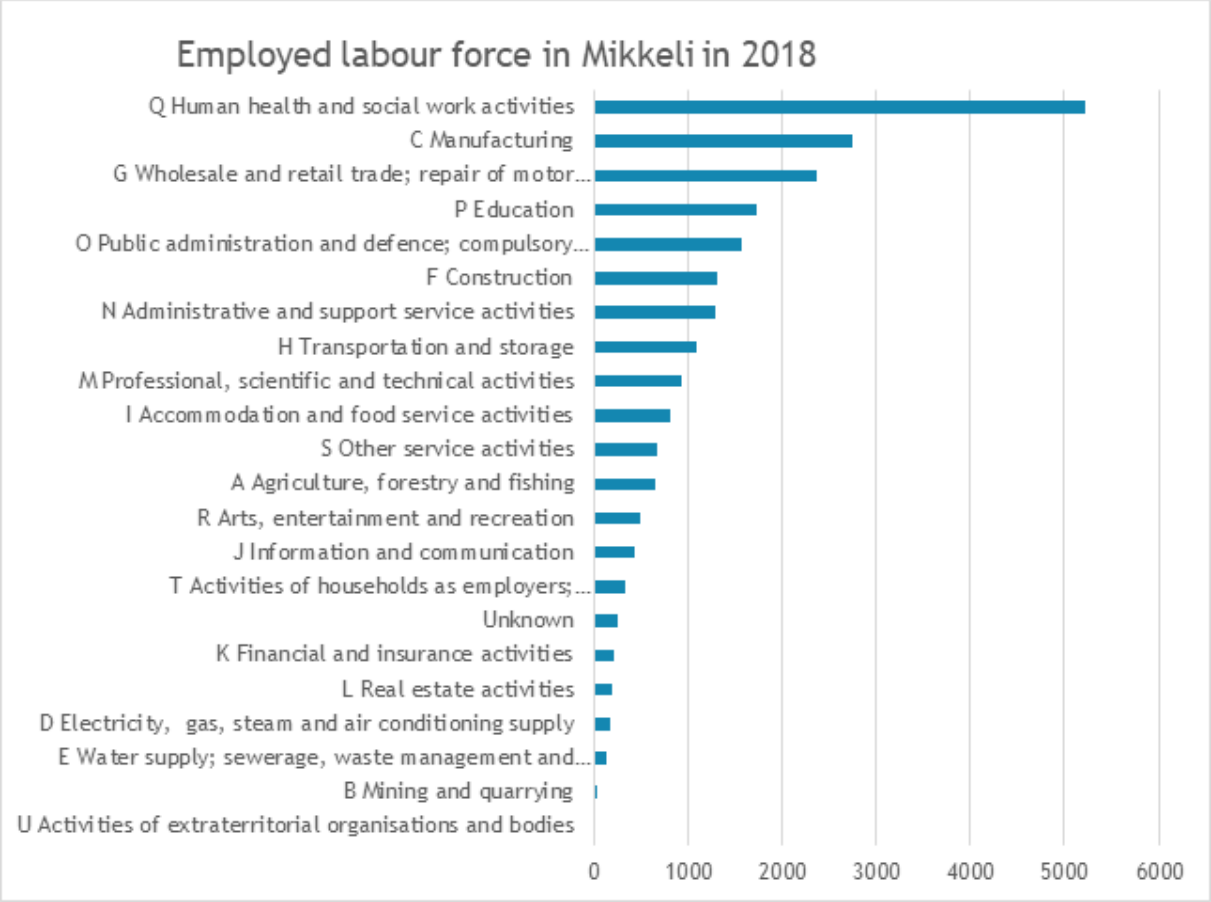


Figure 6 - Mikkeli employment numbers (excel link available here)

The biomass sector in Mikkeli

Mikkeli is rich in forest resources and water bodies, but its industrial production relies heavily on the forest cluster surrounding the city. The major industries in Mikkeli are mechanical wood processing and engineering. According to Kumpusalo (2020), important future trades in Mikkeli might be with the production of various bioproducts, expertise in bioenergy and environmental technology.

The biomass sector is smaller in Mikkeli compared to the surrounding areas in the South-Savo region. In South-Savo, forestry-, farming- and fishing industries are the fourth largest in the employment sector (Etelä Savo Ennakoi 2022). In Mikkeli, these are only the twelfth largest industry sectors in employment. The most significant employment sectors (figure 6) in Mikkeli are health- and social services, manufacturing and in wholesale- and retail trade. (Statistics Finland, Employment Labour Force in Area, 2022)

The construction sector in Mikkeli

The construction sector employs 11,2% of employees in Mikkeli. The corresponding percentage for the whole country is 7%. Construction accounts for about 10% of Mikkeli's net sales. Based on turnover, the most significant industries in Mikkeli are wholesale and retail trade 28% and industry 26%. (Data of Statistics Finland, Employment labour Force in Area, 2022) Data is from year 2018. (GVA and employees data from reference year 2019 was not available).

In Mikkeli, the largest construction projects are often managed by national companies and employees can also come from outside the area. According to the 2019 statistics, from the 16812 buildings of Mikkeli, the number of new buildings was 171 and the total floor area was 19,994 m^2. About half of the floor area (48 %) was of residential buildings. Up to 76% of the house types were detached houses (figure 7).

By material intensity, detached houses and residential apartment buildings hold most of the construction materials in Mikkeli. Commercial and industrial buildings have both very similar amounts of material intensity in the city (figure 8).

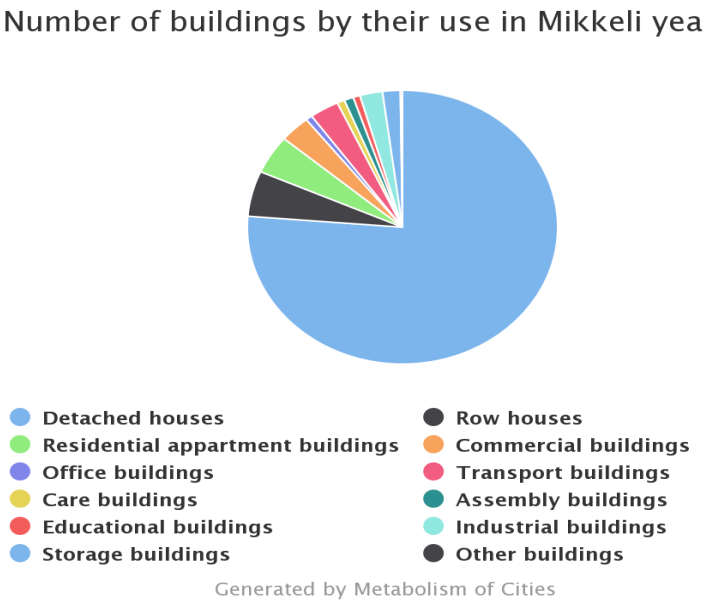


Figure 7 – Detached houses and residential apartment buildings are the main types of buildings in Mikkeli.. (Interactive graphic)

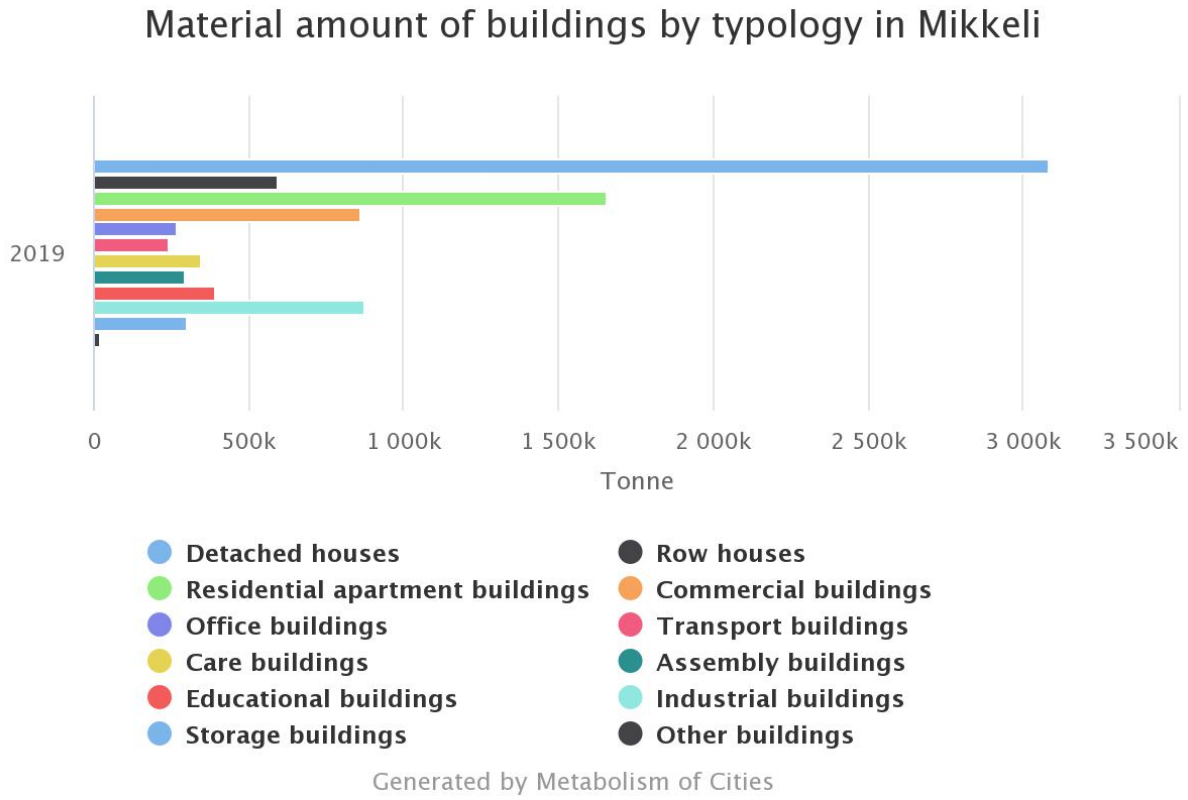


Figure 8 – Detached houses and residential apartment buildings are the main types of building in Mikkeli, when compared by material amounts. (Interactive graphic)

Actors in waste collection and treatment

- **Metsäsairila Ltd.** is the municipal waste company of Mikkeli. Metsäsairila has one main waste collection- and treatment area and three smaller waste stations in conurbations in Mikkeli. All construction and demolition waste generated from the City of Mikkeli's own sites is delivered to Metsäsairila.
- **RL Huolinta Ltd.** concentrates in the collection of waste.
- **Lassila & Tikanoja Ltd**. collects and recycles paper, glass, cardboard, metal, and plastic.
- **RINKI** collection points are organised by packaging producers. These collection points collect glass, cardboard, and metal packaging. Some RINKI collection points also have a glass and ceramics collection container which are emptied by the municipal waste company, Metsäsairila. A few Rinki collection points collect clean and dry plastic packaging.

There are around **60 recycling points** in Mikkeli where one can recycle paper, glass, cardboard, metal, and plastic. Some recycling points may be seen in the map (figure 9). In

the very centre of Mikkeli there are several recycling points in a small area. The number within the circles depicts the number of recycling points within the area.

