Ref. Ares(2023)4540686 - 30/06/2023

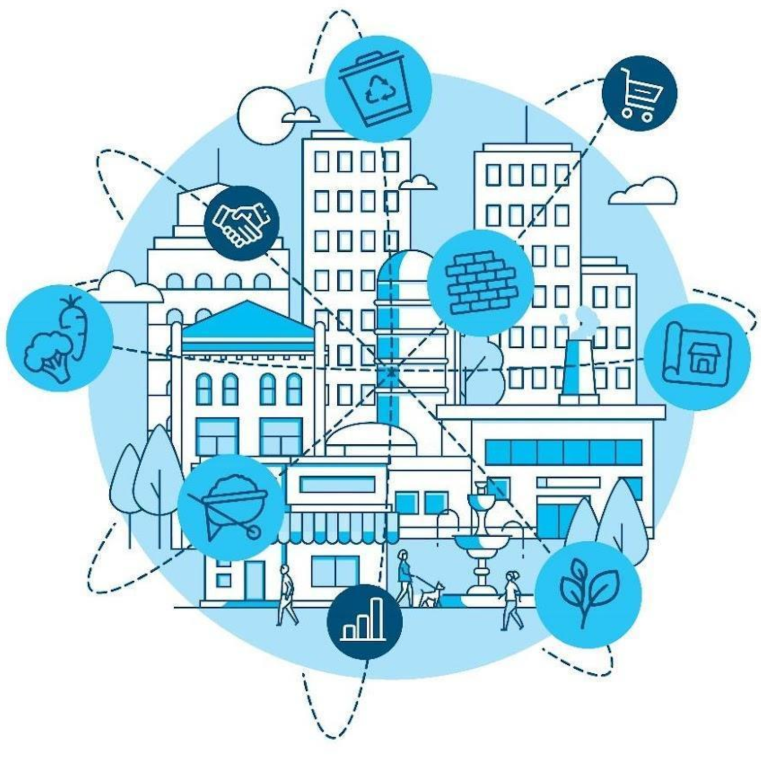
CIRCULAR Bio-waste in Mikkeli

Demonstration Report

Demo 1: BW collection and sorting: pilot project

Demo 2: BW treatment: pilot and laboratory scale experiments

City of Mikkeli



Version	1.0
WP	WP3
Deliverable	D3.6
Date	22.5.2023
Dissemination level	Public
Deliverable lead	Hanne Soininen
Authors	Vuokko Malk, Hanne Soininen, Janne Junninen, Tiina Saario, Leena Pekurinen, Juha-Pekka Ontronen, Xamk Johanna Järvinen and Ilkka Liljander, MikseiMikkeli
Reviewers	Edwin Keijsers Simon Gresset Malen Otero
Abstract	Circular economy of bio-waste sector was demonstrated in Mikkeli with two demonstration actions: 1) BW collection and sorting, pilot project and 2) BW treatment: pilot and laboratory scale experiments. This report describes the implementation, results and conclusions of these demonstration actions.
Keywords	Bio-waste, circular economy, sorting of waste, biogas, soil improvement products, nutrient recovery
License	This work is licensed under a Creative Commons Attribution 4.0 International License(CC BY 4.0). See: https://creativecommons.org/licenses/by/4.0/

Contents

1. Executive summary

The CityLoops project brought together seven European cities – Apeldoorn, Bodø, Mikkeli, Porto, Seville, Høje-Taastrup and Roskilde - to pilot a series of demonstration actions to close the loop of two of the most important waste streams in Europe: Construction and Demolition Waste, and Bio-waste. The ultimate aim was to become circular cities in which no resource goes to waste, driving the transition to the circular economy. The project started 1.10.2019 and ended 30.9.2023. The project was coordinated by ICLEI – Local Government for Sustainability and it received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 821033. South-Eastern Finland University of Applied Sciences Xamk and Mikkeli Development Miksei Ltd were responsible for the project implementation in Mikkeli. This report presents Mikkeli´s demonstration actions of bio-waste stream – their implementation, results and lessons learned, as well as replicability and future perspectives.

Introduction

The focus of bio-waste demonstration actions in Mikkeli was on improving the recovery of nutrients from bio-waste streams into recycled products and creating business opportunities for local companies. Two demonstration actions were conducted in Mikkeli. Demonstration 1 was focusing on activating residents to sort bio-waste more efficiently to increase nutrient recovery and the business opportunities. Demonstration 2 was targeting on optimizing biogas process and utilizing final products with laboratory scale experiments, techno-economic evaluation, and procurement guidelines. Both demonstrations were conducted in collaboration with three stakeholder groups. The main stakeholders were waste management company Metsäsairila Ltd, biogas company BioSairila Ltd, municipal housing company Mikalo Ltd, residents in Peitsari demonstration area and local environmental authorities.

New approaches/instruments

Demonstration 1: BW collection and sorting: pilot project

Through collaboration with the residents and local companies, the collection of bio-waste in the apartment building area in Peitsari district of Mikkeli was improved. In order to raise

awareness and promote participation, promotional events were organised where paper bio-waste bags and information on sorting were distributed to the community. In the events, the benefits and challenges related to bio-waste sorting were discussed. The goal was to increase the collection of bio-waste in quality and quantity while simultaneously reducing the bio-waste sent to incineration with mixed waste. The effects were evaluated by monitoring amounts of separately collected bio-waste and mixed waste in the area and by implementing composition studies for household mixed waste.

To guide demonstration activities and to discuss generally the promotion of the circular economy of bio-waste, two stakeholder groups were established. A workshop on separate bio-waste collection using service design as a tool, was held to find out the barriers that influence to poor bio-waste collection. Bio-waste sorting was promoted to the citizens of Mikkeli in numerous events.

Alongside the demonstration actions and stakeholder dialogues, an analysis of the business cases underlying different separated collection and logistics systems were explored. This analysis explored the potential for nutrient recovery and issues affecting profitability of bio-waste collection.

Demonstration 2: BW treatment: pilot and laboratory scale experiments

This demonstration action explored new processing and end-product optimisation techniques in laboratory- and pilot-scale. The focus was on the biogas process, which includes pre-treatment of bio-waste and anaerobic digestion. The end products of the process are biogas and digestate, which is usually mechanically separated to solid and liquid fractions. The project developed and tested mechanical pre-treatment methods such as crushing, mixing, and sieving. The aim of these methods was to prepare bio-waste flows before the actual waste treatment, biogas digestion. One area of research was the combined use of bio- and garden waste in biogas production.

To increase the value of the remaining streams after biogas production five methods/techniques were tested in laboratory. One of the tested new methods was using biochar as an additive for organic material, which enables more complex functional properties of the produced fertiliser (e.g., water and nutrient storage). A second technology was using electrochemical methods for the recovery of nutrients from rejection waters of dry digestion process. A techno-economic evaluation of the new processes was performed to obtain possible business cases for Mikkeli.

Two procurement guidelines were created to enhance circular economy in public procurement :1) transportation, logistics and traffic services procurement to increase the usage of biogas as a motive power and 2) reduction of the amount of organic waste via procurement. The procurement guidelines were tested during demonstration phase together with the City of Mikkeli and stakeholders.

Results

Mikkeli achieved many of the expected outcomes associated with demonstration actions already at the halfway the evaluation.

The demonstration 1 campaign to promote bio-waste sorting in the demonstration area was successful: the proportion of bio-waste in household mixed waste decreased from 35 % (year 2020) to 27 % (year 2021) during the demonstration based on waste composition studies. At the same time (2020-2021), the amount of separately collected bio-waste increased by 53 % based on monitoring rounds of waste amounts (2020-2021). During 2021-2023, the amount of separately collected bio-waste increased by an average of 47 % per inhabitant compared to the baseline (2020) based on monitoring rounds. Available data on changes support the hypothesis that a significant increase in the separate collection of bio-waste has taken place as a result of demonstration initiatives. This increase has led to reduced incineration of bio-waste and a reduction in carbon emissions. However, in order to establish a cost-efficient service for both service provider and customer, it is necessary to implement different service models for separate bio-waste collection based on population density.

In demonstration 2, an increase in biogas production from bio-waste collected in Mikkeli led to emission savings, as expected. Laboratory and pilot scale experiments showed that the material flows fed to biogas reactor should be d so that the process remains balanced, and the biogas production can be maximised. For example, materials that inhibit the process like citrus fruits should not be fed into the reactor too much at the same time.

Additionally, several final product optimisation techniques were tested, and lot of useful information was obtained. E.g., biochar addition in the biogas process prevented the effects of harmful or inhibiting materials and improved the quality of biogas. However, the technical and financial viability of these techniques for larger-scale replication and adoption by external stakeholders remains unclear. E.g., the liquid fraction of the digestate of the biogas reactor was found to be a very challenging matrix in terms of struvite precipitation. There are numerous factors interfering with the chemical reactions and many pre-treatment steps were required to precipitate struvite. This is a challenge for a cost-effective full-scale process. The method still requires plenty of development work and optimization to be used as a method for nutrient extraction from bio-waste digestate in a full-scale commercial process.

Lessons learned

Demonstration 1 was very successful in activating residents of the Peitsari demonstration area to recycle their bio-waste. This was largely due to the use of versatile communication methods, and the organization of residential events, which resulted to be a relatively easy and a simple way to activate people. Similar events could be repeated with the same formula several times.

Nevertheless, the most effective measure was certainly the distribution of free bio-waste bags to residents.

In addition to the demonstration area, the promotion of bio-waste sorting was extended to several other events throughout the Mikkeli area, targeting people of different ages. Face-to-face discussions proved to be effective in promoting bio-waste sorting, and the use of imagination, creativity and visuality were found to be important in engaging with people. Moreover, for the event that targeted children, the project team dressed up as fairy tale characters and organised exciting games to engage with them and share the message about sorting bio-waste in an inspiring way. In all events, paper bio-waste bags were distributed to people which proved to be a practical and effective way of conveying the message.

Demonstration 2 showed that laboratory-scale experiments can safely and cost effectively test new methods and their actual effects of e.g., potentially harmful substances in a process without compromising the operation of a full-scale plant. The results obtained from these experiments can often be utilized almost directly on a plant scale, such as in feed material or process optimization. However, new treatment methods tested at the laboratory scale may need further development to be functional in full-scale processes, and the commercialization of these methods can take several years.

The city of Mikkeli is a good base customer for a product like biogas, therefore promoting the circular economy criteria in public procurement can further drive this market. Both the city and private companies make investment plans well in advance and options for logistics are considered, for example, to meet carbon neutrality goals. The markets for biofuels are strongly influenced by the EU directives concerning environmental- and energy policies, and a stable, long-term decision-making culture is needed to ensure market stability.

In both demonstrations, thematic stakeholder groups and regular meetings were an effective way to cooperate with stakeholders. Even short meetings kept the participants up to date and committed to the project.