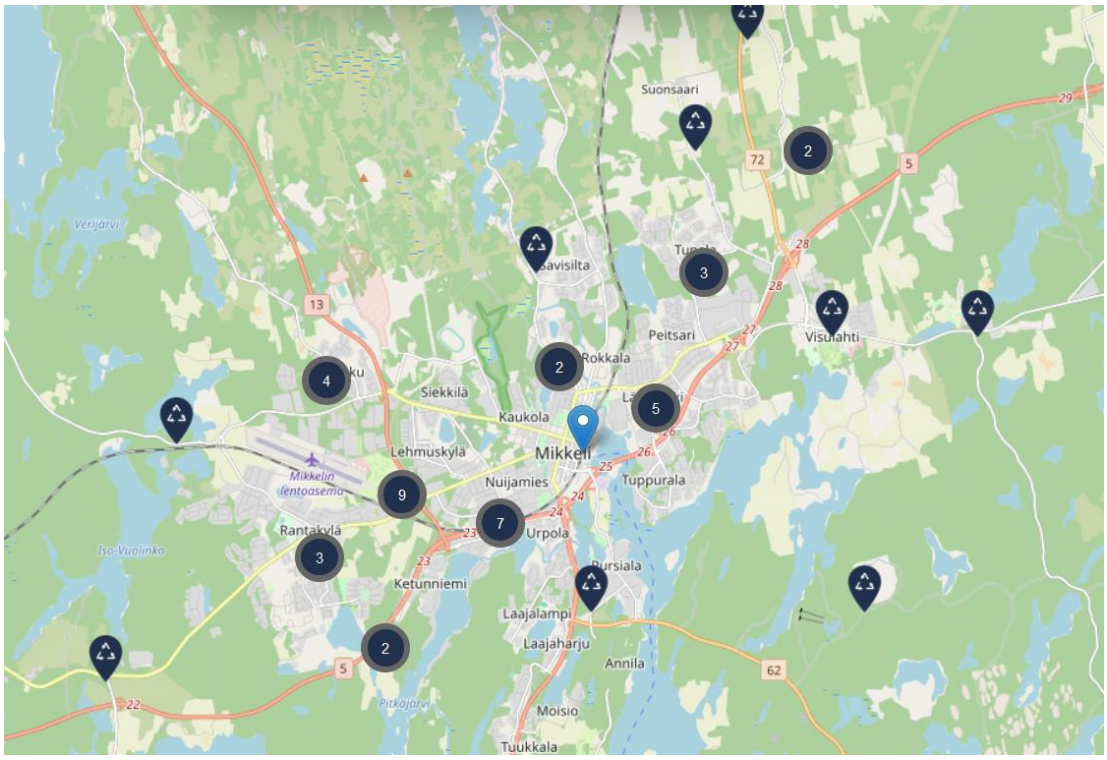


Figure 9 – Recycling collection points at the centre of Mikkeli (Kierrätys info, Kivo, 2023)

Actors in recycling

- **Mikkelin Toimintakeskus** assoc. focuses on the re-use fixing and upcycling of goods and materials. They collaborate with the waste companies and sell small quantities of materials from e.g., renovation and demolition sites to reuse.
- **ViaDia** Mikkeli assoc. collects food waste (expiring food) from grocery stores to distribute it as food aid. ViaDia has three flea markets, with a fourth one on the way. The association also sells recycled pallets.
- **Mikkelin Työttömät assoc.** also collects food waste (expiring food) from grocery stores to distribute it as food aid.
- **Otavan Metalli Ltd** and **Mikkelin Romu Ltd** receive scrap metal in Mikkeli. Mikkelin Romu Ltd also receive construction, wood and demolition waste.
- **Suutarinen Ltd** can also crush concrete waste from the construction and demolition sites in their concrete plants in Tikkala and Suomenniemi. Concrete and timber manufacturers treat (e.g. crush) waste fractions generated from their own production and deliver for recycling or incineration.
- **Mikkelin Autokuljetus Ltd** has an environmental permit for crushing and receiving concrete waste.

4. Material Flows in Mikkeli

Measuring material flows and circularity is a data heavy exercise. Numerous datasets were collected and visualised throughout the Urban Circularity Assessment process. To synthesise these findings, a Sankey diagram (figure 10) illustrates how material flows of the local economy of Mikkeli are circulating from one lifecycle stage to another. The height of each line is proportional to the weight of the flow. This diagram therefore helps to quickly have an overview of all the materials flows that compose the economy and their respective shares. The flows that are coloured in light blue in the Sankey diagram, are return flows. This means that they flow in the opposite direction of the lifecycle stages and are subjected to reuse, redistribution, or remanufacturing. Their size relative to the others is a good indication for a materials' circularity.

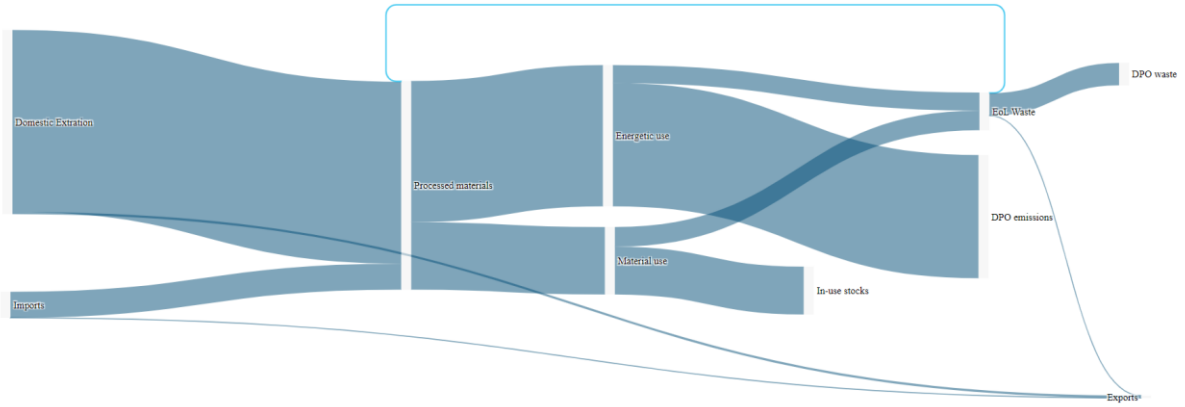


Figure 10 - Mikkeli Sankey diagram (interactive diagram in online report)

Four main material flows were studied for the Urban Circularity Assessment in the Mikkeli city. These main categories of materials were biomass, metal ores, non-metallic minerals, and fossil energy materials/carriers. In addition to collecting data on the extraction, import and export of these materials, the amounts of different waste materials and their treatment were studied.

The main waste materials that the data collection included were chemical and medical wastes, recyclable wastes, equipment, animal and vegetal wastes, mixed ordinary wastes, mineral and solidified wastes, and metallic wastes. The waste was sorted according to the different waste treatment; landfill disposal, releasing into water bodies, incineration disposal and incineration for energy use, and recovery of materials for recycling uses.

4.1. Domestic Extraction

Biomass extraction in Mikkeli

Domestic extraction in the biomass category was dominated by the wood material. In the year 2019, 555787 tonnes of timber (industrial roundwood) and 702027 tonnes of wood fuel and wood for other purposes were extracted. The amount of wood extracted in 2015 and 2019 in comparison has changed very little.

Fodder crops and grazed biomass were extracted 71113 tonnes, cereals 21278 tonnes and lastly one major extraction materials were roots and tubers of 313044 tonnes in the year 2019. Although being surrounded by lakes, wild fish catch is only 268 tonnes in 2019. There is little or no professional fishing in Mikkeli, only leisure fishing. The amount of cultivated vegetables has declined slightly with the total of vegetables produced in 2015 being 2048 tonnes and in 2019, 1962 tonnes (figure 11). The amount of berries cultivated has stayed quite stable.

In Mikkeli area, there is some primary production of food, but only a little of further processing. Cultivation of vegetables, berries, cereals, and production of milk have had an important role both in the South-Savo region and in Mikkeli. Carrots, cabbages, and lettuces are the main vegetables produced in Mikkeli. Strawberries, currants, and raspberries are mostly cultivated berries in the area. For cereals, farming oats is clearly favoured, but in the years the amount of cultivation of cereals has declined.

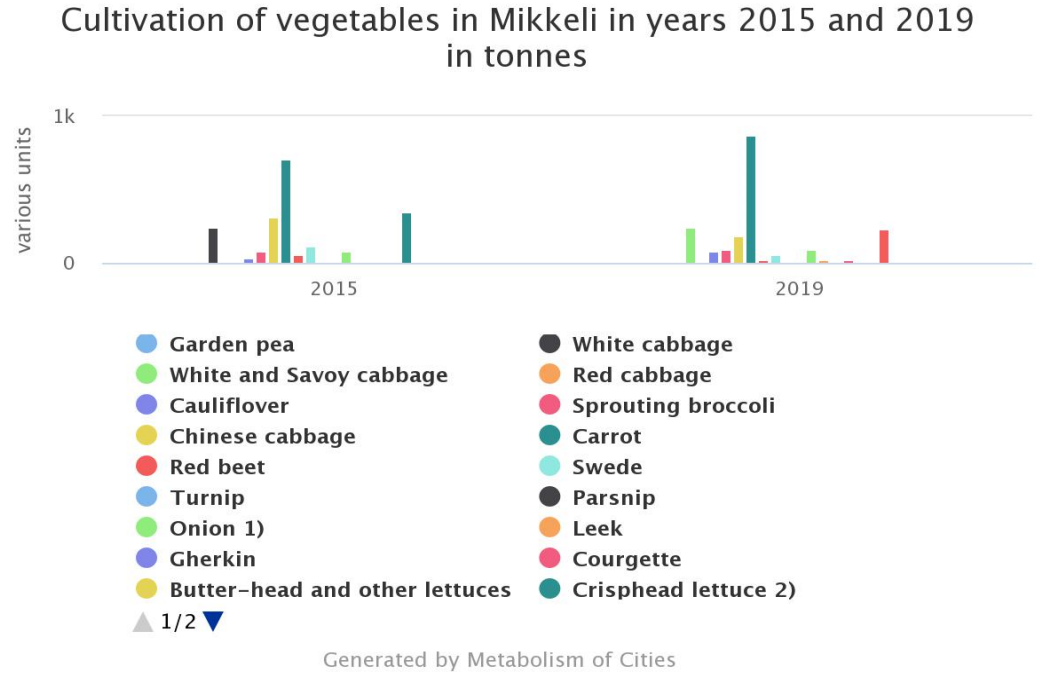


Figure 11– Amount of vegetables cultivated in Mikkeli in years 2015 and 2019 downscaled rom South-Savo Data (interactive data)

The number of farms is declining in Mikkeli, since small farms either need to invest and grow or find other means to support their livelihood in the countryside. The consumption of milk has been declining throughout Finland influencing understandably the number of dairy farms to decline as well. All this has had a cause effect on the decline of fodder crops and grazed biomass being extracted in Mikkeli. These materials were extracted in 2015, 113116 tonnes and in 2019, only 65786 tonnes.

Wood extraction and manufacturing in Mikkeli

Forests and forest-based industries are a very important sources of economic well-being in Southern Savonia. The income from the harvesting of provincial forests is the highest in the country. The forests are mostly owned by private forest owners. (Metsäkeskus 2020)

In Mikkeli 1274225 tonnes of wood were extracted in 2015. Not much change in the amount in the year 2019, when 1257814 tonnes of wood was extracted (figure 12). The extracted wood is increasing in fuel use, since the energy crisis of 2022 and the fact that no more wood is imported from Russia to Finland.

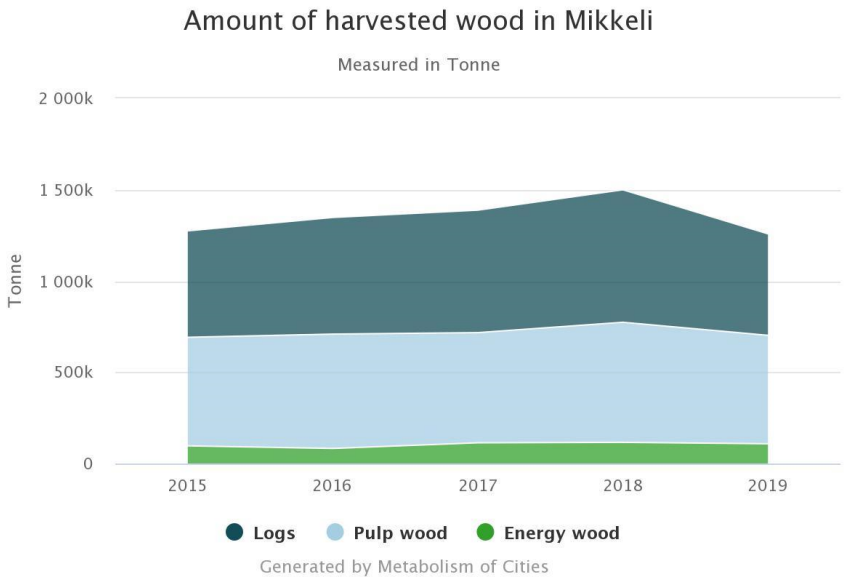


Figure 12 – The amount of wood harvested in Mikkeli in years 2015-2019 (Interactive data)

The most important actors in timber manufacturing in Mikkeli are:

- **UPM Pellos'** plywood mill is Europe's largest plywood mill. It produces approximately 480,000 cubic metres of plywood per year from approximately 1.1 million cubic metres of Southern Savonia spruce logs for the Finnish and European markets. The factories employ about 600 people and are the largest industrial employer in Southern Savonia (Kumpusalo 2020)

- **Versowood Otava Ltd**. The production capacity of spruce sawing at this mill is about 275,000 m³ per year. 90% of production is exported.
- **Misawa Homes of Finland Ltd** is a sawmill which exports spruce lumber to Japan.
- **SWM-Wood Ltd** manufactures heat-treated wood for the needs of the construction and carpentry industries and retailers. Company is the 2nd largest manufacturer of Thermowood® in Europe.
- **Oplax Ltd** manufactures pallets.
- **Parla Floor, Timberwise** manufactures parquet floors.

In addition to manufacturing, wood is used for energy and heat production locally. **Etelä-Savon Energia Ltd.** is a local energy company in Mikkeli that produces energy, heat, and biogas. At the Pursiala power plant, Etelä-Savon Energia Ltd. (ESE) produces about 100 GWh of electricity, 400 GWh of district heat and 20 GWh of industrial steam annually. The plant is fuelled by wood, roughly 80% and peat about 20%.

The peat extraction in Mikkeli has declined by half since 2015. In year 2015, peat was extracted 89 000 tonnes and in year 2019 only 44 000 tonnes. ESE pursues to stop using peat in its power plant, because of the negative effects its extraction has on the environment as well as being counted as a non-renewable energy source. This will most likely also increase the energy use of locally extracted wood.

Non-metallic minerals extraction in Mikkeli

Mikkeli has a total of 52 soil extraction permits for gravel and sand, 35 for stone materials and 8 for other materials. Materials are used for construction and for manufacturing of concrete. There are no statistics on actors available, but some information may be found e.g. Metsähallitus, concrete manufacturers and earthwork companies own extraction sites. (Liiteri-tietopalvelu 2022)

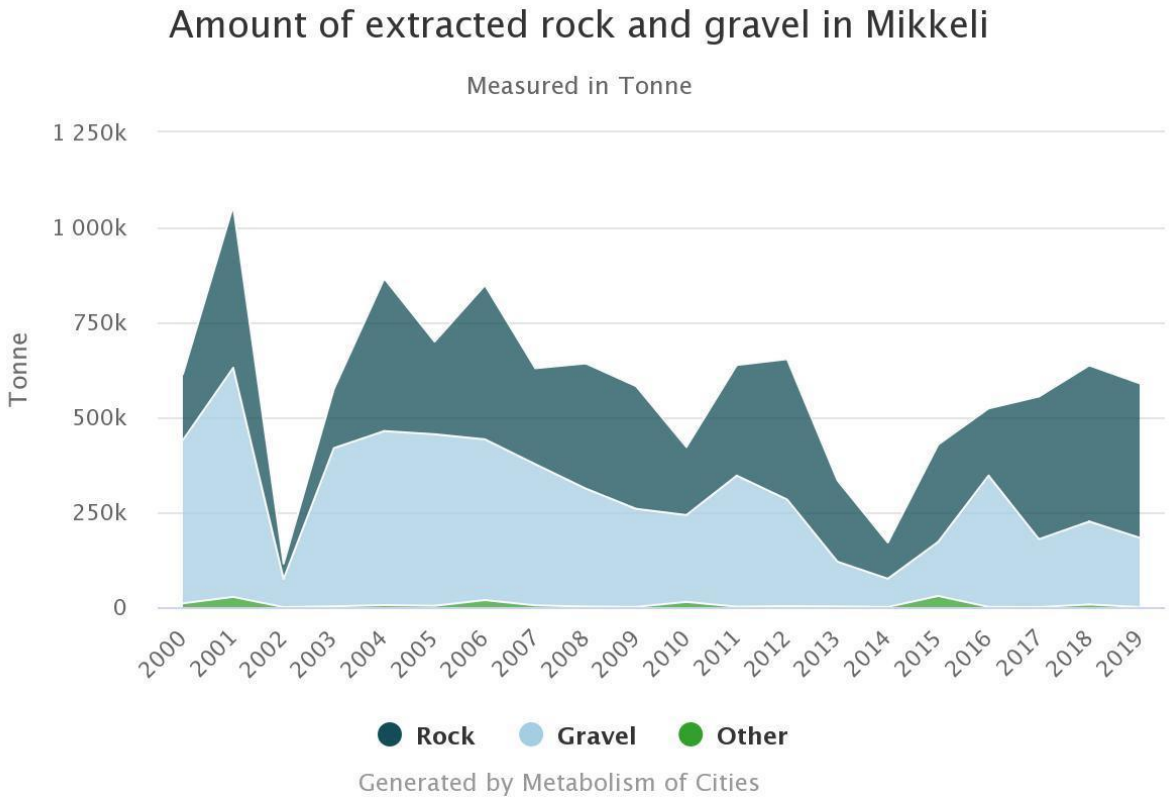


Figure 13. Amount of extracted rock and gravel and other soil materials in Mikkeli based on land extraction permits and announcements. (interactive data)

In 2015, 234029 tonnes of non-metallic minerals were extracted in Mikkeli. From this, 136859 tonnes of building stones such as granite were extracted. In the same year, 82444 tonnes of gravel and sand were extracted in Mikkeli. Compared to the year 2019, the extraction of these materials has increased about 10-16 % in four years. Perhaps this is explained by the slump in extraction in the year 2014 as seen in figure 13.

According to Anna Kiviniitty, despite its excellent qualities, granite quarrying and product manufacture in Finland has not increased, but on the contrary, imports of natural stone from elsewhere have increased. Cheaper and of inferior quality granite from China is imported and used in Finland, even though its environmental impacts are far greater than granite quarried and produced locally. (Kiviniitty 2022)

Metallic minerals extraction in Mikkeli and Finland

There is no metallic mineral extraction in Mikkeli. The closest metal ore mine has been at Polvijärvi more than 200 km from Mikkeli. Mining at this mine ended on 15th November 2020. Copper, cobalt, nickel, zinc, and gold were mined. Around 550 000 tonnes of ore were extracted from the mine each year and transported to the enrichment plant in Luikonlahti, Kaavi. (Ruuskanen 2020)

Metal ore mining in Finland started to grow strongly in 2008, when several metal ore mines were established in Finland within a few years. In 2018, there were 11 metal ore mines in

Finland and more ores were mined than ever before, totalling 32.5 million tonnes. The largest metal ore mine in 2018 was Terrafame in Sotkamo (17.9 Mt), whose main products are nickel, zinc, and copper. The second is Kevitsa (7.9 Mt) in Sodankylä, whose main products are nickel, copper, and platinum group elements. More than 1 million tonnes of metal ores were also mined in Kemi, Kittilä Suurikuusikko and Pyhäsalmi. (Geologia.fi 2019)

4.2. Imports & Exports

Imports & exports account for a substantially smaller share of the flows entering and exiting Mikkeli's economy, as it may be seen in the Sankey diagram. These values are not as reliable as the extraction values, as they are very difficult to obtain at a city level. In Mikkeli no city-wide data was found for the imports and exports flows, so the data is collected from the Finnish customs and is downscaled from the national values into city values. Downscaling was calculated using employee numbers in relation to the two NUTS areas.

Mikkeli city is a logistical centre via roads for goods imports and exports. New transport terminals are and have been built lately by the **Posti Ltd.** which is the leading postal and logistics services company in Finland. Also, **Kaukokiito Ltd.** built a new terminal in Mikkeli in 2021. They offer transport services for parcels, general cargo, and freight. One of the biggest retail chain groups, **SOK**, is also building a terminal in Mikkeli. The flow of imported and exported goods may be seen in the map below (figure 14), where the material flows are presented in volume through the Eastern Finnish roads. Through Mikkeli flows an estimated 2.6 M tonnes of goods (Rantala et al. 2020). How much of this material remains and is consumed by the city's inhabitants may be found in the calculations of domestic material consumption (DMC).

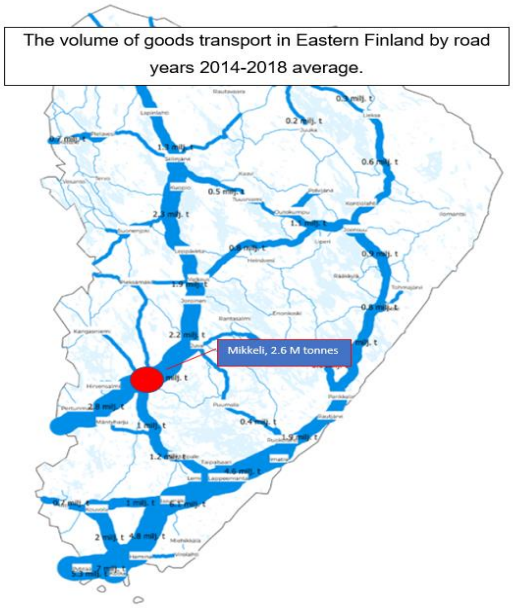


Figure 14 - The volume of goods through Mikkeli city by roads is 2.6 million tonnes on average in the years 2014-2018. (Rantala et al. 2020)

Imports of biomaterial to Finland and Mikkeli

In 2019, 8.73 million cubic metres of timber were imported from Russia to Finland. Of the wood imported from Russia, 53% was pulpwood, 34% chips and 4% logs. Imports of chips (+30%) and softwood (+11%) had grown in mass. Imports of softwood logs fell by 16% and hardwood logs by 70%. Imports of hardwood also fell by 2%. Russia accounted for 74% of Finland's timber imports, which is up 3% from the previous year of 2018. (LUKE 2020).

Most of the wood material imported to Mikkeli comes from the surrounding municipalities, but foreign import comes from Russia. As can be seen in the pie chart below (figure 14), the wood materials are the main biomaterials imported to the city.

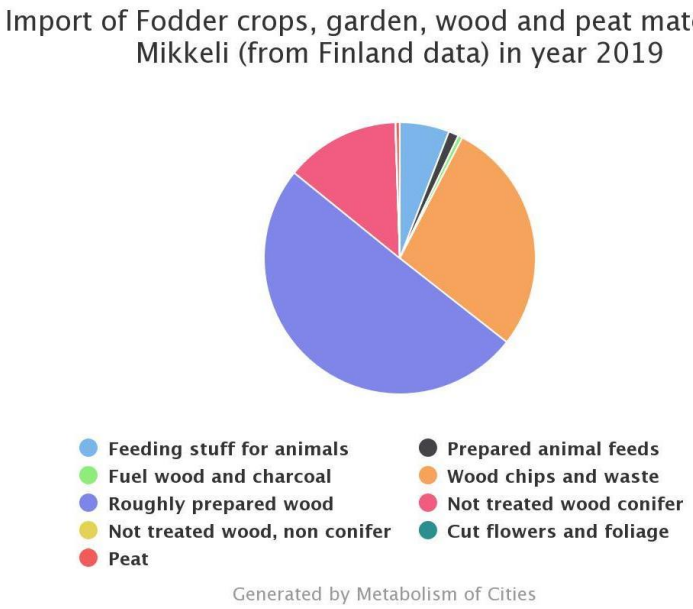


Figure 14 – Wood is the major biomass import material to Mikkeli also in year 2019 (interactive graphic)

The imports of different goods have been on the rise in Finland, and therefore in Mikkeli as well. When total imports of all materials were counted for in the Urban Circularity Assessment, in 2015, the imported weight of the chosen materials were 227414 tonnes and in the year 2019 they were 238797 tonnes. The growth in four years was 5%.

A greater growth may be seen in the Statistics Finland's data, which shows the rise in monetary value in the export and import of all goods and services to and from Finland in the time span of year 2005 to year 2021 (figure 15). The rise in imports was 25% from 2015 to year 2019, counting all materials. The scope for the materials was different between the UCA study and this data of all materials exported and imported in Finland, so they are not directly comparable. (Elinkeinoelämän Keskusliitto 2022)

The data collection for import in city scale was challenging due to downscaling from country statistics data for the UCA work, therefore it should be considered while examining the materials flow changes in imports and exports (see data quality).

Figure 15 -The export and import of goods to and from Finland in milliards of euros in years 2005-2021. (Elinkeinoelämän Keskusliitto 2022)

Imported materials to Mikkeli

From metal materials in year 2015, iron (24857 tonnes), zinc (4343 tonnes) and copper (1739 tonnes) were mostly imported to Mikkeli. Since there is no metal industry and very little production of metal goods in Mikkeli, these country derived amounts of metallic materials are most likely well over actual import amounts to the city. In 2015 non-metallic minerals such as clays, and kaolin (1933 tonnes) and limestone and gypsum (1539 tonnes) were mostly imported. Fossil carriers were largely imported since there is only peat and wood extracted in Mikkeli. From these, liquid and gaseous energy materials (143135 tonnes) were imported and crude oil of 106000 tonnes (figure 16). Compared to the year 2019, there was almost a 5% growth in the fossil energy carriers.

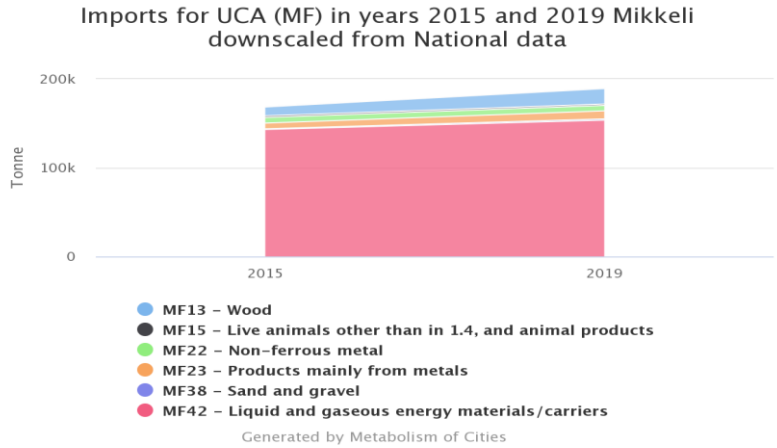


Figure 16 - The rise in mass of a pick of imported materials to the city of Mikkeli from the year 2015 to 2019 (interactive chart).