Scalability and replicability

Many tools and activities demonstrated in Mikkeli can be easily replicated in other cities. Demonstration 1 is replicable for every city. For example, the campaign implemented in the Peitsari area to promote bio-waste sorting can be used as a model for other areas. The effectiveness of the campaign can be measured through composition studies and by monitoring the waste amounts, similar to what was done in Mikkeli, with detailed methods outlined in a separate report (Xamk and Miksei 2023a: Implementation of demonstration 1).

Additionally, demonstration 2 is replicable if the bio-waste is or will be processed through an anaerobic digestion. laboratory and pilot scale testing methods can be replicated in other laboratories. The same workshop formula implemented in Mikkeli can be used to organize them in other regions. Reports are available that document how each event was organised and held. Procurement guides and support documents developed for Mikkeli can also give ideas for other cities on how to consider the circular economy in their procurement processes. However, it is important to note that these guides need always to be adjusted to suit city-specific needs. All the activities and methods used in Mikkeli have been documented to facilitate their replication for other cities.

Recommendations for replicating both demonstrations in other cities are given in the end of this report. Recommendations are presented chronologically in a very practical way for any city to adapt for their own use.

In Mikkeli, the results of CityLoops demonstrations have been disseminated at the city level, as well as regionally and nationally. Upscaling and replication of the results and practices continues in several spin off projects in collaboration with stakeholders.

2. City context

Mikkeli is a city of 53 000 inhabitants, located 230 km northeast of Helsinki (Figure 1). Mikkeli is the capital city of the South-Savo Region. The population has been stagnant or slightly declining since 1980. The municipality is very popular as a summer house location, hosting more than 10 000 summer houses. The municipality covers an area of 3230 km^2 including 680 km^2 of waterways. The population density is 20,5 inhabitants per km^2. The urban centre is not very dense, and the vast rural area is sparsely populated.

The GDP of the region is the second lowest of all regions in Finland. Agriculture and forestry are important in the region. Employment is mostly based on services with a low percentage of industrial jobs and a high percentage of jobs in the public services (e.g., education).

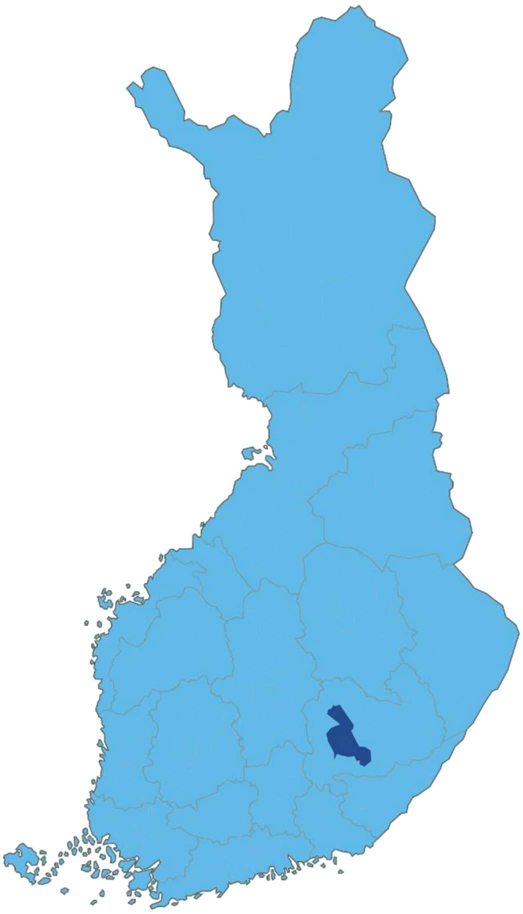


Figure 1. Location of Mikkeli in Finland (figure: MikseiMikkeli).

2.1. Governance related to waste management

In the city of Mikkeli, the waste management authority is the City Development Board. The control authorities of waste management are the Mikkeli Region Environmental Board and the The South Savo Centre for Economic Development, Transport and the Environment. The waste inspector acts as the waste management officeholder. Metsäsairila Ltd, a waste management company owned by the City of Mikkeli, handles statutory service tasks for waste management, such as the maintenance of a waste treatment plant, recycling of exploitable waste, waste management of hazardous waste, maintenance and development of the waste point network in the sparsely populated areas. The company also provides development, advice and information for waste management in the area. (Figure 2)

The city of Mikkeli has its own waste management regulations which are approved by the City Development Board. Municipal waste management regulations are local regulations issued under the Waste Act. Regulations supplement the waste legislation and are followed in the Mikkeli city area.

The city's procurement department contributes to the circulation of biomaterial flows by being responsible for tenders, e.g., restaurant services, biogas-powered waste trucks and buses as well as soil products used in green areas.

Mikkeli Development Miksei Ltd. and South-Eastern Finland University of Applied Sciences – Xamk have been responsible for the implementation of the CityLoops project in Mikkeli. Mikkeli Development Miksei Ltd. (MikseiMikkeli) is a business development company jointly owned by the City of Mikkeli and Xamk. Its mission is to support the local economy and also help companies to grow and internationalise. Recently, the importance of circular economy has grown as a means of developing new businesses in Mikkeli.

South-Eastern Finland University of Applied Sciences – Xamk operates in three entities: education, research, development, and innovation (RDI), and support services. The aim of the RDI activities is to promote the sustainable well-being, business, expertise, and competitiveness of the region by improving the conditions for regeneration, growth, and entrepreneurship, as well as national and international innovations. Xamk has four campuses in four cities: Kotka, Kouvola, Mikkeli and Savonlinna and it is owned by these cities. Mikkeli campus operate closely in RDI activities with local and regional stakeholders and companies e.g., waste management company Metsäsairila Ltd.

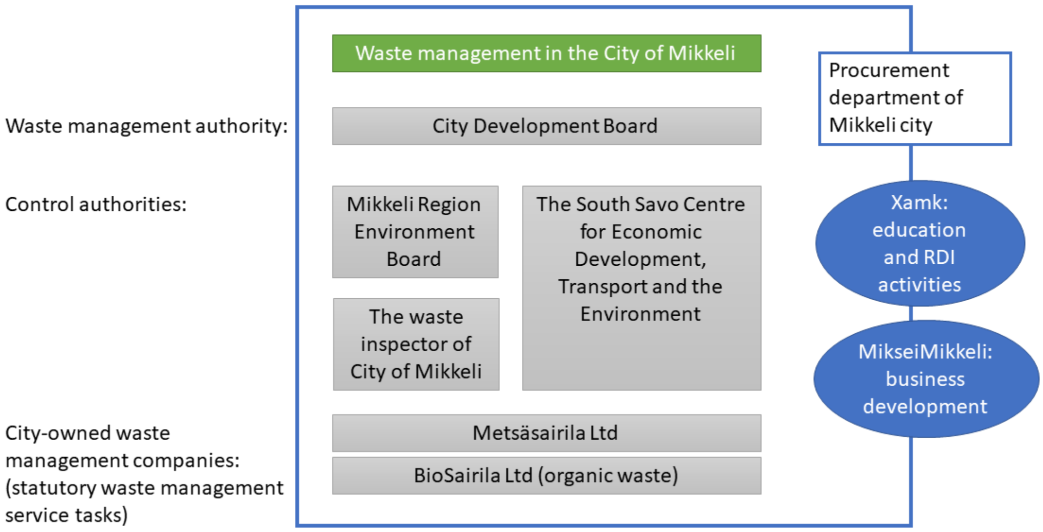


Figure 2. Governance related to waste management in the City of Mikkeli. South-Eastern Finland University of Applied Sciences (Xamk) and Mikkeli Development Miksei collaborate and support authorities and companies by RDI (research, development, and innovation) activities and business development.

2.1. Bio-waste collection

In the city of Mikkeli, it is mandatory for all properties to sort bio-waste. The property owners can have their own separate collection container or use a shared bio-waste container with neighbouring properties. There are also regional collective containers for bio-waste. There is a lot of rural area in Mikkeli. Both in urban small house areas and in rural areas, many people use their own composters to process bio-waste. A composter has to be closable, thermally insulated and ventilated. Since January 2023, the Waste Act requires the municipal waste management authorities to maintain a register of composting bio-waste on properties. By May 2023, 7 600 composters have been registered in the Mikkeli area, but the number is likely to be much bigger than this, since many should still register their composting.

Despite the obligation to sort and collect bio-waste, a large part of bio-waste still ends up as mixed waste, indicating the need for more efficient recycling. In the beginning of the CityLoops project (year 2018), only 38% of the 6,900 tonnes of bio-waste produced yearly by Mikkeli's citizens‘was recycled mainly as compost (Metsäsairila Ltd). The composition study performed in Peitsari area under CityLoops demonstrations showed that there is still a considerable amount of bio-waste in the mixed household waste that could be prevented from going to incineration. This bio-waste could be recycled if it were collected separately and placed in the proper bio-waste collection bins by the citizens. The study showed that about 35% of the household mixed waste was of recyclable biomaterial in 2020.

Mixed waste is transported from Mikkeli to Leppävirta and Kotka (100 - 160 km) for incineration. Bio-waste in mixed waste causes harm in the incineration plant and weakens the calorific value of the incinerated material. The main reason for the lack of sorting in Finland is attributed to human ignorance, as well as having poor bio-waste bins in apartments and impractical bio-waste bags. Additionally, many people also think misleadingly that they generate only a small amount of bio-waste in their households, that source separation is not necessary (HSY 2018).

2.2. Bio-waste treatment

Bio-waste produced by citizens is received by the city owned municipal waste company Metsäsairila Ltd. For years, Mikkeli has recycled its bio-waste into soil products by composting, however the intention is to now upcycle the bio-waste material into biogas. Landfilling is not an issue in Finland or Mikkeli, since the beginning of 2016 organic waste has not been allowed to be disposed in landfills (The Government Decree on Landfills (331/2013).

BioSairila Ltd. began its biogas production in year 2021 (Figure 3). The biorefinery treats sewage sludge, bio-waste and agricultural and industrial by-product streams generated in Mikkeli and the surrounding areas. Sewage sludge and bio-waste are processed separately because there are different legislations and requirements for sewage sludge end products as soil products given that they may contain more harmful substances.

Figure 3. Bio-waste is processed in biogas plant of BioSairila Ltd. The traditional compost plant supports the operation of the biogas plant. (Photo Metsäsairila Ltd)

The end products of biorefining are biomethane processed into transport biomethane and fertiliser and soil improvement products. At full capacity, the plant will produce approximately 1.5 Mm^3 (1,000 tons, 15 GWh) of transport biomethane, which corresponds to the annual consumption of approximately 2,000 passenger cars. Transport biomethane is distributed through four biogas stations in Mikkeli and Kuortti. From the by-products of the production of biogas, the digestate, rich in nutrients, is transformed into soil improvers and fertilisers. By producing and using biogas from bio-waste, the city is able to replace, and thus reduce the usage of fossil fuels. The extraction of nutrients from the reject water of the biogas process, reduces the need to extract and use virgin fertiliser chemicals. The traditional compost plant continues to support the operation of the biogas plant. E.g., digestate of biogas plant is composted and utilised as soil products. In 2022, the production of soil products was outsourced to a commercial operator (Kekkilä Ltd).