Exported materials from Mikkeli

The total amount of exported materials from Mikkeli were 23086 tonnes in 2015 and 21523 tonnes in 2019. There is a decline of 6.8% in exports in four years. Some major changes between the years 2015 to 2019 may be seen with the export of roots and tubers. In 2015 they were exported 46 tonnes, and in 2019, 167 tonnes. Wood export grew from 6103 tonnes in 2015 to 8868 tonnes in 2019 (figure 17). There was however a decline in the export of biomass products in total. The mass differences of the biomaterials may be seen in the figure 18. Exporting cereals declined by almost 38%. Export of non-metallic minerals such as sand and gravel, declined by 27% from year 2015 to year 2019 (figure 17).

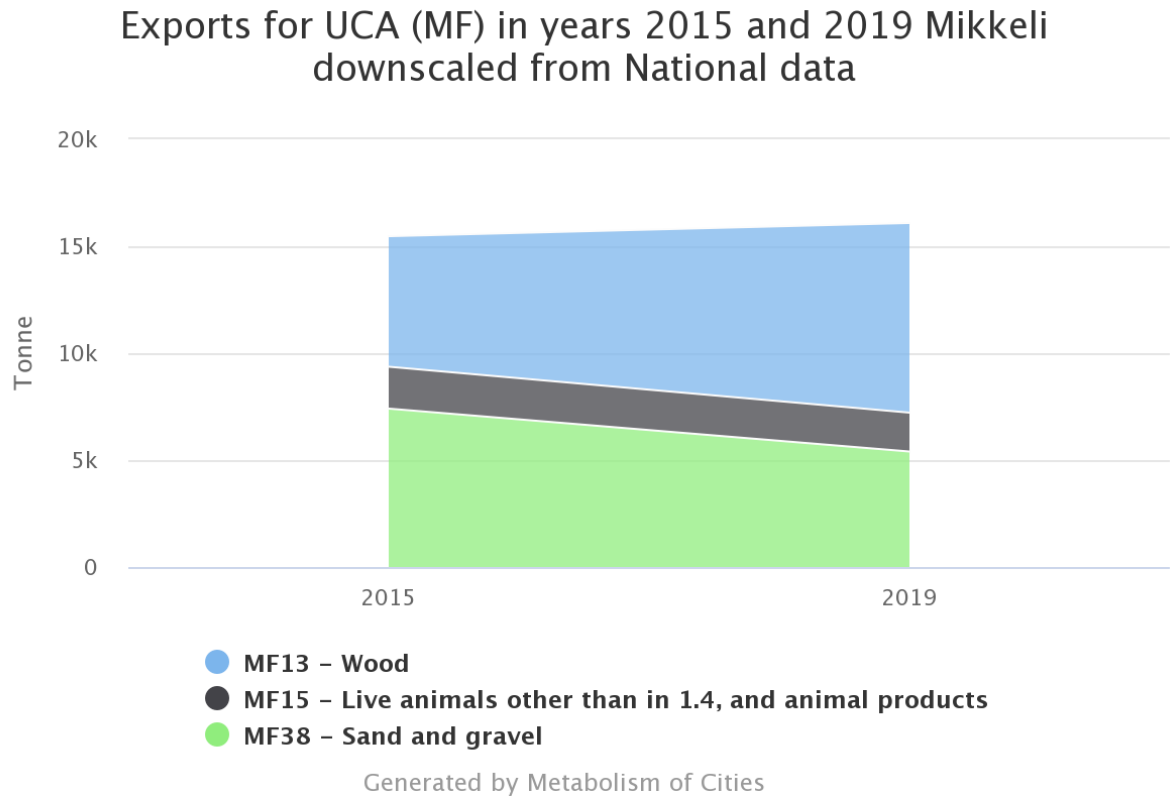


Figure 17 - A pick of materials exported from the city of Mikkeli and the difference in mass from year 2015 to 2019 (interactive chart)

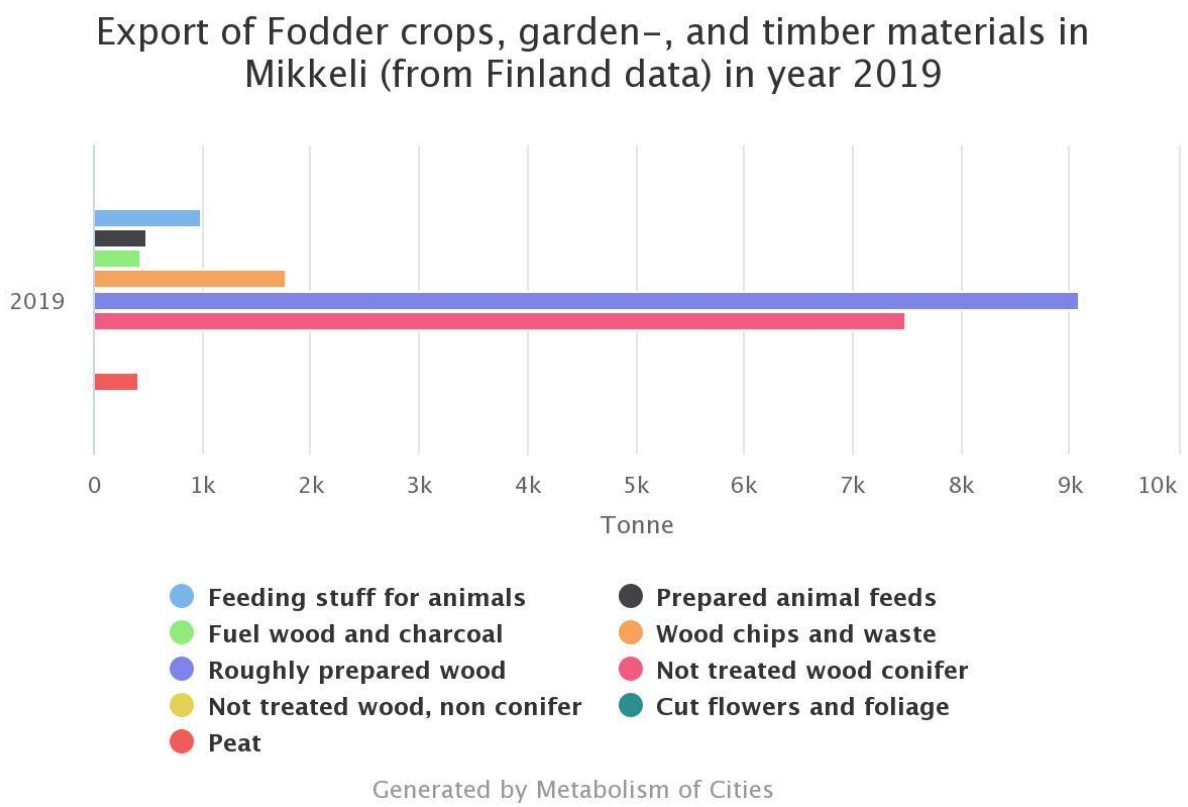


Figure 18 -Wood materials are the main export of the city of Mikkeli in 2019 (interactive chart)

4.3. Domestic Material Consumption

The domestic material consumption (DMC) is calculated by adding the domestic extraction with imports and subtracting exports. It represents the quantities that are consumed in the municipality and totaled in the biomass sector in 2015, 1445372 tonnes and in the year 2019 it was 1320471 tonnes. In the biomass materials, this mass comes mainly from the wood materials that are either further processed in Mikkeli or used for heat and energy. A big change in the DMC could be seen in the fodder crops between the year 2015 DMC of 117004 tonnes and 2019 DMC of 7567 tonnes due to declining number of farms.

When examining the fossil carriers, the DMC in 2019 for coal is 19222 tonnes. This must be untrue in practice, since the local power plant that is owned by Etelä-Savon Energia, uses 80% wood, 19% peat and 1% of oil, to produce heat and energy for the city (Etelä-Savon Energia). The same problem lies also with the metal materials. The odd DMC numbers come from the troublesome way of using the downscaled Finnish import and export data. As long as there is no city-wide data available for the materials flows in import and export, one should look at the DMC numbers for indicative purposes only.

For waste materials, in 2015 the DMC for final treatment and disposal of waste was 1971106 tonnes, when in 2019 the amount had declined to 1836326 tonnes.

4.4. Waste

Here is a review of processing and recovery waste materials according to the municipal waste treatment company Metsäsairila in the year 2019. Most of the company's waste treatment activities are centred on the Metsäsairila waste treatment centre (figure 19 and 20). In 2019, the waste centre received a total of approximately 75 000 tonnes of waste (Metsäsairila, 2020).

- Mixed waste sorted at source (household waste) is delivered to Leppävirta to Riikinvoima Ltd´s Ekovoima power plant and Kotkan Energia Ltd´s energy recovery plant five days a week for incineration and energy recovery. Mixed waste is transferred to containers at the Metsäsairila waste centre and then transported to Leppävirta110 km from Mikkeli, and Kotka 160 km from Mikkeli. As seen in the figure 18, landfilling mixed waste ended in 2017, and is now all incinerated.
- Biowaste and sewage sludge were composted at the waste centre's composting plant in 2019. The composted material was used for landscaping in Mikkeli. Since 2019, a biogas plant BioSairila has been built, and all biowaste material is dry-digested to collect methane and make biogas for mainly vehicle-fuel use.
- Wood byproducts and clean wood waste were shredded at the Metsäsairila waste centre. After shredding, the materials were transported for energy recovery.
- Concrete and brick waste and glass were stored and crushed at the Metsäsairila waste centre. The crushed material was used in the road and field structures of the area. Concrete and brick rubble was also used in 2019 for the construction of the new Metsäsairila road.
- Metals and electrical and electronic waste were temporarily stored at the Metsäsairila waste centre, from where they were delivered further as industrial raw materials.
- Paper and cardboard were baled in the Encore Environmental Services Ltd baling hall at the Metsäsairila waste centre. The materials were delivered to the paper industry for reuse.
- The contaminated soil was treated in a landfill built for its treatment. After treatment, the soil materials that were below the limit values, were recycled in a waste bed as daily cover layer. (Metsäsairila, 2020, 15)

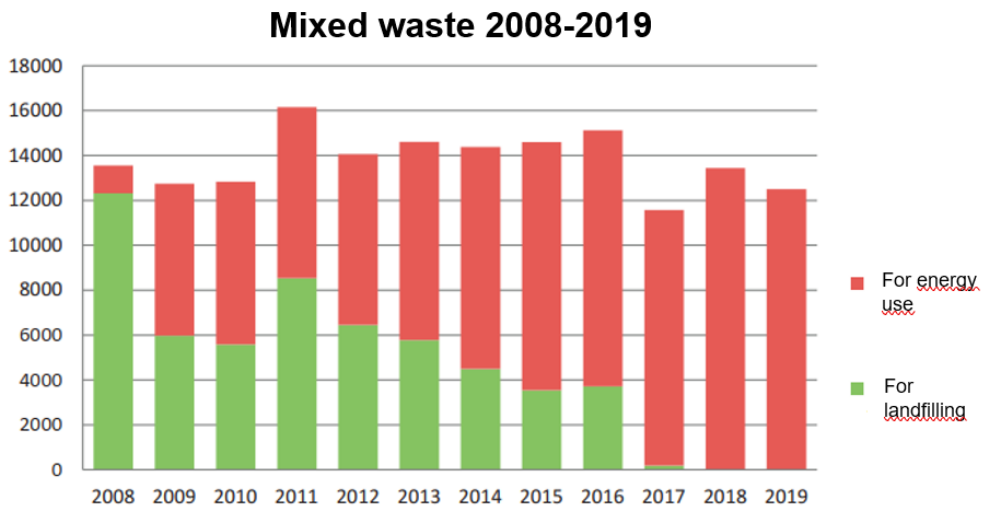


Figure 19 -Since 2018, mixed waste (graph in tonnes) has all been incinerated for energy use (Metsäsairila, 2020, 15)