There is also a small biogas refinery, Biohauki Ltd. situated in the rural area of Mikkeli, Haukivuori. It is designed to produce methane from the manure of livestock and hay from the surrounding areas. Biogas produced there is also used as transport biomethane. The by-products of this refinery are transported back to the farms in order to use as soil improvers for the cultivation of crops.

Biosairila biogas plant was first owned by the municipal waste company Metsäsairila Ltd. (70%) and the energy company Etelä-Savon Energia Ltd. (30%). ESE also owned Biohauki biogas refinery and was responsible for biogas distribution. The city of Mikkeli reorganised ownership of biogas plants from the beginning of 2023. The gas stations and the Biohauki biorefinery were transferred to BioSairila Ltd. The new company includes two biogas plants BioSairila and BioHauki and also the gas distribution stations. Metsäsairila Ltd. is the majority shareholder in the new company and ESE is a minority shareholder.

2.3. Circular transition

In Mikkeli, the circular transition related to biomaterials had already begun prior to the CityLoops project. The construction of a new biogas plant was planned for the city and the first biogas-powered waste trucks had been purchased. The demonstration actions were designed to address the most critical challenges. The main challenge was to increase the efficiency of bio-waste collection and activate people to sort their bio-waste, which is crucial to be able to produce and distribute more biofuels in Mikkeli. This raw material could be used in upcycled products such as biofuel and soil products. Demonstration 1 responded to this problem by identifying the obstacles related to bio-waste sorting and the ways to make it more efficient, by activating people with versatile campaigns.

The second challenge was related to the processing of bio-waste and particularly to improving the utilization of the end products and the stimulation of business opportunities. Therefore, the goal was to optimise the new biogas plant to maximise biogas production, as well as improve the recycling of nutrients into fertilisers, to close the loop of biomaterials. Additionally, the potential related to nutrient recycling has not been fully utilised until then. Demonstration 2 tacked these challenges by conducting laboratory and pilot testing to optimise of the biogas production process and end products, as well as identifying new business cases. Additionally, under demonstration 2, guidelines for public procurement were developed as a practical instrument to implement circular economy within the city by increasing the demand and sales of the produced biogas and soil products.

Relevant strategies, action plans, or targets

The city of Mikkeli has signed the Circular Cities Declaration in 2020.

Mikkeli pursues to pioneer in the transition for a more circular economy. The city has been building EcoSairila development platform to enable closing material loops and supporting new sustainable businesses to develop. Mikkeli has promoted and invested especially on the research, development and infrastructure of water technology, material cycles and renewable energy, including the new biogas plant BioSairila.

The city council has approved an City Strategy for the years 2022-2025. One of the key priorities in this strategy is Circular Economy. Mikkeli Development Miksei Ltd. is responsible for promoting companies to launch their own eco-efficiency and sustainability projects.

The city council has approved a climate program for Mikkeli for years 2022 – 2035. The main goals related to circular economy of bio-waste are:

- The most important area of development in waste management is the better collection and sorting of bio-waste
- To increase the use of locally produced transport biomethane.
- The city will acquire only cars that run on biogas or electricity.
- the sorting and collection of bio-waste is enhanced so that less bio-waste ends up within the mixed waste (the share of bio-waste is a maximum of 20% in 2025 and 15% in 2030).
- Biomass processing and nutrient recycling has become more efficient as well as development of valorised products from biomass has been further developed.
- The municipality is committed to include circular economy issues in all vocational education curricula.
- 25 % of public tenders related to CDW and bio-waste should include climate related requirements.

Mikkeli has chosen Green Economy as one of its main business promotion focal sectors in the city strategy. The content of this concept is under discussion, but it might be interpreted as Sustainable Materials Management or Resource Efficiency. MikseiMikkeli has been assigned a key role in promoting this goal.

3. Implementation

The focus of bio-waste demonstration actions in Mikkeli was on improving the recovery of nutrients from BW streams into recycled products, creating business opportunities for local companies. Based on a thorough analysis of biowaste streams and potential valorisation pathways, a series of innovative collection, treatment and product optimisation processes and techniques were demonstrated. New collection and sorting processes were implemented in a pilot district in collaboration with local citizens to upgrade the quantity and quality of biowaste collected.

Two demonstration actions were conducted in Mikkeli. Demonstration 1 was focusing on activating residents to sort bio-waste more efficiently to increase nutrient recovery and the business opportunities. Demonstration 2 was targeting on optimizing biogas process and utilizing final products with laboratory and pilot scale experiments, techno-economic evaluation, and procurement guidelines. Both demonstrations were conducted in collaboration with three stakeholder groups. The main stakeholders were waste management company

Metsäsairila Ltd, biorefinery company BioSairila Ltd, municipal housing company Mikalo Ltd, residents in Peitsari demonstration area and local environmental authorities.

3.1 Demonstration 1: BW collection and sorting: pilot project

The goal of this demonstration action was to increase the collection of bio-waste in quality and quantity, while simultaneously reducing the percentage of bio-waste in the collected mixed household waste, and the amount of bio-waste that are incinerated. As a result, and in collaboration with citizens and local companies, the collection of bio-waste from the Mikalo Ltd apartment building area in the Peitsari district of Mikkeli was improved. Additionally, the quality of separately collected bio-waste was improved with communication to residents and distribution of paper bio-waste bags. Bio-waste sorting was taught to different age groups in several events both in Peitsari and in the entire city area. The quality of separately collected bio-waste improves when people know how to sort waste correctly. For the purpose of this demonstration action, bio-waste refers to household bio-waste, mainly kitchen bio-waste.

3.1.1 Peitsari demonstration action

The new collection and sorting processes were tested in apartment houses of Mikalo Ltd city-owned rental housing company in Peitsari (Figure 4). The area has about 370 inhabitants.

In the city of Mikkeli, it is mandatory for all properties to sort bio-waste, and, for example, apartment houses have had separate collection bins for bio-waste for years. In the Peitsari demonstration area, there are waste collection bins for seven waste fractions (bio-waste, cardboard, paper, glass, metal, plastic and mixed waste) based on national and EU legislation and Mikkeli’s waste regulations. The waste collection bins are in the waste sheds (Figure 4 and 5) in the yard beside the buildings. The challenge is, that despite the obligation and opportunities to sort and collect bio-waste, a large part of bio-waste still ends up as mixed waste. This indicates the need for activating people to sort their bio-waste more efficiently. Demonstration actions focused on improving sorting efficiency by communication campaign and by distributing paper bio-waste bags to residents.

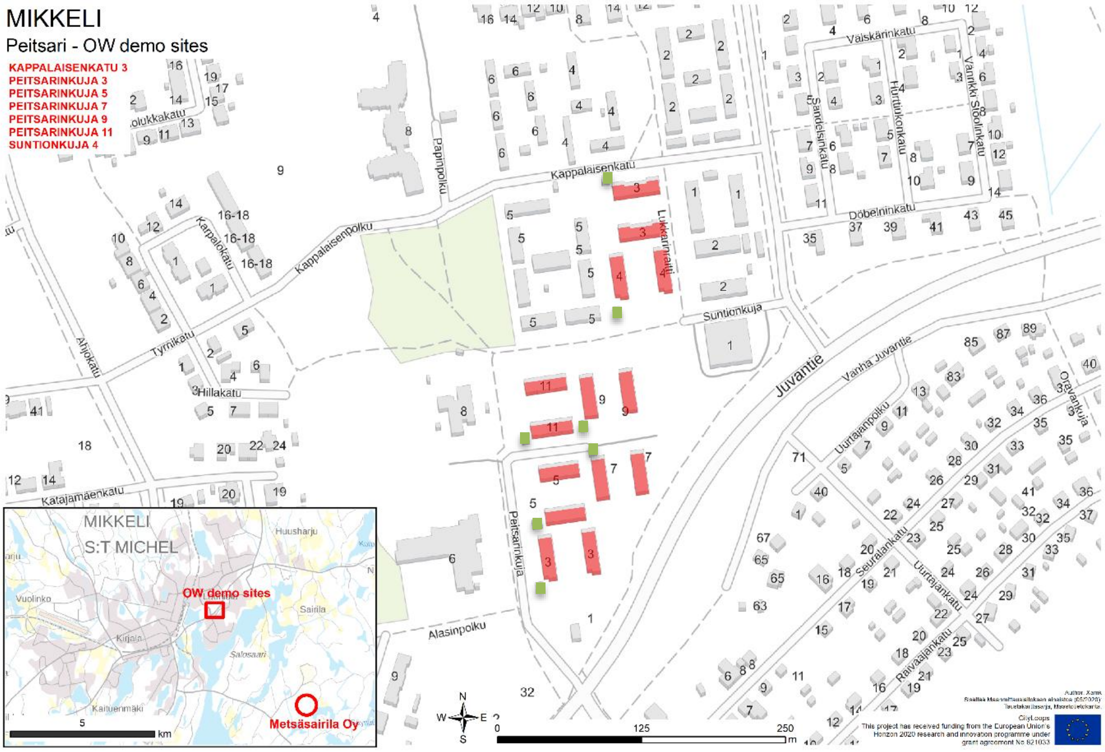


Figure 4. Peitsari demonstration area is located 2,5 km from the City Centre and consist of 7 apartment houses. Waste collection bins are located in the waste sheds in the yard beside the buildings (marked green). (Figure Esa Hannus, Xamk)

Figure 5. Apartment houses in Peitsari demonstration area. Waste collection bins are in the waste sheds in the yard beside the buildings. (Photos Mikalo Ltd (left up), Marleena Tirkkonen, Xamk (left down) and Panu Jouhkimo, Miksei (right))

In order to be able to successfully process the bio-waste in the biogas plant, paper bio-waste bags were distributed to the residents in the area, to substitute the use of the biodegradable plastic bags given that they cause problems in the biogas plant by stretching and wrapping around the parts of the crusher and screen. Therefore, separately collected bio-waste should preferably be packed in a paper bag or a newspaper cone. Many households have long sorted their bio-waste into a biodegradable plastic bag and switching to a paper bag is a challenge.

To encourage the use of paper bio-waste bags by the residents, and thus improve the separate collection of bio-waste, Xamk and MikseiMikkeli organised five events for residents where compostable paper bags and information on sorting were distributed to them together with Metsäsairila Ltd and Mikalo Ltd (Figures 6-7). The benefits and challenges related to bio-waste sorting were discussed face to face with the residents, when holding residential events at the demonstration site (Figure 4). Bio-waste bags and leaflets were also distributed directly to the apartments.

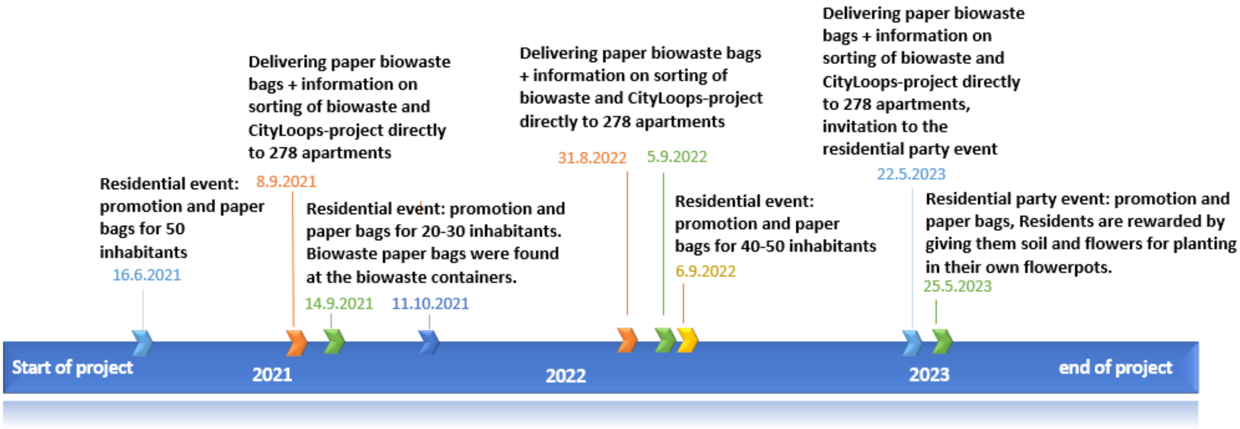


Figure 6. Communication campaign and events organised in the Peitsari area.

Figure 7. Communication campaign and residential events were organised in the Peitsari demonstration area. Paper bio-waste bags were delivered to residents together with Metsäsairila Ltd. waste management company. (Photos Hanne Soininen)

The impact of the demonstration on the volume of separately collected bio-waste was assessed by ordering separate waste collection rounds from L&T waste transport company. Only the waste from the study area was collected by the waste truck and weighed at the weighing station of the Metsäsairila Ltd.'s sorting and recycling centre. There was a total of 11 waste collection rounds in the area.

The quality of the bio-waste and the mixed waste was established by composition studies, which was relevant to find out the share of recyclable bio-waste in mixed household waste that could be utilised in a biogas plant and as soil improver. The composition study was performed by collecting mixed household waste from the demonstration area from period of four days. Two 660 litre samples were selected and sorted manually into 11 waste fractions. The composition study was carried out before and after the demonstration actions and communication campaign. (Figure 8) It is worth noting that composition studies require labour and resources and must be carried out every time in the same way so that the results are comparable.

Figure 8. Composition study was performed to find out the share of recyclable bio-waste in household mixed waste of Peitsari area before and after demonstration actions. Left: sampling. Right: manual sorting of mixed waste. (Photos Hanne Soininen and Anne Laitinen).

The campaign in the demonstration area was successful: the proportion of bio-waste in household mixed waste decreased from 35 % (year 2020) to 27 % (year 2021) during the demonstration (Figure 9). At the same time (2020-2021), the amount of separately collected bio-waste increased by 53 % based on monitoring rounds of waste amounts (2020-2021). During 2021-2023, the amount of separately collected bio-waste increased by an average of 47 % per inhabitant compared to the baseline (2020) based on monitoring rounds (Figure 10). The success of the campaign can be attributed to the face-to-face discussion with residents and the distribution of bio-waste bags, which proved to be an effective and easy way to increase bio-waste sorting. This campaign can be easily replicated in other areas, and monitoring waste amounts and composition studies enable to measure its effectiveness.

The implementation and results of the composition studies and demonstration activities are described in more detail in a separate report (Xamk and Miksei 2023a: Implementation of demonstration 1).

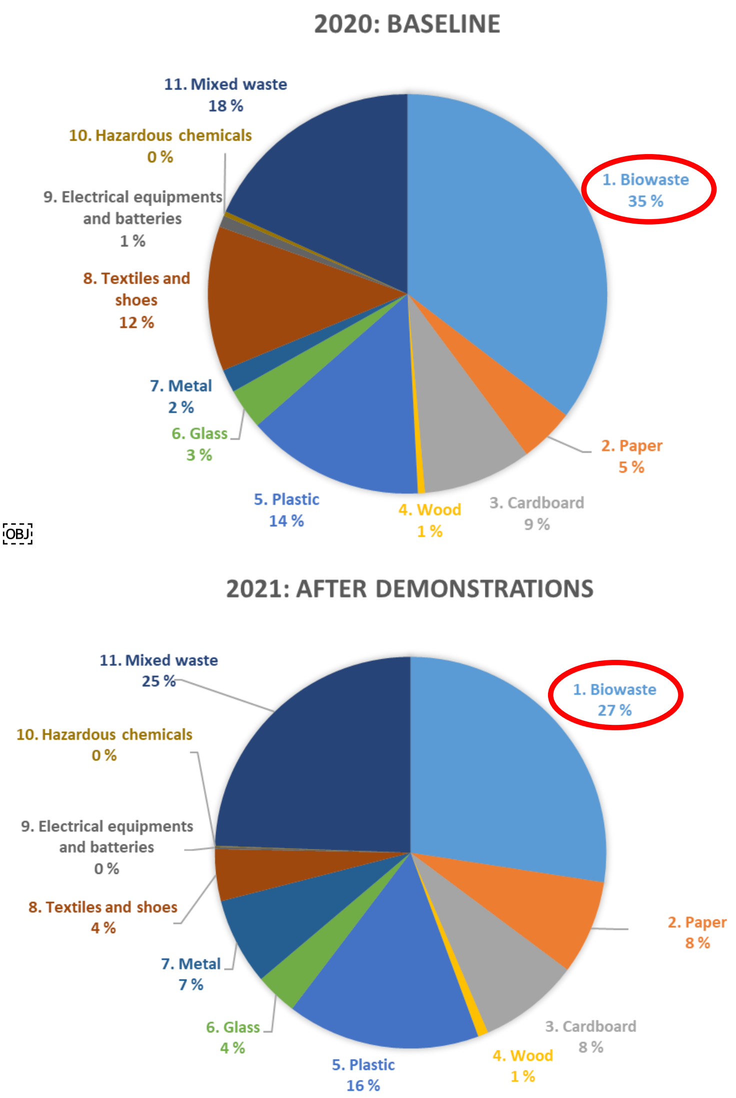
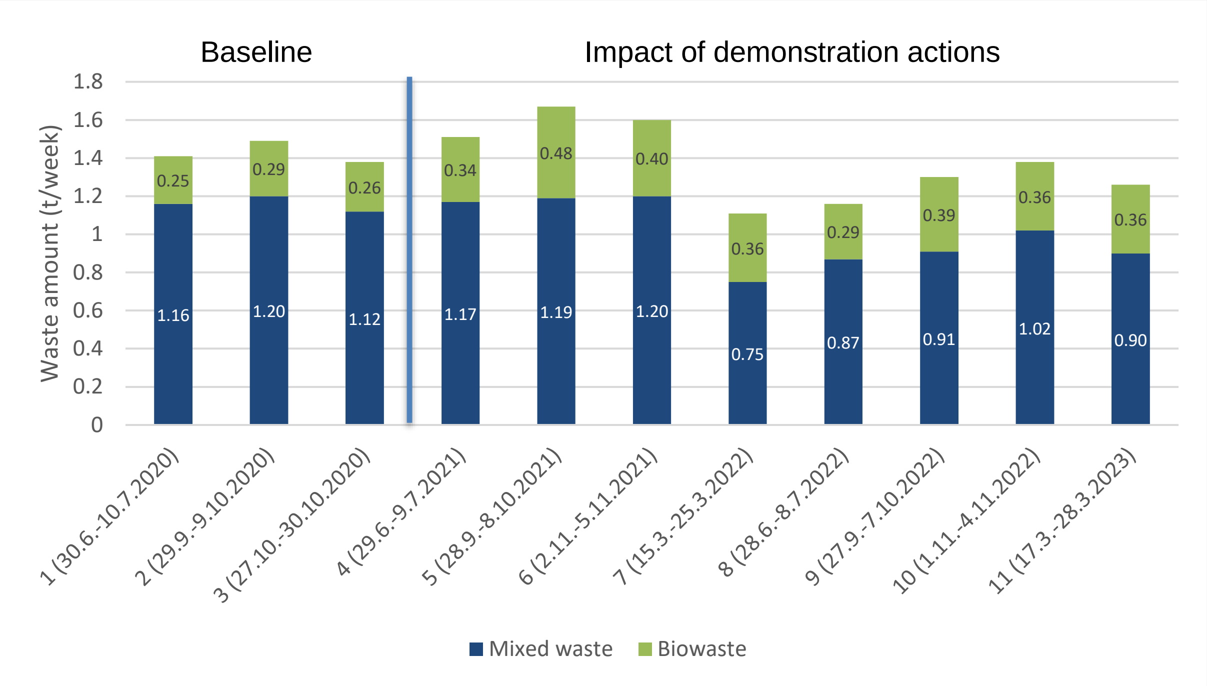


Figure 9. Mass distribution of waste fractions in the household mixed waste in Peitsari area before (above) and after (below) the demonstration actions. Share of bio-waste in mixed waste decreased from 35 % to 27 % as a result of the communication campaign.