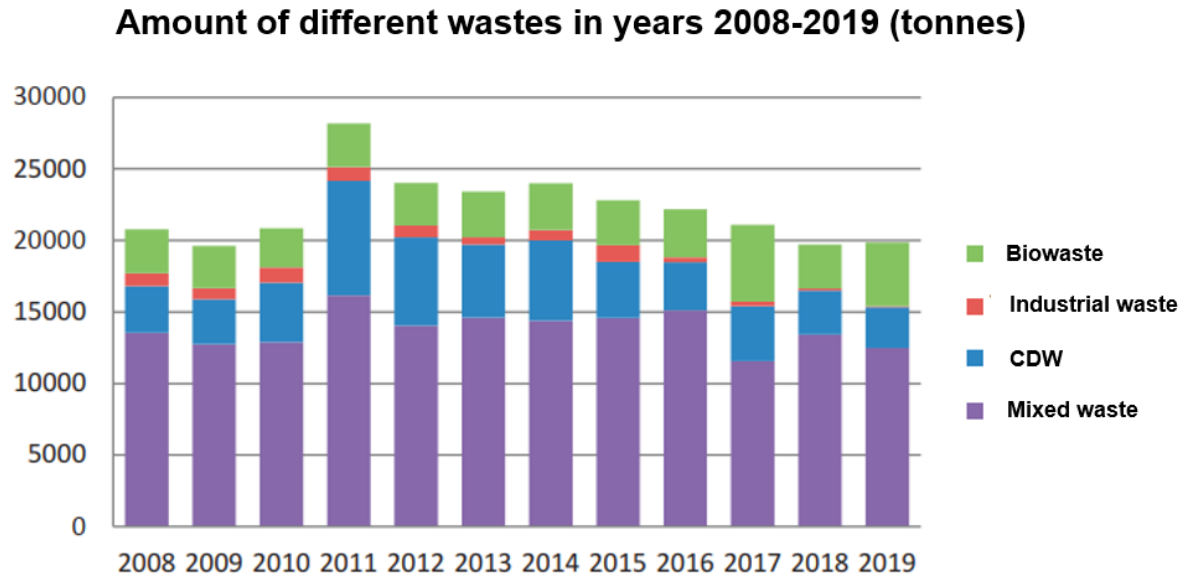


Figure 20 -Since 2014 the total amounts of waste have declined until year 2019 with a slight rise.(Metsäsairila, 2020, 15)

On the right hand side of the Sankey diagram, is the waste output of Mikkeli. There was good data available on the different wastes collected and treated in Mikkeli. This data was received from the municipal waste company Metsäsairila Ltd.

In 2015 the total amount of waste was 97366 tonnes and decreased in 2019 to 78559 tonnes. A large part of the waste in 2015 went into the landfill, about 60338 tonnes. In 2019 waste going to landfill had dropped to 37664 tonnes. No more mixed waste was landfilled but was instead incinerated for energy recovery use. Incineration for energy recovery grew from 17567 tonnes in 2015 to 22766 tonnes in 2019. Recovery of waste materials other than for energy, had decreased from 2015 to the year 2019 by about 8%.

Recyclable waste such as metal, paper, rubber, plastic, wood, and textiles were recovered 9612 tonnes in 2015. In 2019, this number declined to 7135 tonnes. This should not indicate poor recycling, especially when considering the decrease in the total amount of waste of 19.3% between these years. Although the decrease percentage on the recyclable waste was greater than the decrease in the total waste amount of 25.8%.

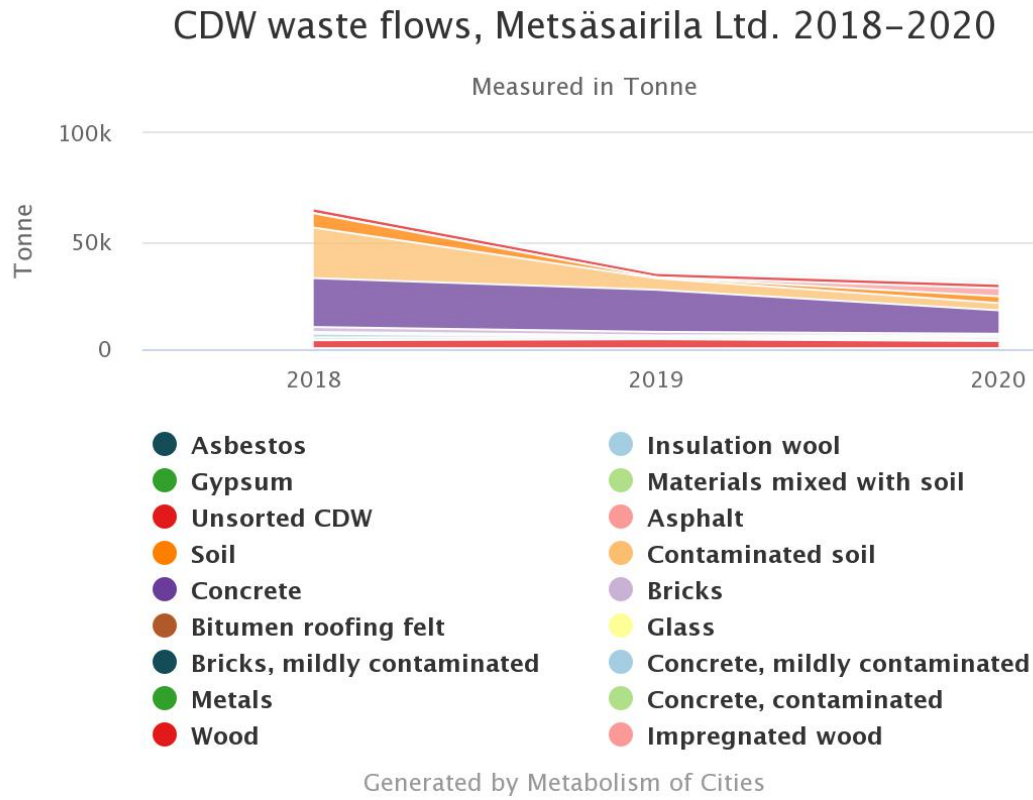


Figure 21. Waste flows in Mikkeli 2018-2020 (interactive chart)

The different actors in waste collecting and treatment as well as recycling different materials may be found in the list at pages 12-13.

5. Material stock in Mikkeli

Determining and analysing the material stock of a city can, similarly to the material flow accounting, also be a data intensive endeavour. The intensity depends on the scope and the data availability. For the Urban Circularity Assessment, the scope includes all residential and non-residential buildings in the municipality. Unlike for the material flow quantification, the analysis is not done for one or several specific reference years but considers all buildings that have been constructed and still exist, up until and including 2022 (year of study). The aim is to quantify the materials that buildings in Mikkeli contain. Depending on the data availability around building typologies, age cohorts, building height and material intensities, different, specific quantifications and investigations can be made.

Much of the in-stock material in Mikkeli is in buildings. The total number of buildings in 2022 is approximately 53000, or 10 per capita, according to the cadastre. Almost all the buildings are wooden (90 %). This is due to the great amount of holiday houses in Mikkeli. Mikkeli is one of the biggest leisure-time municipalities in Finland, and holiday houses are traditionally made of timber in the area and elsewhere in Finland .

The total mass of the building stock (in-use construction material) in Mikkeli is around 14000[1] kt, consisting of:

- Concrete 4700 kt
- Bricks 4700 kt
- Timber 3700 kt
- Mineral and glass wool 580 kt
- Metals 250 kt
- Soil 130 kt

5.1. Building typologies in Mikkeli

An essential component for material stock of buildings in Mikkeli is building typologies (more detail is provided in the next section). To define them the following pieces of information are needed: building footprints of all buildings (ideally geo-spatialised) as well as their land use, age, height, and gross floor area. These pieces of information were provided by the Mikkeli Cadastre.

[1] Mikkeli Cadastre, 2022; DVV, The amounts are estimates, based on the total floor area of the buildings, and amounts of material received from the recent public demolition projects in Mikkeli,

Buildings per typology, Mikkeli 2022	
0110,0111 Detached and semi-detached houses	**14054**
0112 Terraced houses	**966**
012 Apartment buildings	**857**
013, 014 Dormitory buildings and residential buildings for special groups	**29**
02 Leisure homes, summer cabins	**9660**
03 Commercial buildings	**404**
04 Office buildings	**124**
05 Transport buildings	**477**
06 Nursing buildings	**92**
07 Assembly buildings	**185**
08 Educational buildings	**176**
09 Industrial and mining buildings	**270**
10 Energy supply buildings	**290**
11 Public utility buildings	**16**
12 Storage buildings	**377**
13 Rescue buildings	**21**
14 Farming buildings	**705**

19 Other buildings	**22705**
Not classified	**2461**
Altogether	**53869**

Table 2 - Buildings per typology, Mikkeli 2022

The provided material is a summary of building typologies in Mikkeli, Finland for the year 2022. There are 19 categories listed, which include specific types of residential, commercial, industrial, and public buildings, along with an unclassified category with a remarkable amount of buildings. Principally the same data is shown in graph, on page 11, fig. 7.

- Detached and semi-detached houses are the most common type of buildings in Mikkeli, with a total of 14,054. This suggests that single-family residences constitute a significant portion of the city's-built environment.
- Terraced houses: These are considerably fewer in number, with a total of 966.
- Apartment buildings (012): Mikkeli has 857 apartment buildings, indicating a smaller but still significant multi-family residential presence.
- There is a significant number of leisure homes and summer cabins, pointing to Mikkeli as a potential holiday or second-home destination.
- In the city there are 404 commercial buildings, representing places of business.
- 124 office buildings, housing various local, regional, or national companies and organisations.
- 185 Assembly buildings, which include places of worship, civic centres, and other gathering places.
- 176 educational buildings, potentially housing schools, colleges, universities, or other educational facilities, and 270 industrial and mining buildings indicate a certain level of industrial activity in the city.
- 290 Energy supply buildings, reflecting the infrastructure needed to supply power to the city and 377 storage buildings, used for various purposes.
- 705 Farming buildings indicating some agricultural activity within or around the city.
- 22.705 classified as "other" buildings, possibly including a variety of structures not classified elsewhere. This is 41 % of all buildings, consisting only of small courtyard buildings and such simple constructions under 30 m2.
- There are 2,461 buildings that do not fall into any of the predefined categories, but these can be assumed to be mainly the same kind of buildings as "other buildings".

The total number of buildings in Mikkeli in 2022 is 53,869. This includes all the above categories, providing a snapshot of the city's built environment in that year. It's worth noting that this data can be used for urban planning, environmental impact studies, and similar analyses.

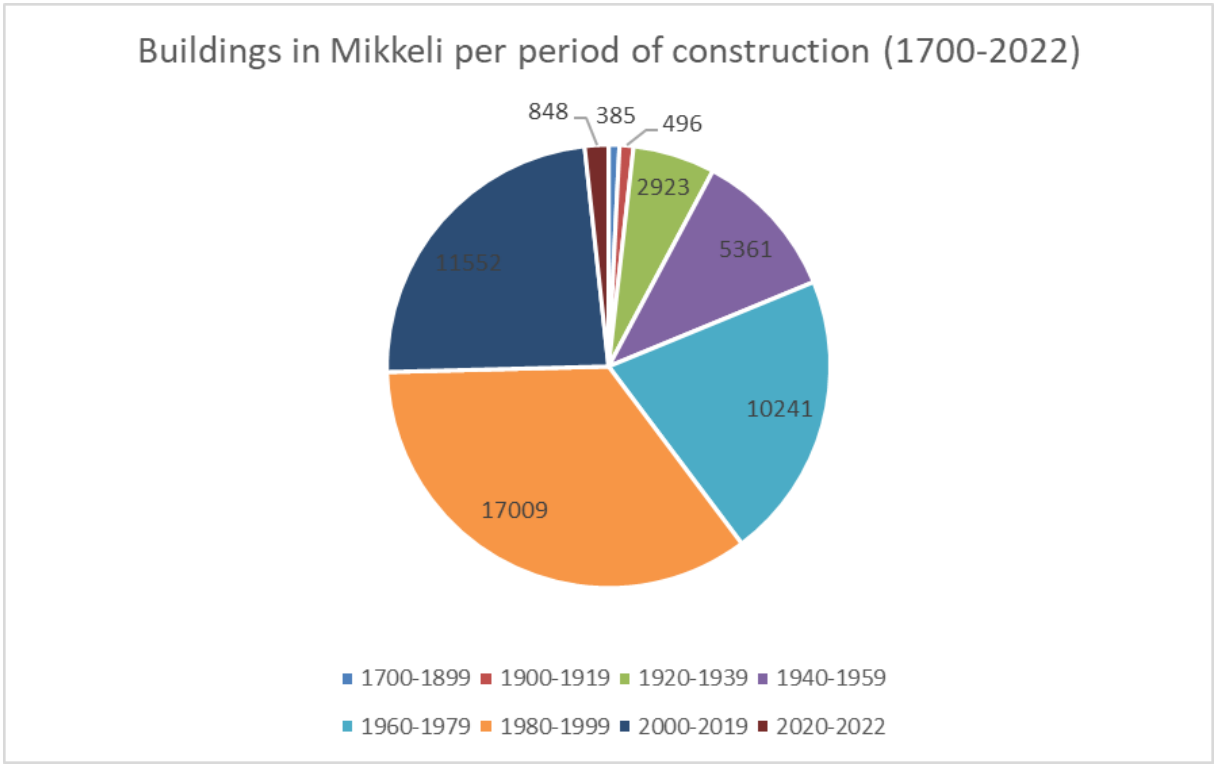


Figure 22 - Mikkeli's building stock by construction period

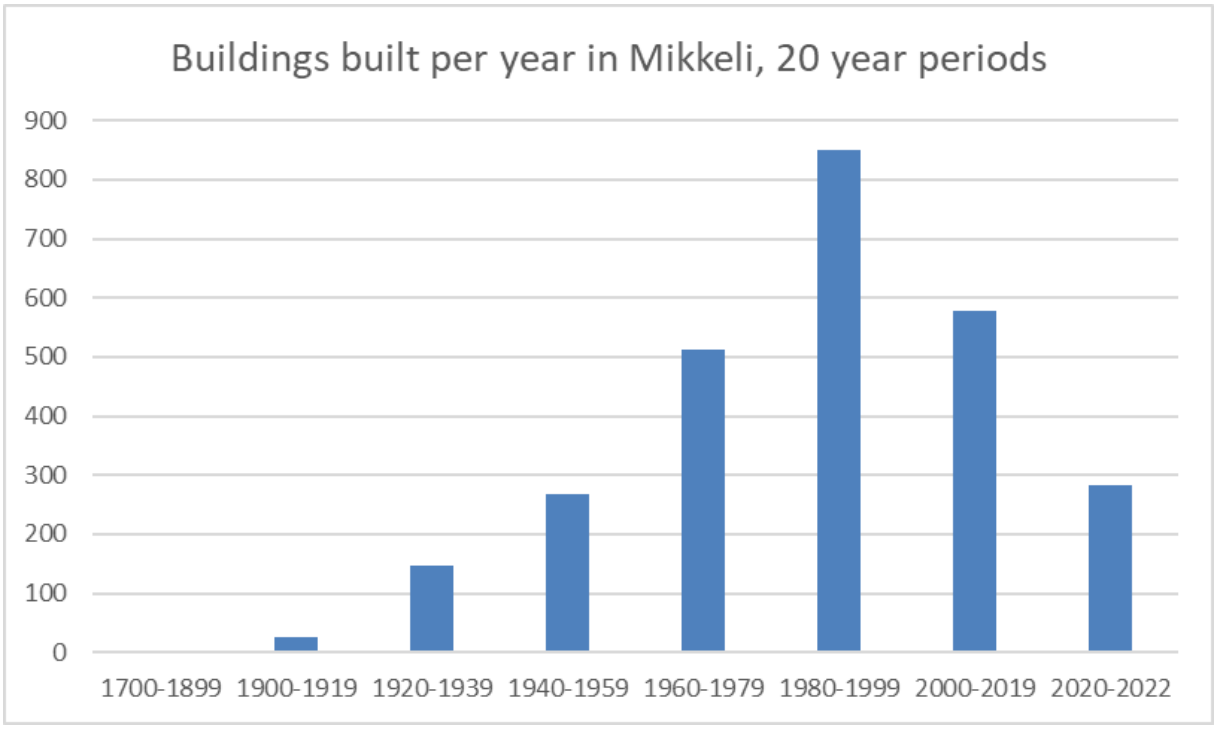


Figure 23. Buildings built per year (average) per period.

During the 1940-1959 period, construction activity almost doubled from the previous period, reaching 5361 buildings (Figure 22). This could be associated with post-World War II rebuilding efforts and population growth.

From 1960-1979, building construction skyrocketed to 10241. This could be related to the significant economic growth, urbanisation, and technological advancements in the construction industry in the second half of the 20th century.

The highest construction activity occurred during 1980-1999, with a total of 17009 buildings, or 850 buildings per year on average (Figure 23). This trend could be driven by a combination of population growth, economic prosperity, and advancements in building technology, among other factors.

5.2. Analysis of Material Stock

Using the building typologies developed in the previous part and the material intensities from Lilja et al. (2021, available at MOC ID 989983), it was possible to measure the material stock of Mikkeli's building stock. To obtain it, the gross floor area for each building was multiplied by its associated material intensity, which depends on the typology of that building. Overall, it is estimated that Mikkeli's **building stock weighs approximately 14 million tonnes**.

The greater floor area and material intensity of buildings located in the city centre, coincide with a greater material building stock per building. However, given the recent date of construction of these buildings, these materials will not become available until their renovation or demolition in the future. Besides those buildings, 19% of the total building stock in Mikkeli was built before 1960 and 21% was built between 1961 and 1980. 34 % of the buildings have been built between 1981-2000. Assuming the lifespan of buildings constructed in the post-war period is about 50 years (Thomsen and Straub 2008), the materials embedded in some of the buildings built before 1980 will soon become available and be used to satisfy future resource use demands. Thus, the buildings could be thought to be a real material stock for future purposes.

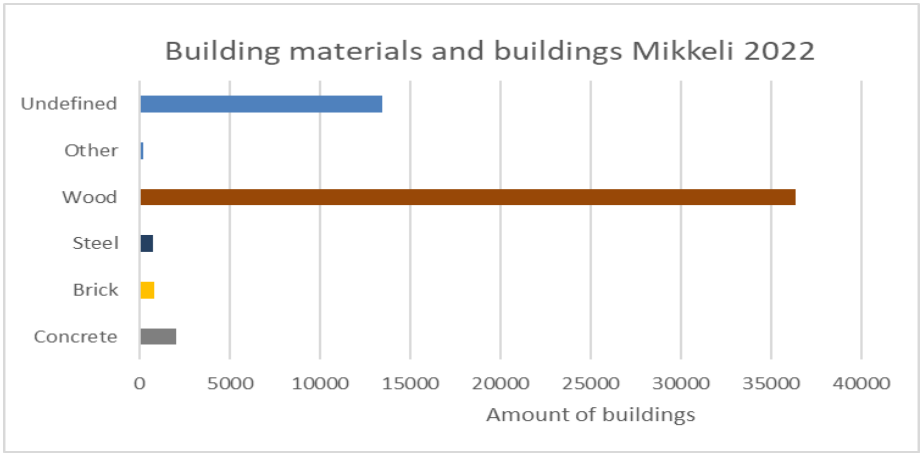


Figure 24 - Building stock by the main structure materials

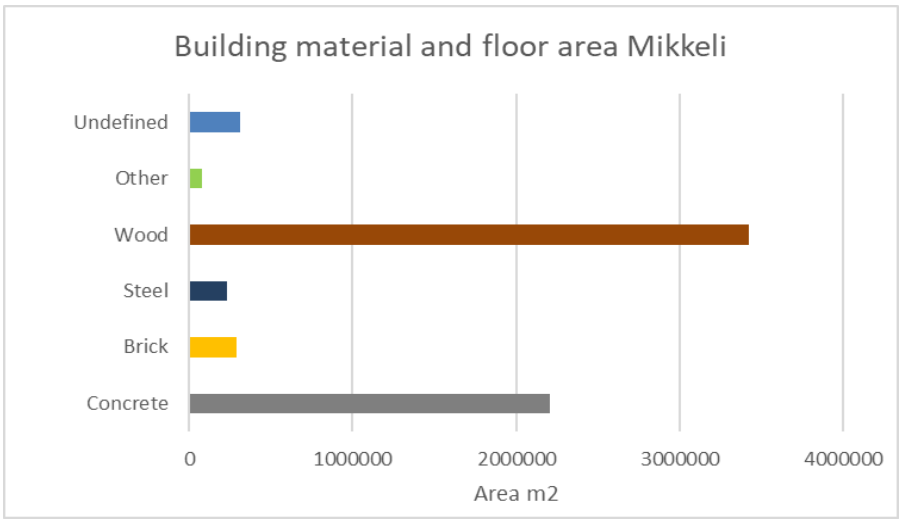


Figure 25 - Floor area of the building stock by the main structure materials

The upper table (Fig. 24, p.31) contains the number of buildings in Mikkeli in 2022 classified by their primary construction material.

1. **Wood:** By a significant margin, wood is the most commonly used building material, with a total of 36.371 buildings constructed from it. This is not surprising given that Finland has a tradition of wooden buildings and has abundant forest resources. The extensive use of wood also has considerable environmental benefits, as it is a renewable resource that can sequester carbon, potentially helping to combat climate change. Wood is the most usual building material used for summer cabins
2. **Undefined:** The second most frequent category is "Undefined" with 13.427 buildings. This high figure suggests many buildings for which the primary construction material has not been identified or recorded. It may be beneficial for city planning or other municipal purposes to update these records for a more accurate understanding of the building stock and more reliable data for future analyses.
3. **Concrete:** Concrete is used in the construction of 2,066 buildings. Concrete is a popular building material globally due to its strength and durability. Most of the city's larger or more modern buildings are made of concrete.
4. **Brick:** the structures of 793 buildings are constructed with brick. Brick has been a traditional building material for centuries and is known for its durability and thermal properties. It's likely used in a variety of building types in Mikkeli.
5. **Steel:** Close to brick, there are 747 buildings made from steel. Steel is often used in larger commercial or industrial buildings due to its strength and versatility. It's less commonly used in residential buildings.
6. **Other:** The least common category is "Other" with only 201 buildings. This category doesn't have a material clarification, but it represents such a small portion of all buildings (0,4 %), that it can be left out of the analysis.

In summary, the building stock in Mikkeli is dominated by wooden buildings, likely due to cultural, historical, economic, and environmental reasons. A significant number of buildings

have undefined material, suggesting potential gaps in the data. The use of concrete, brick, and steel is low when considered in the amount, but rises significantly as we look at the floor area of the buildings (figure 25).

The data on the floor area of the buildings (figure 25) offers a new perspective on Mikkeli's buildings when measured in square metres (m^2), according to the principal construction material. It offers a different way to consider the prevalence of each material, which is not necessarily directly proportional to the number of buildings.

1. **Wood:** Wood remains the most used construction material in terms of total floor area, clocking in at 3,419,768 m^2. Despite the high number of wooden buildings, the difference in total floor area compared to concrete buildings is not as high as the difference in the number of buildings. This could imply that while wooden buildings are numerous, they might be generally smaller (for example, residential houses or cabins).
2. **Concrete:** With a total floor area of 2,209,353 m^2, concrete is the second common material when compared to the floor area. Compared to the number of concrete buildings, this indicates that concrete is often used in larger buildings (possibly commercial or industrial structures).
3. **Undefined:** The total floor area for undefined buildings is 310,964 m^2. Again, the data shows a large proportion of buildings are not categorised. However, the total floor area is quite small compared to wood or concrete, suggesting these undefined buildings are smaller in size.
4. **Brick:** Brick buildings make up a total floor area of 292,138 m^2. Given the smaller number of brick buildings, this suggests that brick may be used in mid-sized buildings on average.

In conclusion, the overall trends between the number of buildings and the total floor area of each material type show some expected consistencies but also reveal a new layer of complexity. While wood dominates both the number of buildings and total floor area, the difference between the floor area of wooden and concrete buildings is not as drastic as the difference in their numbers, pointing to potential differences in average building size. These comparisons underscore the rich diversity of Mikkeli's building stock and the varying roles that different materials play in the city's built environment.