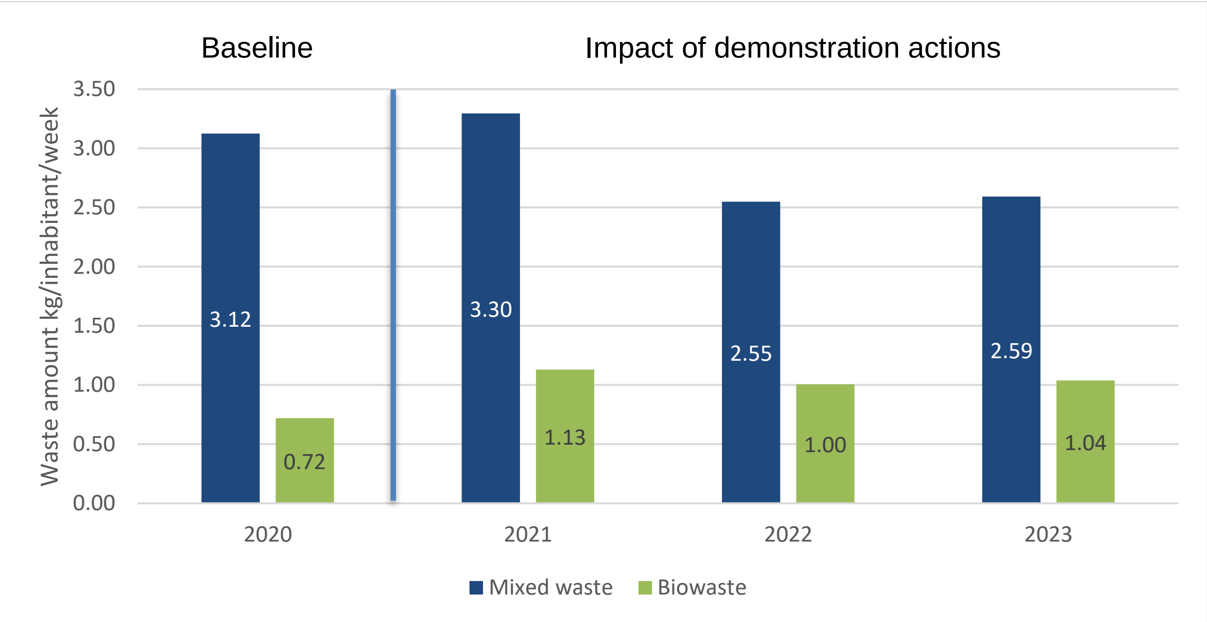


Figure 10. Amount of separately collected biowaste and mixed household waste in Peitsari area (t/week) (above). In the figure below, the amounts are presented per inhabitant (kg/inhabitant/year). Year 2020 indicates baseline and years 2021-2023 impact of demonstration actions (communication campaign and distribution of paper bio-waste bags to residents). There were totally 11 waste monitoring rounds in the area.

After evaluating the demonstration actions, Xamk and MikseiMikkeli have prepared for upscaling, in cooperation with stakeholders involved. The work in Mikkeli and the Peitsari area is continued under a regional spin-off project (Biovirtaa), which aims to expand the activities to sparsely populated areas and nearby municipalities, such as Mäntyharju and Pertunmaa. The stakeholder dialogue activities have generated new ideas and approaches that have been integrated into the Peitsari demonstration project and spin-off project.

3.1.2 Stakeholder dialogue

Two stakeholder groups were established in Mikkeli related to demonstration 1 to guide demonstration activities and to discuss generally the promotion of the circular economy of bio-waste.

- **Bio-waste stakeholder group** consisting of waste management companies and municipal bodies as well as citizens from Peitsari was established in February 2021. The group has met three times and the meetings will continue until the end of the project. At these meetings, the progress of the demonstration project was examined, the results were presented, and optimisation adjustments were discussed. During the replication phase alternative collection models (e.g., joint collection bins, collection fees) and citizen engagement actions aimed at maximising volume and quality of collected bio-waste were discussed, which aims to feed into later replication and upscaling activities.
- **Collection and sorting stakeholder group** was established involving the organisations directly involved in the operation of bio-waste collection and sorting in the Mikkeli region, namely: Metsäsairila Ltd (municipal waste management company), and Mikalo Ltd (municipal housing company). This group had 25 meetings during the project. This group also analysed and discussed on an ongoing basis different collection and sorting models and will be ultimately responsible for operationalising future activities across the city.

Workshop on bio-waste collection and sorting through service design was held in 16.11.2021, where both stakeholder groups were involved. The main objective of the workshop was to find out what are the barriers to collecting more biowaste from households, and how can these barriers be overcome. The aims and findings of the workshop are described in more detail in Chapter 3.1.3.

Bio-waste sorting was promoted to the residents of Mikkeli in numerous events, during which the benefits and challenges related to bio-waste sorting were discussed, and information and paper bio-waste bags were distributed to them. These events also provided valuable insights about the possible obstacles on separate bio-waste collection.

- 30.8. – 3.9.2021: Recycling event for youth, about 50 reached.
- 12.-13.10.2021: Energy saving week in Mikkeli Market Place. Delivered 115 paper bio-waste bags. Discussion with people.

- 25.11.2021: Residential event of Mikalo inhabitants and other municipal housing residents. Around 50 people attending the event.
- 27.6. and 2.7.2022: Hulivili carnival event for families. Altogether around 3200 people visited the event in the two days that CityLoops attended. Children had the opportunity to get acquainted with a waste truck that runs on biogas. A game for children that taught how to sort bio-waste and how biogas was made from their sorted bio-waste. A short video was made where Biofairy teaches children on bio-waste and biogas.
- 28.9-1.10.2022: Everyday circular economy pop up –event at shopping center Akseli, Mikkeli.28.9-1.10.2022. Event where circular economy in everyday life is promoted. CityLoops was one of the presenters in the event with the bio-waste theme.
- 8.3.2023: Mikkeli's circular economy days in local shopping center Stella. CityLoops was one of the presenters in the event with the bio-waste theme. The character Biofairy also attended the event to teach children about separate bio-waste collecting and biogas.
- 5.4.2023 Presentation in Aalto University for international students on recycling materials in Finland together with Metsäsairila Ltd.
- 20.5.2023: Mikkeli's circular economy days in Mäntyharju municipality. Regional upscaling of the CityLoops results. CityLoops was mainly to support the spin-off project Biovirtaa, in the event with the bio-waste theme.
- 23.5.2023: Regional upscaling event of the CityLoops results. Presenting CityLoops results to rental housing companies in Eastern Finland (Itä-Suomen vuokralaispäivä) of Mikalo inhabitants and other municipal housing residents. Around 100 people were attending the event in Saimaa Stadium at Mikkeli. The event was organised by Mikalo Ltd.
- 6.9.2023: Final webinar/seminar for regional and national stakeholders will be organised to present results of CityLoops project. In addition, a workshop will be organised for key stakeholders of City of Mikkeli to discuss main conclusions and future perspectives of biowaste streams.

Residential events organised in Peitsari demonstration area are described in Chapter 3.1.1.

3.2 Demonstration 2: BW treatment: pilot and laboratory scale experiments

This demonstration action explored new processing and end-product optimization techniques in a laboratory- and pilot-scale for the production of biogas as fuel for vehicles from bio-waste, and the production of soil amendments from the nutrients present in the digestate, residual streams from the biogas production.

The biogas process includes pre-treatment of bio-waste and anaerobic digestion by microbes. The end products of the process are biogas and digestate, which is usually separated to solid and liquid fractions (Figure 11). In this demonstration action, pilot and laboratory scale experiments were performed to optimise the production of biogas (Figure 12). Household bio-waste and garden waste were studied as raw materials. Various mechanical pre-treatment methods such as crushing, mixing, and sieving were tested to prepare bio-waste flows for biogas digestion. This action focuses on the combined use of bio- and garden waste to enhance biogas production.

In addition to optimizing the biogas production, this demonstration action also aimed to increase the value of the remaining streams through five methods/technologies, which were also tested in a laboratory. The goal was to establish at least two innovative nutrition extraction and product creation technologies, along with related business models in collaboration with local companies. One of the tested new methods/technologies was the use of biochar as an additive for organic material, which enables the production of fertilisers with more complex functional properties (e.g., water and nutrient storage). The second technology involved the use of electrochemical methods for the recovery of nutrients from rejection waters in the dry digestion process.

Lastly, to determine possible business cases for the city of Mikkeli, a techno-economic evaluation of the new processes was performed. Two procurements guidelines were created to enhance circular economy in public procurement as well:1) transportation, logistics and traffic services procurement to increase the usage of biogas as a motive power and 2) reduction of the amount of organic waste via procurement. The procurement guidelines were tested during demonstration phase together with the City of Mikkeli and stakeholders.

RAW MATERIALS	PROCESS IN BIOGAS PLANT	FINAL PRODUCTS
E.g. household bio-waste, agricultural waste, waste-water sludge	1. Pre-treatment, e.g. removing plastics, crushing, sieving, mixing 2. Anaerobic digestion (mesophilic or thermophilic, dry or wet process, continuous or batch reactor) 3. Other treatments, e.g. hygienisation	1. Biogas -> purification of biogas -> e.g. transport biomethane or combined heat and power (CHP) 2. Digestate: productisation e.g. separation to liquid and solid fractions -> nutrient recovery as soil products and fertilisers

Figure 11. Raw materials, steps and final products of biogas process. (Adapted from photo Metsäsairila Ltd)

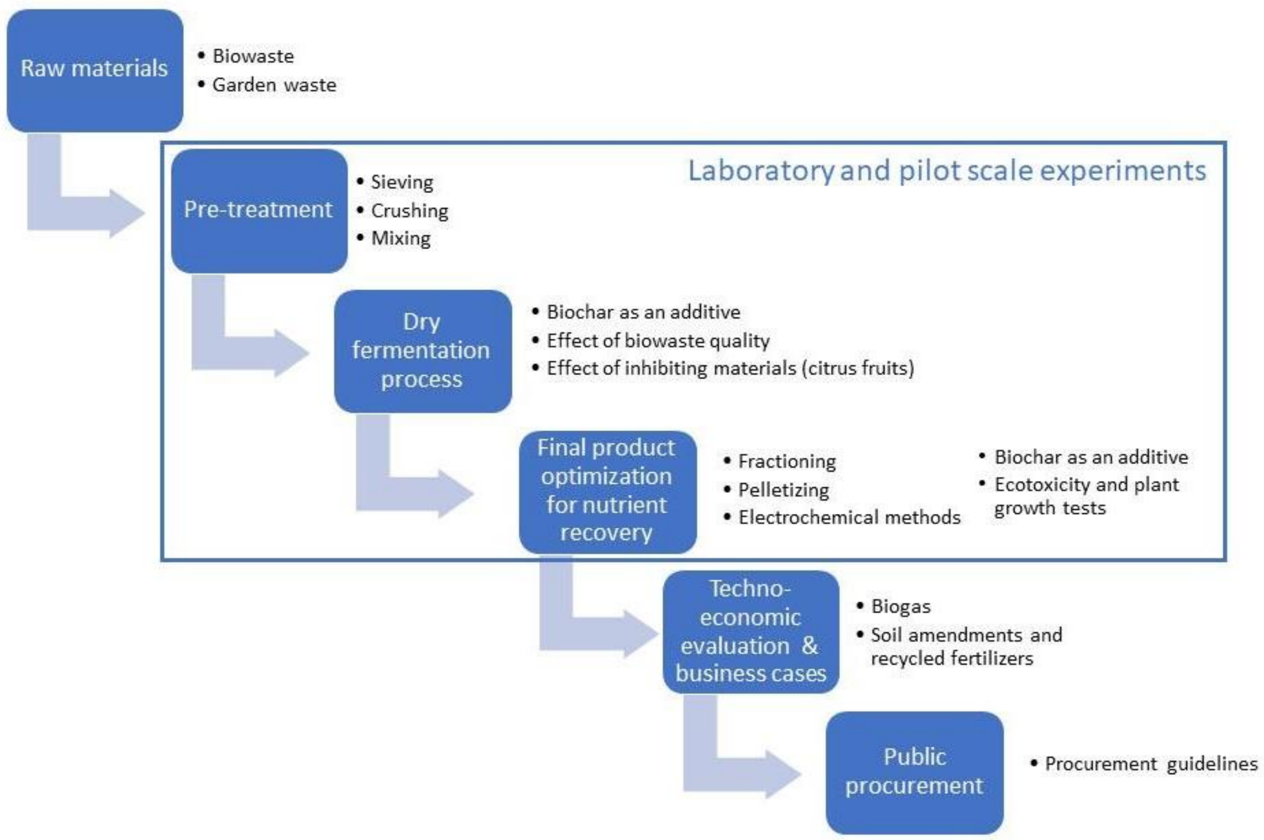


Figure 12. Processes tested in Demonstration Action 2 to promote circular transition.