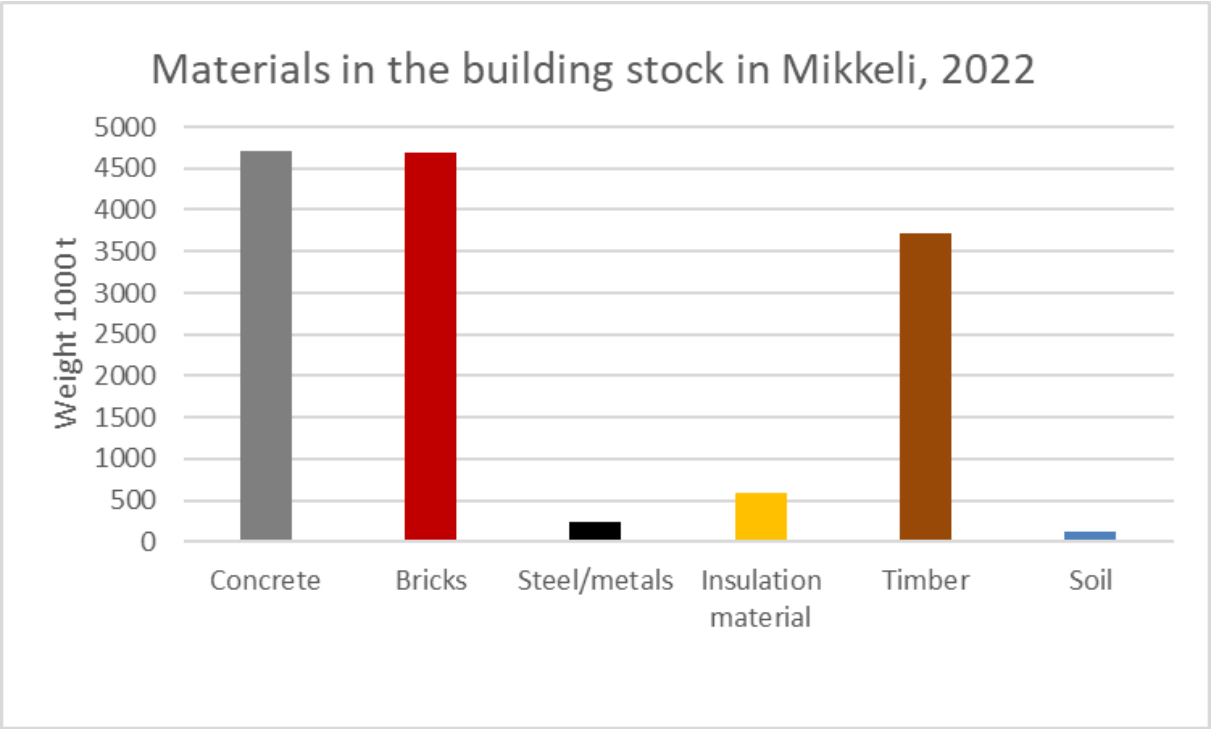


Figure 26 - Total weights of materials in the building stock in Mikkeli. Calculated with research by Lilja (2021) of the materials from demolished buildings in Mikkeli 2019-2021.

The data in figure 26 represents a rough estimation of the weight of various building materials used in Mikkeli's building stock, measured in thousands of tonnes (1000 t). It also provides the percentage each material contributes to the total weight. We must note that glass is not included, because glass was not collected separately from the buildings in the research.

1. Concrete: With a total weight of approximately 4,701,000 tonnes and representing at least 33% of the total material weight, concrete remains a prominent building material in Mikkeli in terms of weight. This aligns with the earlier insights about its usage in larger, robust structures.
2. Bricks/Ceramic tiles/concrete Mix: This category, with an estimated weight of 4,696,000 tonnes and accounting for ca 33% of the total weight, combines the weights of bricks, ceramic tiles, and some concrete. As the exact breakdown between these materials is unknown, it's harder to draw specific conclusions about each material's individual prevalence or impact. However, this weight still underscores the substantial use of dense, durable materials in Mikkeli's buildings. Given that some concrete is included in this category, the total weight represented by concrete in Mikkeli's building stock might be higher than initially noted.
3. Timber: Timber, the most common material by count and total floor area, has a total weight of approximately 3,712,000 tonnes, contributing 26% to the overall weight. This illustrates timber's lighter nature despite its extensive use, consistent with our previous observations.

4. Insulation Material: Weighing approximately 588,000 tonnes and constituting 4% of the total weight, insulation materials signify the importance of thermal efficiency in building construction.
5. Steel/Metals: Steel and other metals contribute around 248,000 tonnes, forming 2% of the total weight. This relatively small percentage, despite steel's high density, is in line with its lesser use in Mikkeli's buildings.

In summary, considering the clarified data, concrete and the bricks/ceramic tiles/concrete mix represent the highest proportions in terms of weight (66 %), indicating the substantial use of these dense, durable materials in the city's structures. The other materials, while lighter in weight, still play significant roles in the building stock. The distribution of these weights can offer insights for future resource management and waste reduction strategies, particularly regarding material reuse and recycling.

From a circular economy perspective, it appears that perhaps the most important strategy would be to maintain the building stock. When this is not possible the reuse (slab or columns) or recycling of concrete (using it as aggregates in new concrete structures and as whole elements where possible), and reuse of bricks, wood and steel would be most desirable.

Where do the masses lie?

Concrete and bricks (including a mix of ceramic tiles and concrete) are the materials with the greatest weight in Mikkeli's building stock. Therefore, the building types that generally use these materials more intensively have the largest material masses. Such structures usually include commercial buildings (like offices, malls, and warehouses), industrial buildings (factories, storage facilities), and larger residential complexes (multi-storey apartments). These types of buildings often require more robust, durable materials to support their size and structural loads, hence the use of concrete and brick.

In terms of carbon sequestration, timber is the clear leader. Wood naturally absorbs and stores carbon dioxide from the atmosphere as it grows, a process known as carbon sequestration. When trees are harvested and used in construction, that carbon remains stored in the timber for the lifespan of the building. Therefore, buildings constructed primarily from wood – which in Mikkeli is likely to include a significant number of residential houses, detached houses, cabins, and some smaller commercial structures – would be the types of buildings that bind the most carbon.

The exact material masses and carbon sequestration would depend on many factors, including building design, construction methods, and material sourcing practices.

6. Analysis of Flows and Stocks: Measuring Indicators

To monitor the progress of the local economy towards circularity, a number of indicators were proposed and measured. Altogether, these indicators depict several facets of circularity of the sector. As such, they need to be considered in combination rather than in isolation when assessing circularity. In addition, these indicators can be compared to other cities or spatial scales (such as the country level). However, this has to be done with great care and use of the contextual elements in the previous sections of the report. Finally, the value measured from these indicators can be traced over time to track the city's progress towards circularity. The below table provides the value for two reference years, where possible, and the percentage change between the two.

Indicator table

Indicator	2015	2019	Unit	Change from 2015 to 2019 (%)
Input Socioeconomic Cycling Rates (ISCr)	0.6	0.4	%	-33.3
Output Socioeconomic Cycling Rate (OSCr)	0.8	0.5	%	-37.5
Input Ecological Cycling Rate Potential (IECrp)	72.9	71.7	%	-1.6
Output Ecological Cycling Rate Potential	79.8	81.1	%	1.6
Input Non-circularity Rate (INCr)	12.3	11.3	%	-8.1
Output Non-circularity Rate (ONCr)	17.0	16.2	%	-4.7
Remaining non-renewable primary resources	14.2	16.7	%	17.6
Remaining interim outputs	2.4	2.2	%	-8.3
Material recovery	5.0	3.2	%	-36
Direct Material Input (DMI)	1994192.4	1824501.2	tonnes / year	-8.5
Domestic Processed Output (DPO)	1419445.1	1280122.1	tonnes / year	-9.8
Domestic Material Consumption (DMC)	1971106.4	1836326.3	tonnes / year	-6.8
Domestic Material Consumption Corrected (DMCcorr)	1971106.4	1802978	tonnes / year	-8.5
Local and Exported Processed Output (LEPO)	1419445.1	1280122.1	tonnes / year	-9.8
Processed Material (PM)	1987730	1842859.3	tonnes / year	-7.3

Interim Outputs (IntOut)	1431198.7	1286655.1	tonnes / year	-10
Secondary Material (SM)	16623.6	6533	tonnes / year	-61
Net Addition to Stock (NAS)	551661.2	556204.1	tonnes / year	0.8
Physical Trade Balance (PTB)	204328	217274	tonnes / year	6.3
Material Productivity (MP)	1.2	1.4	kg/1000€GDP	16.7
Material Intensity (MI)	0.8	0.7	kg/1000€GDP	-12.5

Table 3- Indicator table shows the numeral changes in each indicator from year 2015 to year 2019.

Indicators chosen and their development over time

The first two indicators, ISCr and OSCr, are related to socioeconomic cycling rates. Both indicators have decreased from 2015 to 2019, with ISCr decreasing by 33.3% and OSCr decreasing by 37.5%. This suggests that the system may be less sustainable in terms of socioeconomic cycling than it was four years prior.

The next two indicators, IECrp and OECrp, are related to ecological cycling rate potential. While IECrp has decreased slightly by 1.6%, OECrp has increased by 1.6%. This suggests that the system may be slightly more sustainable in terms of ecological cycling rate potential than it was in 2015.

The next two indicators, INCr and ONCr, are related to non-circularity rate. Both indicators have decreased, with INCr decreasing by 8.1% and ONCr decreasing by 4.7%. This suggests that the system may be more sustainable in terms of non-circularity rate than it was in 2015.

The remaining indicators provide information on various aspects of resource use and productivity within the system. The remaining non-renewable primary resources have increased by 17.6%, while material recovery has decreased by 36%. Direct material input (DMI), domestic processed output (DPO), domestic material consumption (DMC), and local and exported processed output (LEPO) have all decreased, with DMCcorr showing the largest decrease of 8.5%. Processed material (PM) and interim outputs (IntOut) have also decreased, with IntOut showing the largest decrease of 10%. Secondary material (SM) has decreased significantly by 61%, while net addition to stock (NAS) and physical trade balance (PTB) have both increased, with PTB showing the larger increase of 6.3%. Finally, material productivity (MP) has increased by 16.7%, while material intensity (MI) has decreased by 12.5%.

Overall, the table suggests that while the system may be less sustainable in terms of socioeconomic cycling rates, it may be more sustainable in terms of non-circularity rate and ecological cycling rate potential. There are also some mixed results in terms of resource use and productivity, with some indicators showing decreases while others show increases.

7. Data Quality Assessment

Numerous datasets were collected and considered in the Urban Circularity Assessment and this section qualitatively assesses how reliable the data used is. In some cases, datasets were not available for some materials or for some lifecycle stages for the city. Therefore, estimations needed to be done by looking at data at higher spatial scales (region or country) and downscaling it with proxies, described in the part on data gaps and assumptions.

The overall data quality is considered as well and depicted in the data quality matrix below. It is expressed through four data quality dimensions: reliability, completeness, temporal correlation, and spatial correlation. Each dimension has its own criteria for the ranking of high (green), medium (yellow) and low (red), which is based on this Pedigree report and shown in the table here. There may be additional explanations in some cells, as supporting information.

Rating	Reliability	Completeness	Temporal correlation	Spatial correlation
high	Reviewed or measured data	Data exists for all of the single sub-material groups and/or materials	1 data less than 3 years difference to the time period of the data set	City-level data
medium	Estimated data	Data exists for most of the single sub-material groups and/or materials	2 data less than 6 years difference to the time period of the data set	Regional-level data (NUTS 3)
low	Provisional data	Data exists for the main material group only	3 data less than 10 years difference to the time period of the data set	NUTS 2 and country-level data

Data quality matrix

Lifecycle stage	Reliability	Completeness	Temporal correlation	Spatial correlation
Domestic extraction				
MF1 - Biomass				some downscaled
MF2 - Metal ores (gross ores)	From different sources			
MF3 - Non-metallic minerals	From different sources	some uncertainties		
MF4 - Fossil energy materials/carriers		some uncertainties		
Imports & Exports	Uncertainties in nomenclature and MF comparability			National data

MF1 - Biomass	Uncertainties in nomenclature and MF comparability			National data
MF2 - Metal ores (gross ores)	Uncertainties in nomenclature and MF comparability			National data
MF3 - Non-metallic minerals	Uncertainties in nomenclature and MF comparability			National data
MF4 - Fossil energy materials/carriers	Uncertainties in nomenclature and MF comparability			National data
MF5 - Other products	Uncertainties in nomenclature and MF comparability			National data
MF6 - Waste for final treatment and disposal				Some data downscaled
Waste				
Material stock			Data from year 2022	

Table 4- Data Quality matrix of the data collection and process and its reliability in a scale of high, medium or low.

7.1. Data Quality

The data gathered for the report is a combination of public-, company-, and municipal data. Some of the data has been downscaled from higher spatial scales and therefore the accuracy is somewhat compromised, this especially in the data collected for import and export.

As can be seen in the data quality matrix above, the overall quality of the data is high to medium for most lifecycle stages (LCS) and material groups:

- **The reliability** of the data is acceptable. For domestic extraction most data was available from reliable public sources, and did not need downscaling. For imports and exports all data was downscaled from national data. There was some difficulty in the correlation of the nomenclature of the import and export data to the MF naming of the materials.

- **The completeness** of the data was mostly high, but there was some uncertainty if all the extracted materials for non-metallic minerals and fossil energy carriers were accounted for.
- **The temporal correlation** was good for all materials and lifecycle stages, as the data was nearly all from the reference years 2015 and 2019.
- **The spatial correlation** was low for export and import data, since all this data needed to be downscaled from the national data.
- **The waste data** was reliable and retrieved mostly from the local waste company, but some recyclable waste data was from the responsible collector.
- **The material stock data** is reliable concerning reliability, completeness and spatial correlation. The data is however mostly from the year 2022, not the year 2019 as from most of the data collected for the analysis. But in the nature of the stability concerning building stocks, this should not weaken the overall data collection and it´s reliability in all.

7.2. Data Gaps and Assumptions

Domestic Extraction

To measure biomass domestic extraction of crops in Mikkeli in 2015 and 2019, data was obtained mostly from the **LUKE, Natural Resources Institute Finland**. The data was mainly from city scope, and only a little data needed downscaling from regional area data. Also, a **Biomass Atlas map** was used to measure the amount of biomass produced from forestry, agriculture, and communities and industry (biodegradable waste) in Mikkeli. Data collected from these sources is highly reliable. The data collected was complete and were found well for both years 2015 and 2019.

If needed, Eurostat information on crops yield data at a NUTS 2 level was used to calculate the weight of extracted crops by multiplying yield with arable land area values. The weight of extracted crops was calculated using CBS arable land area data for the years 2015 and 2019.

For metallic minerals and non-metallic minerals extraction data, information was gathered from the **Centre for Economic Development, Transport and the Environment (ELY Centre South-Savo)** and the environmental permits. Since there is no extraction of metallic minerals in Mikkeli, most of the extraction information was of the non-metallic minerals. Some data was collected via e-mail to the responsible official, and some data was directly from the open data sources. The information of extraction of peat, which is the only fossil fuel carrier extracted from Mikkeli, was received from the **Neova company.**

Imports & Exports

Imports and exports data at the city level does not exist. **Customs Finland data for Imports & Exports** in the national level was used by downscaling the data to city-level. Proxies were used from employment by Industries. There were some uncertainties in matching the classes (NACE 2 and 4) with relevant material codes (MF) since they were not thoroughly comparable.

The method of downscaling imports and exports from national level to smaller NUTS levels, using economic activities is a used practice in similar assessments. In this case, downscaling with this method was not reliable, because of the major dissimilarities in the industries and businesses in the different areas of Finland, especially when comparing imports and exports at city-level.

Data from local production companies on imports and exports would have been necessary to present a reliable image of these actions at the city level. Data collection directly from the local companies is however hard to obtain, since the companies feel the information should be kept private and not published.

Domestic Material Consumption

As DMC is a measured indicator (DMC = DE + IMP - EXP) no other assumptions were made, or further data collected to calculate this indicator. It should be noted that this indicator inherits all assumptions and uncertainties from the import and export data collection process.

Waste

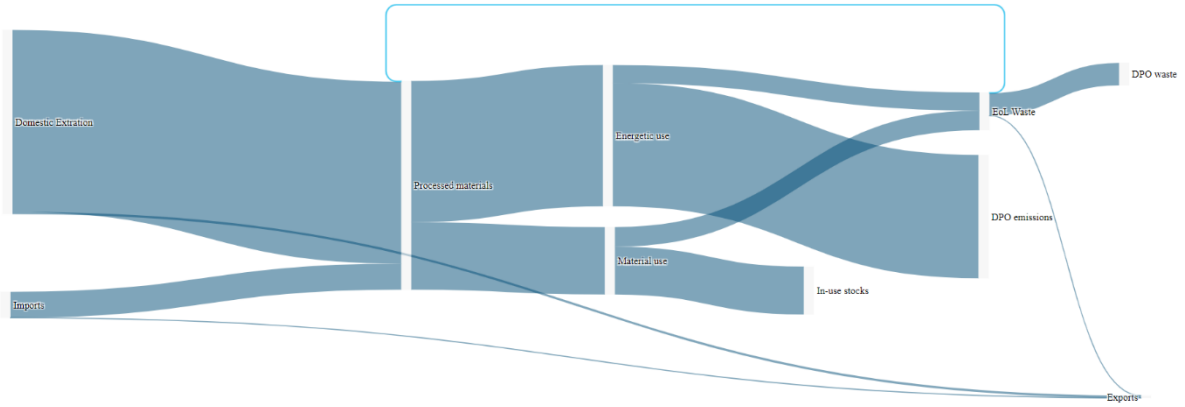
The waste data was collected mainly from the municipal waste company **Metsäsairila** with the help of the company employees. Some received data was hard for an outsider to comprehend without a deep understanding of the different waste materials collected and the processes the materials go through locally. In addition, some recyclable waste that is collected by the responsibility of the producer, information was obtained by contacting the appropriate companies managing the waste. In these cases some downscaling needed to be done, since the data collected was from a greater NUTS area.

Material Stock

For the analysis of the building stock material, data from the Finnish cadastre were used. The following information on the buildings was obtained: geometries, year of construction, gross floor area and typology.

8. Analysis of Data and Indicators: Assessing Circularity

This last section of the UCA report analyses the status quo in terms of material circularity in Mikkeli. It considers the findings visualised in the (Sankey below) diagrams and the conclusions from the indicators. The overall results of the Urban Circularity Assessment are discussed and interpreted here, before providing recommendations to accelerate the transition towards a more circular Mikkeli.



8.1. Insights on Status Quo of Mikkeli

After assessing the circularity of Mikkeli, according to the Sankey diagram, it indicates that the city is quite a closed system, which processes most of its locally extracted materials and uses this for energy. Differing from most European cities, the import flows are way smaller than the domestic extraction. In addition, a minuscule amount of local extraction and production of mostly wood is exported to satisfy the consumption of other territories.

More than half of the materials extracted locally are used for energetic uses whereas roughly one third of this goes to material use. This may be the result of large amounts of timber being extracted and used in local industry. The side streams of this extraction are well used for heating and energy in the local Pursiala Power plant. Energetic use is responsible for some of the city's emissions. There has been a positive change in this since the use of peat as an energy source in Mikkeli has declined. According to the **Etelä-Savon Energia**, most of its materials used for incineration are extracted less than a 100 km from the plant.

Other heavy extractions, such as sand and gravel are used locally for the building of the infrastructure, housing as well as for concrete production. Used building materials such as concrete and bricks are mainly crushed and used for building roads and other infrastructure. Used wood materials go to incineration and energy use. Only a small quantity of waste generated is following a circular economy practice as reusing or recycling the material.

Concerning the material flows of organic matter and biowaste, Mikkeli has developed its circularity by building a new biogas plant, where organic matter is dry digested into methane and produced as local biofuel. This is also a great leap toward becoming more self-sufficient in environmentally friendlier and locally produced fuels.

As a critique to the city, too much of the material flows goes to incineration and energy use. From processed materials (1.2kt) most (1.04kt) goes to incineration. However, from processed materials (647t) materials flow to material use (452t) and to in-use stocks. Most of the materials

are extracted, processed, and used locally, which might increase the environmental effects locally, but on the other hand, lessen the carbon dioxide load of materials being imported to the city from elsewhere.

The results provide a unique indicative insight into the materiality of Mikkeli's economy. In the future, more knowledge of cities´ material flows and their circularity is needed. For this, the problem of data collecting on import and export regarding cities needs to be addressed. A more accurate picture of the flows and use of the materials is needed to be able to pursue a more circular city. The difficulty of collecting data on building stocks became clear over months of trial and error in searching and inquiring the data.

For this urban circularity assessment work, a great amount of data was analysed and processed. Some of the needed data were missing at Mikkeli´s scale, although they existed at higher spatial levels. Therefore, assumptions and calculations needed to be carried out, to downscale data to a city level. This compromised the quality of the results, but still provided a basis for understanding the material flows of the city. The used accounting methods have been validated at a national and European context. In the future, further validations by comparing values with other Finnish cities and the Finnish economy could be carried out. Further recommendations about how to use the results of this study and how to improve it can be found in the next section.

8.2. Recommendations for Making Mikkeli More Circular

The essential systems for which a sustainability breakthrough is needed are energy, food, and transportation in industrial and private consumption. Finland consumes more than 2 times as much natural resources and produces more than 4.5 times as much waste as the EU average. In terms of resource productivity (GDP/DMC) we are among the lowest third in the EU. The circular economy rate in Finland is 7%, while the EU average is 13%.

Several opportunities to make Mikkeli more circular appeared through the UCA:

- **Develop a bioeconomy:** Given the land use of Mikkeli and the 12,747 ha of agricultural land with 479 farms in total, this provides a considerable opportunity to develop a circular bioeconomy using the sidestreams of primary production of food and fodder crops.

  For instance, a satellite organisation of small biogas production units at farms would help farmers upgrade the organic matter (vegetation and manure) to a valuable energy form, biogas. This biogas would help farms become more sustainable and self-sufficient in energy. A main operator would be needed to operate, supervise, and guide the farmers in the biogas production. The farmers could simply concentrate on feeding

the organic matter to the process of digestion and methanisation. Any biogas spared from the farms own use, could be sold by the operator for public use.

This kind of circular development would save in GHG-emissions for the farms themselves, and Mikkeli city as well. Additional production of in demand, local and greener energy/fuel would help many struggling farms become more viable. This is a new kind of possibility, with little or no examples to benchmark from. A wide project would be needed to test the idea through demonstration and trial.

There are numerous lakes in Mikkeli, some of these lakes have become eutrophic because of the cultivation of the lands and nutrient deposition in the water bodies. Collecting aquatic vegetation and finding further use for this as new product, it would help the lake's ecosystems heal as well as find new openings in bioeconomy.

- **Development through stock material in Mikkeli:** The data of the buildings in Mikkeli should be better used for urban planning, environmental impact studies, and similar analyses.

  Overall, it is estimated that Mikkeli's building stock weighs approximately 14 million tonnes and the materials used to build (especially before 1980) will soon become available to be used as material for the future buildings and infrastructure in the city.

  Wood is the most used building material in Mikkeli as it has a long tradition of wooden buildings and available, abundant forest resources. Wood has considerable environmental benefits as a renewable resource that can sequester carbon. This can help combat climate change.

  There is still a mass of undefined building materials in Mikkeli. It could be beneficial for city planning to update these records and data for a more accurate understanding of the building- and material stock and better decision -making in the future.

  Wooden buildings are numerous but they are generally smaller in size. On the other hand, concrete is often used in larger buildings and the material amounts are on the rise when comparing the floor area of the buildings. The distribution of the materials can offer insights for future resource management and waste reduction strategies, particularly regarding material reuse and recycling.

  From the perspective of circularity it seems that the most important strategy would be to maintain the current building stock in use as long as possible. When this is no longer possible, then pursue to reuse or recycle concrete (using it as aggregates in new concrete structures and as whole elements), and reuse bricks, wood and steel when possible.

  Timber is a great building material for carbon sequestration. Carbon remains stored in the timber of the buildings for its whole lifetime, therefore building from wood should be

promoted in the city as a way of reducing the carbon footprint when constructing new buildings.

- **Create reuse opportunities:** Benchmarking Apeldoorn's smart reuse of construction and demolition materials such as soil, bricks, concrete products and stones for infrastructure building (road paving, yard construction etc.), Mikkeli should seek to try the idea locally. A centre for used materials for especially outdoor construction purposes should be established. This could be operated by a private company and the products could be sold both for public- and private use. This could reduce the use of virgin materials for construction use as well as reduce construction and demolition waste generation.

  Too much of waste materials is being incinerated instead of finding new use for it. A good example of this is wood waste. Almost all waste wood is incinerated, when it could be used for construction purposes or making biochar for different applications.

- **Support collaboration:** Mikkeli and Miksei could play an active role in these proposed new actions by developing a circularity roadmap together with other stakeholders. This could be carried out by elaborating further the actions presented and identifying the stakeholders responsible for implementing these actions as well as budgeting the efforts and money required.

  Collect better data to monitor the situation: Societal decision-making should be the driving solution of the green transition. Vast and clear data is needed to able the use of financial, legal, and economic instruments, information governance, and solutions based on cooperation between different actors

  This Urban Circularity Assessment provides a first baseline look into Mikkeli´s circularity. It provides some insights on how to make the city more circular. For the assessment, data collection of material flows was essential to be able to propose actions on circularity. Some data collection needs to be enhanced for the quality of the assessment for future iterations.

  - For imports & exports, it is essential to get local data on the import and export of goods and consumption flows so that downscaling from the national data could be used to the minimum.
  - For waste, more detailed information on their treatment and possible circular use would be needed. Some of this information on how materials are sold and forwarded to circular use in Mikkeli is not available because of contract secrecy between the waste company and other counterparts.

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CITYLOOPS

CityLoops is an EU-funded project focusing on construction and demolition waste (CDW), including soil, and organic waste (OW), where seven European cities are piloting solutions to be more circular.

Høje-Taastrup and Roskilde (Denmark), Mikkeli (Finland), Apeldoorn (the Netherlands), Bodø (Norway), Porto (Portugal) and Seville (Spain) are the seven cities implementing a series of demonstration actions on CDW and soil, and OW, and developing and testing over 30 new tools and processes.

Alongside these, a sector-wide circularity assessment and an urban circularity assessment are to be carried out in each of the cities. The former, to optimise the demonstration activities, whereas the latter to enable cities to effectively integrate circularity into planning and decision making. Another two key aspects of CityLoops are stakeholder engagement and circular procurement.

CityLoops started in October 2019 and will run until September 2023.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 821033.