3.2.1 Laboratory testing of pre-treatment, treatment and final product optimization techniques

Xamk collaborated with local companies to test new treatment and final product optimization techniques in both laboratory and pilot scale, aimed at optimizing the biogas production process utilizing bio-waste and the development of new products from by-products of biogas plants. These experiments were conducted for the new biogas plant, which started operating in Mikkeli in the year 2021.

Anaerobic digestion is a complex process and requires optimization to achieve the maximization of biogas production. In this regard, laboratory-scale experiments provide a safe, and cost-effectively means of testing the effects of e.g., potentially harmful substances in a process without compromising the operation of a full-scale plant. The results obtained can often be directly applied to a plant scale, for example, for optimizing material feed or process parameters.

The digestate, a by-product from the biogas production, contains valuable nutrients and can be processed into commercial recycled fertilisers and soil conditioners. While digestates are currently composted into soil products in Mikkeli, upcycling this by product for a more efficient recovery of nutrients and the production of valuable commercial products is still under development all over the world.

The laboratory scale experiments conducted in the demonstration action covered the entire bio-waste treatment process, including the testing of pre-treatment methods, the anaerobic digestion process, as well as the final product optimization. These experiments were carried out in collaboration with local stakeholders to support the bio-waste management of the municipality. Especially the testing of biochar as an additive component in the biogas process and the electrochemical precipitation of phosphorus as struvite from bio-waste digestate had high innovation value.

In addition to laboratory and pilot scale experiments, the current process of Mikkeli's new full scale biogas plant is documented in a separate report (Xamk and Miksei 2023b: Implementation of Demonstration 2), aiming to facilitating replication by other cities.

1. Pre-treatment (sieving, crushing, and mixing)

The purpose of pre-treatment is to optimise material flows before the actual waste treatment, such as digestion. In the demonstration phase, the following mechanical pre-treatment methods were tested on a laboratory scale:

Crushing

Crushing is an effective pre-treatment method, which allows the full potential of the raw material to be used more effectively in the biogas process. By reducing the size of the bio-waste, this method can increase the total surface area of the raw material, enabling better utilization of the bacteria in the biogas process and speeding up the degradation in the reactor. In the demonstration tests, the bio-waste was pre-treated with a food processor and manually with a knife for the biogas tests, while garden waste was crushed with scissors. Biochar was crushed using a knife and hammer. In manual processing, the piece size of bio-waste, garden waste and biochar were no more than 1 cm^3.

Mixing

To optimise the operation of a biogas plant, it is important to maintain a homogeneous feed with no large fluctuations between feeds. Given that the bio-waste stream is very heterogenous and consists of several different material streams, they should be mixed before being added to the reactor. Mixing is a good way to achieve this goal. In the case of the demonstration tests, manual mixing by hand was mainly used as the mixing pre-treatment method, and by the utilization of a food mixer to facilitate the mixing.

Sieving

To remove non-degradable materials such as plastic (food packaging, disposable containers) and metals (food cans), often contained in bio-waste, the bio-waste was pre-treated by sieving out non-degradable materials. Also stones and large clumps of soil were sieved out of the garden waste.

In addition to these small-scale experiments, the pre-treatment methods used in full scale BioSairila biogas plant located in Mikkeli were documented and can be found in a separate report (Xamk and Miksei 2023b: Implementation of Demonstration 2).

2. Optimization of dry fermentation process

The aim of the demonstration tests was to optimise the dry fermentation process used in biogas production on a laboratory scale. The goal was to find materials that support or possibly inhibit gas production from bio-waste. In the preparation and inception phase of the project, pre-tests were carried out to test the equipment. In the demonstration phase, nine series of demonstration experiments were conducted. Tested materials were bio-waste and garden waste. The experiments provided information on the effect of variation in the quality of bio-waste on biogas and methane production. In addition, the effect of citrus fruits on biogas and methane production was investigated. The experiments also investigated the effect of biochar as an additive component on the biogas process (this is explained in more detail below).

Two-liter glass bottles were used as bottle batch reactors which were connected with a hose to a methane measurement connection and a gas collection bag (Figure 13). Three parallel reactors were used for each tested material. Inoculum without any other material feed was used as a blank sample. After adding the materials, the reactors were filled with distilled water and the surface of the batches was flushed with a nitrogen flow to remove oxygen. The bottle reactors were placed in a temperature cabinet at a temperature of +42 °C. Bottles were mixed manually 3-5 times a week. The tests were running for 28 days or until the gas production stopped. Biogas and methane production was measured twice a week. The biogas collected in the bags was measured based on water displacement, and the methane concentration was measured with a gas chromatography. In some test series, hydrogen sulphide concentrations were determined with the Optima 7 biogas field analyser.

Pilot-scale semiautomatic 15 litre reactors were used to test the effect of mixing in a biogas reactor, as well as the effect of biochar on the formation of hydrogen sulphide on a larger scale. About 10-12 L of a mixture of inoculum and pre-treated feeding materials were added to the reactor, after which the reactors were closed, and heating and mixing were started. The biogas volume was determined with the equipment's own gas meters. The methane concentration was determined by gas chromatography.

Dry matter (TS, total solids) and organic matter (VS, volatile solids) were determined from inoculum, digestible materials and digestates. Alkalinity, pH and conductivity were also determined from the inoculum and the digestates. Furthermore, total nitrogen and carbon-nitrogen ratio were determined with an elemental analyser from some samples.

The results showed that there is seasonal variation in the quality of bio-waste, and this is also reflected in gas production. Biogas potential varied between 754-810 m^3/tVS in laboratory test series and the share of methane was 70-77 %. Mixing garden waste with bio-waste (1/3 grass waste in bio-waste) weakened the methane production potential. The lack of mixing also weakened the gas yield. Citrus fruits had inhibition effect on the gas production as well.

Details of the implementation and results of the demonstration experiments are described in a separate report (Saario 2023).

Figure 13. 2 L bottle batch reactors and 15 L pilot scale reactors were used in the demonstration experiments to optimise dry fermentation process of bio-waste (photos Tiina Saario (left) and Manu Eloaho (right)).

Biochar as an additive component in biogas process

One of the main objectives of the demonstration experiments was to investigate the use of biochar as an additive component in the biogas process and in the final product, which would enable more complex functional properties of the productised fertiliser (e.g. water and nutrient storage). According to the literature review conducted, the addition of biochar to the digestible biomass would increase the production of methane and hydrogen (Inthapanya et al. 2012, Dudek et al. 2019) while at the same time decreasing carbon dioxide and ammonia emissions (Kabir et al. 2015). In addition, biochar acts as a carbon sink and may improve the properties of the final product when using it as soil amendment. However, as far as we know, biochar has not yet been tested in Finland for its potential to enhance the biogas process in full scale. For this reason, laboratory experiments were conducted to demonstrate the effect of biochar in order to create a new business model and to promote biogas production and nutrient recycling.

In the laboratory scale demonstration experiments, the effect of biochar addition of 1 %, 5 % and 10 % on the biogas process (digestion of bio-waste) was tested on bottle batch reactors. Birch based biochar from local company SoilCare was used in the experiments (Figure 14). While the biochar addition did not increase methane production in this study, it slightly compensated the inhibiting effect of citrus fruits on biogas and methane production. Furthermore, biochar decreased hydrogen sulphide concentration of the biogas in a case study where 15 litre pilot scale reactors were overloaded with bio-waste, cabbage, and minced meat.

Figure 14. Birch-based biochar from local company was tested as an additive component to enhance biogas process (photo Tiina Saario).

3. Final product optimization

The digestate produced from the biogas process contains valuable nutrients and has great potential for circular economy business, but it requires further processing to become commercially available. A lot of research and development work is needed to promote the efficient recycling of these nutrients. Typically, digestate is fractioned to liquid and solid fractions to make handling and storage easier. Nutrients can be recovered from the separated liquid and dry fractions of the digestate and processed into fertiliser products. The liquid fraction can be directly used as fertiliser or nutrients can be recovered e.g., using electrochemical or chemical methods. The dry fraction can be used as soil amendment, or it can be further refined through e.g., granulation and pelletizing. To create new business models and valuable products from digestate, various methods of final product optimization were tested in demonstration experiments.

Fractioning (separation of liquid and solid fraction)

At Biosairila's full-scale biogas plant, the digestate produced in the digestion process of bio-waste is directed to the separation unit, where it is separated into liquid and dry fractions using a screw pressure technique. With a screw press, the dry matter content (TS) of the liquid fraction is about 4–8% and the dry matter content of the solid fraction is about 35–45% Currently the dry fraction is composted to make soil products, and the liquid fraction is used as field fertiliser. (Heinonen 2022)

In the CityLoops-project, the proportion of organic material, dry matter content and nutrients present in the solid and liquid fractions were determined by an accredited laboratory (ALS Finland Ltd) with the aim of optimizing the final products. Results showed that nitrogen is mostly present in the liquid fraction and phosphorus in the solid fraction of the digestate. Approximately 90% of ammonium and ammonium nitrogen, 83% of the total nitrogen and 81 % of the soluble nitrogen were distributed in the liquid fraction of the digestate. Instead, 70% of the total phosphorus was in the dry fraction, but 82% of the soluble phosphorus was in the liquid fraction.

The separation of the liquid and the solid fractions from digestate of full-scale biogas plant was also tested on a laboratory scale using the centrifugation and suction filtration methods. The experiments and results are described in more detail in a separate report (Xamk and Miksei 2023b: Implementation of Demonstration 2).

Testing electrochemical methods

Nutrients such as phosphorus can be recovered from the digestate. There are several methods to do this, including precipitation, crystallization, wet chemical, or thermochemical methods, however many of them are still under development. Phosphorus can also be recovered using an electrochemical method, but the method is relatively new for this purpose. Also, most of the studies have been done with sewage sludge, and only few studies have been done with bio-waste digestates so far.

Struvite (magnesium ammonium phosphate, MAP (NH_4MgPO_4 $6H_2O$) is a crystalline fertiliser with phosphate, ammonium nitrogen and magnesium. The formation of struvite requires suitable environmental conditions. The three most important factors are pH and temperature, as well as the molar ratios of phosphorus, ammonium nitrogen and magnesium in the solution. Struvite crystallization occurs in alkaline conditions. The principle of the electrochemical method is to deposit struvite on the cathode through an electrochemical reaction. Electrochemical reduction of water or oxygen at the cathode forms hydroxide ions which raises the pH to the alkaline range and leads to rapid struvite precipitation in presence of suitable ions.

In the CityLoops project, a literature review was first conducted on phosphorus recovery and struvite precipitation. Electrochemical method was tested on a laboratory scale for the recovery of phosphorus from the liquid fraction of bio-waste-based biogas plant digestate (Figure 15).

Test equipment was built for the experiments and the method and equipment was first tested with a clean analyte solution. A magnesium anode (+) and a carbon cathode (-) were connected to the power source. The electrodes were placed in the solution, and an electric current was applied. The electrolysis was carried out under gentle stirring of the solution with a magnetic stirrer, until visible precipitate was observed. The precipitate was filtered, washed with a small amount of water and dried in a desiccator. The nitrogen content was analysed from the precipitate with an elemental CHNS/O analyser, while phosphate was analysed spectrophotometrically.

Demonstration experiments showed that the liquid fraction of the digestate of the biogas reactor has been a challenging matrix in experiments both in terms of struvite formation and its separation from liquid. Different pre-treatment methods of the liquid fraction, two different magnesium anodes, different voltages, mixing times, reagent additions and filtration methods for precipitation were tested in the experiments. In conclusion, stepwise pre-treatment method was implemented in order for struvite to precipitate. Pre-treatment consisted of drying the sample, extraction with sulphuric acid, centrifuging, decanting and filtration, ion exchange and addition of ammonium.

After these pre-treatment steps, spectrophotometric analysis suggested 83,6 % phosphorous removal rate from solution after one hour of electrolysis with pure Mg-anode. Precipitate was initially analysed with spectrophotometer, and it reached purity of 98 % based on phosphorous and 79 % based on ammonium. Precipitate was also analysed in an external laboratory with XRD to identify crystalline phases. XRD analysis confirmed 100 % of crystalline phase consisting of struvite. In addition, precipitate was studied with SEM (Figure 16), and elemental analysis was done using SEM-EDX spectrometer. In-house EDX analysis was done from untreated crystals. It suggested purity of 96,4 % based on magnesium and 76,9 % based on phosphorous. However, purity based on EDX analysis from milled and pressed sample in an external laboratory was only 57,0 % based on magnesium and 48,4 % based on phosphorous.

While phosphorous removal rate can be described as decent, it would still benefit from additional experimentation with different parameters. The differences within elemental analysis results, along with brownish gray color of the precipitate, suggest presence of amorphic impurities. Further precipitate purification steps would be needed to decrease the amount of impurities in the precipitate.

According to our experiments, the tests showed that the liquid fraction of the digestate of the biogas reactor is a very challenging matrix in terms of struvite precipitation compared to, for example, fractions from the mining industry, where the method has been used more. In our experiments, there were many factors interfering the chemical reactions in the complex matrix, so many pre-treatment steps were required to precipitate struvite. Obviously, this is a challenge for a cost-effective full-scale process. A lot of useful information was obtained from the laboratory scale demonstration experiments, but the method still requires a lot of development work and optimization in laboratory, pilot, and demonstration scale to be suitable for bio-waste digestate in a full-scale commercial process.

The implementation and results of the experiments are reported in more detail in a separate report (Xamk and Miksei 2023b: Implementation of Demonstration 2).

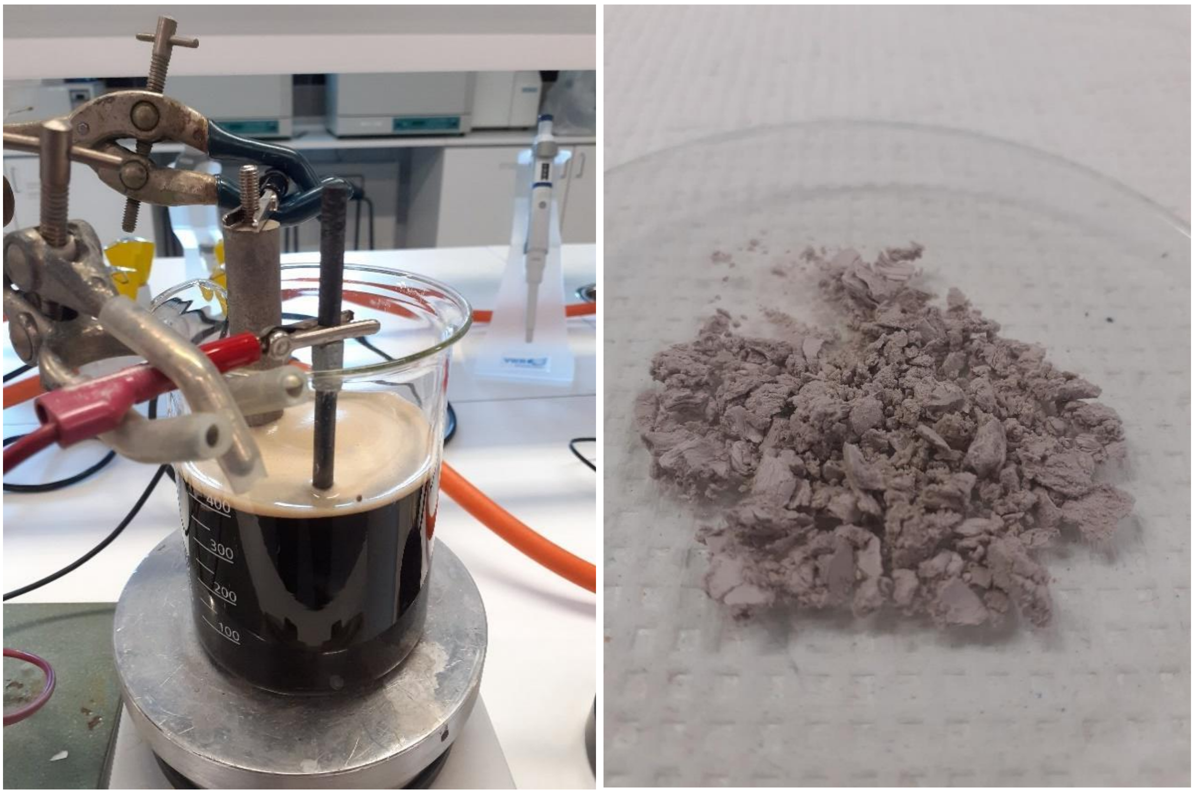


Figure 15. Electrochemical method was tested to precipitate phosphorus as struvite from bio-waste digestate. Right: Experiment set-up with magnesium anode and carbon cathode. Right: Electrochemically precipitated struvite. (photos Janne Junninen)

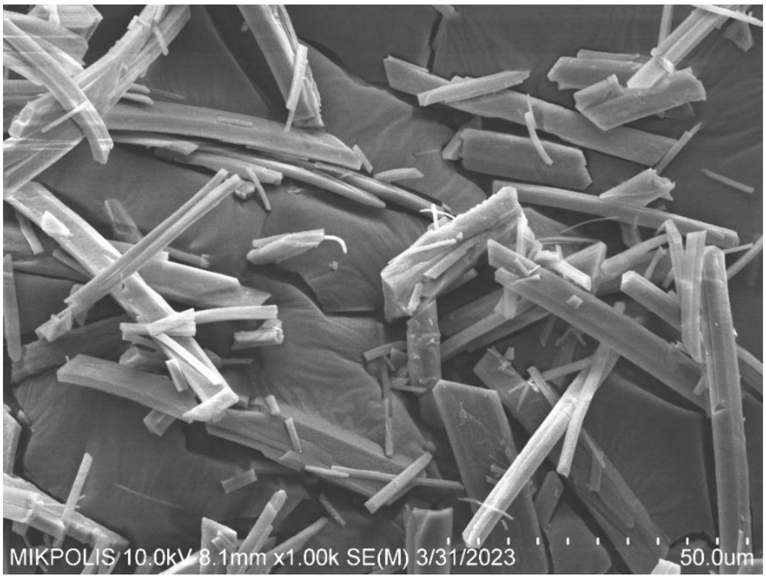


Figure 16. A scanning electron microscope (SEM) picture from struvite precipitate recovered with electrochemical method from liquid fraction of biowaste digestate. (Picture Xamk, Mikpolis laboratory)

Pelletising tests

Pelletising was tested to produce granules from the dry fraction of the bio-waste-based digestate of biogas plant for fertiliser use. The digestate was sieved with 16 mm and 8 mm sieves. Two test series were made. In the first series, only digestate was used. In the second test series, water and wood-based fly ash (10 % mass ratio) were added to the digestate as a binder. Material was pelletised by using granulation method and laboratory scale disc pelletiser (Figure 17) that had 0,4 m diameter pelletiser disc. During the test, the samples were sprayed with water. The formed granules were allowed to dry at room temperature after which the dry matter content and compressive strength were analysed. The granules were tested as a fertiliser in plant growth test (described below).

Figure 17. Pelletising of the dry fraction of bio-waste-based digestate of biogas plant was demonstrated to produce granules for fertiliser use. (Photos Tiina Saario)

Ecotoxicity tests

The *Aliivibrio fischeri* toxicity test was used to determine the ecotoxicity of the biochar and digestates in order to ensure their safe use as soil improvement products. Biochar produced via pyrolysis may contain harmful substances, such as heavy metals or e.g., PAH compounds, dioxins and furans, which can cause adverse effects on the microbes of the biogas process or on the soil organisms if used as a soil amendment. The ecotoxicity of digestates and the effects on soil organisms is still relatively unknown. Moreover, the ecotoxicological effects of digestate can vary significantly depending on the digested raw material and the conditions of the digestion process (Pivato ym. 2016, Da Ros 2018). However, when using digestate as a fertiliser, it is important to pay special attention to the correct application rate, in order to bring out the positive fertiliser effects while ensuring safe use for the soil ecosystem.

Aliivibrio fischeri is a marine bioluminescent bacterium that has been widely used in ecotoxicity tests. Harmful substances cause luminescent inhibition, which can be measured with a luminometer.

The ecotoxicity of pulverised birch-based biochar was tested from water suspension with a mass ratio of 10 %. The digestates were from a laboratory and pilot scale experiments, where biochar was tested as additive component in biowaste digestion as well as from full-scale biogas plant.

The test was carried out in accordance with the standard SFS-ISO 21338 by using BioTox kit (Aboatox Oy, Turku). For the test, the pH of the samples was measured and the NaCl concentration was adjusted to 2%. Dilution series were prepared from the samples into 2% NaCl solution. Two parallel dilution series were made of each sample for luminescence measurement. Bacterial suspension was injected into the samples. Luminescence was measured in the beginning of the test and after 30 minutes contact time with a luminometer (Titertek Berthold SiriusL). A 2% NaCl solution was used as a control and 3,5-dichlorophenol as a reference.

Water suspension of the birch-based biochar used in the demonstration experiments didn´t show any toxicity to luminescent bacteria. EC50 (the median effective concentration) values of digestate samples were 0,05–28%. The causes of toxicity can be, for example, ammonia, volatile organic compounds, salts, or heavy metals. There was variation in toxicity between digestate samples but in most samples around 0.2–2% dilution did not have an inhibitory effect but stimulated the light production of the bacteria. Biochar seemed to decrease the toxicity of the digestate slightly.

The implementation and results of the tests are presented in more detail in a separate report (Xamk and Miksei 2023b: Implementation of Demonstration 2).

Plant growth / phytotoxicity tests

Laboratory scale plant growth / phytotoxicity tests were carried out to test the growth of plants in a soil improvement product made from the dry fraction of bio-waste-based digestate. Also, the effect of biochar on plant growth was tested.

Two products were tested, which contained the dry fraction of bio-waste-based digestate of biogas plant mixed with sand and peat. Another product contained also birch-based biochar. Pellets made from digestate were added to one test series. The dry fraction of the digestate was sieved <12 mm. The pH of the products was adjusted with lime. The pH, conductivity and dry matter content of the product mixtures were determined.

The experiments were carried out in accordance with guidelines of VTT Technical Research Center (Itävaara et al. 2006). Garden cress (*Lepidium sativum*) was used as a test species.

The experiments were performed in 0.3 litre plastic pots and 6 parallel samples were made for each product. The samples were watered, and 50 seeds were added to each pot. The experiments were carried out in an environmental cabinet (Aralab, Fitoclima Bio, S600) with 16/8 h light/dark rhythm (temperature +20 degrees/+15 degrees) (Figure 18). During the experiment, the samples were watered when needed. Seed germination (number of seedlings) was calculated 7 days after the start of the experiment. After 14 days, the seedlings were carefully cut from the soil surface, after which the wet weight and dry matter content of the seedlings were determined. The growth index was calculated compared to the commercial planting soil which was used as control sample.

The functionality of the tested products as a growing medium was weak compared to commercial products, so they cannot be recommended for use as a growing medium as such. Granules made from digestate did not improve the functionality of the commercial growing medium, but their use as an improvement of more nutrient-poor growing medium could be investigated in the future.

The implementation and results of the test are presented in more detail in a separate report (Xamk and Miksei 2023b: Implementation of Demonstration 2).

Figure 18. Plant growth tests were performed for soil improvement product and pelletised granules produced from bio-waste-based digestate of biogas plant (photo Janne Junninen).

TREATMENT AND FINAL PRODUCT OPTIMISATION
New treatment and final product optimisation were tested at laboratory and pilot scale levels. A number of innovative processes and technologies are presented, including mechanical preliminary treatment, waste treatment techniques such as d dry fermentation, and final product optimisation, such as fractioning, pelletizing and drying. The tool development has been largely based on Xamk's and stakeholder's (Metsäsairila Ltd, BioSairila Ltd and Etelä-Savon Energia Ltd) extensive expertise in the biogas and waste research and final product optimization field. All the methods used in Mikkeli´s demonstration experiments as well as detailed results are described in the report: Xamk and Miksei 2023b: Implementation of Demonstration 2.
Lessons learned The methods described in the report can be replicated in other cities for the optimization of the biogas process and the final products. By conducting laboratory-scale experiments, potential risks associated with harmful substances can be identified and addressed without compromising the operation of a full-scale plant. These results can often be directly applied at a plant scale, for example in feed material or process optimization. However, before their implementation at plant scale, these methods may require further development before they can be functional in full-scale processes. Also, the commercialization of new methods can take several years.
<Link to instrument> Xamk and Miksei 2023b: Implementation of Demonstration 2

3.2.3. Procurement

Public procurement plays a significant role in implementing the circular economy in the city. MikseiMikkeli created two guidelines in Mikkeli related to demonstration 2:

1. Procurement **guide** for transportation, logistics and traffic services procurement (to increase the usage of biogas as a motive power)
2. Procurement **guide:** Reduction of the amount of organic waste via procurement

The procurement guidelines were tested during demonstration phase within two specific cases together with City of Mikkeli and stakeholders:

- Case 1: More efficient use of the end product of the biogas plant in landscaping in the city of Mikkeli

  The city's green areas are constructed using soil products sources from Metsäsairila where composted bio-waste digestate is used in their production. Procurements have been made in accordance with the principles of procurement guidelines. The subcontractors responsible for acquiring the soil products have been instructed by the city to source their local soil products from Metsäsairila Ltd / Kekkilä Ltd (Metsäsairila Ltd outsourced the production and sale of soil products to Kekkilä in 2022). However, there are no statistics available on the annual amounts of the Metsäsairila soil products used by the city.

The city group includes other companies, such as the municipal housing company Mikalo Ltd, which also uses soil products from Metsäsairila / Kekkilä. Although subcontractors are responsible for procuring soil products, there is a contract price for the company belonging to the city group, resulting in the purchase of practically all soil products from Metsäsairila / Kekkilä. In 2022, Mikalo used about 250 tons of Kekkilä's compost-fertilised soil. This demonstrates that public procurement practices promote the local recycling of nutrients from bio-waste and other organic waste streams in the city's green construction.

- Case 2: Utilization of biomethane from biogas plants in urban transport: buses and city-owned cars.

  Biogas procurement guide principles and examples of the waste management transport service and local public traffic call for tenders, have already been utilised in several procurement processes:

  - Call for tenders for public transport services for commuting and school trips (2022) Criteria to be evaluate: the number of clean (biogas, electricity, biodiesel) vehicles.
  - School transport services in the city of Mikkeli 2022-24 (2022).
  - Shared-use vehicles - Leased vehicles 2022, biogas/biogas hybrid as a requirement
  - Several calls for tenders valued below threshold e.g., vehicle leasing services.
  - Several calls for tenders (under threshold) within the city concern adapting the principles of the city´s biogas procurement guide.

GUIDE 1: PROCUREMENT GUIDE FOR TRANSPORTATION, LOGISTICS AND TRAFFIC SERVICES PROCUREMENT (TO INCREASE THE USAGE OF BIOGAS AS A MOTIVE POWER)
The guide helps to acknowledge the demands of sustainability, low carbon dioxide emissions and the usage of biogas as a motive power in public procurement process, tenders and documents of traffic, transportation, and logistics contracts in the city of Mikkeli. During the preparation of this guide, logistics and transportation experts in charge of procurement processes in the City of Mikkeli were interviewed: Janne Skott, Mikkeli city and Aki Taavitsainen, Mikkeli city. The guide was developed with the help of iterations, in collaboration with the above-mentioned experts. Other sources of information for the development of the guide were the reports and experiences of the procurement processes as well as the comments received from companies during the market dialogue to develop the procurement process and take the circular economy into account in procurement processes. The instructions have also been checked by the city's former procurement manager Jarmo Autere. The guide was officially approved by the city in April 2023 for use in the city's procurement processes. *Support documents for Guide 1, for internal use, reports of case examples in promoting the use of biogas as motive power in logistics related procurement:* ● Procurement report of local transport procurement process ● Procurement report of waste transportation procurement process *As of examples how to apply the principles suggested in the Biogas procurement guide, we created examples of two successful procurement processes. These reports are intended to give real life examples for procurers considering the use of demands or criteria that aim to support the use of biogas in the tender.*
Lessons learned The principles of the Biogas procurement guide have already been used in several procurement processes implemented in the City of Mikkeli and good experiences have been gained in the city by adding criteria of sustainability, low carbon dioxide emissions and the usage of biogas as a motive power in public procurement process. Procurement guides and support documents for Mikkeli can give ideas for other cities on how to consider the circular economy in procurements. However, the procurement guides need always to be adjusted city specific.
<Link to instrument> *CityLoops WP3 biogas procurement guide in Mikkeli* *(in Basecamp)*

GUIDE 2: PROCUREMENT GUIDE FOR REDUCTION OF THE AMOUNT OF ORGANIC WASTE VIA PROCUREMENT
A guide was specifically created for organic waste within the City of Mikkeli, with the aim of including all procurement processes where organic waste is a factor. This guide helps to raise awareness of the importance of handling organic waste sustainably and reducing their generation, as well as consideration of sorting and recycling in all procurement processes undertaken by the city of Mikkeli. The guide was officially approved by the city in April 2023 for use in the city's procurement processes.
Lessons learned: The adaptation of the guides to Mikkeli's context has varied significantly between the two guides created. This can be attributed to the scarcity of that organic waste-related procurement processes compared to those related to biogas (traffic, transportation, and logistics) in the city of Mikkeli. While the general OW guide (guide 2) has raised awareness and promoted the principles, the Biogas guide (guide 1) has had a more immediate and direct impact on the operational level.
<Link to instrument> *CityLoops WP3 organic waste in procurement in the city of Mikkeli (in Basecamp)*

3.2.4. Stakeholder dialogue

Stakeholder group was established in Mikkeli related to demonstration 2 to guide demonstration activities.

New treatment and final product stakeholder group consisting of Metsäsairila Ltd (municipal waste company), Biosairila (biogas plant) and Etelä-Savon Energia (distributor of biogas in Mikkeli until 2023) was established in January 2021. The group has an operative role in managing and treating the organic waste in the Mikkeli region. The group helped and gave practical guidance to coordinate and facilitate the demonstration actions. The group has met 8 times and the meetings will continue until the end of the project. At these meetings, the progress of the demonstration action was examined, the results were presented, and optimisation adjustments as well as upscaling and replication were discussed.

4. Results

As noted in the CityLoops Interim Evaluation Report (D6.3), Mikkeli had already achieved many of the expected outcomes associated with DA1 and DA2 by the interim point of evaluation. Impacts and results of the indicators are presented in more detail in Annex 1.

4.1. Results of Demonstration 1

The goal of this demonstration action (DA1) was to increase the collection of bio-waste in quality and quantity while simultaneously reducing the percentage of bio-waste in the collected mixed household waste and the amount of bio-waste that are incinerated. In DA1, paper waste bags were distributed to residents, and information campaigns promoting the separate collection of bio-waste were conducted. Available data on changes in the composition of municipal solid waste support the hypothesis that a significant increase in the separate collection of bio-waste has taken place as a result of these initiatives. This in turn has led to reduced incineration of bio-waste and a reduction in carbon emissions.

The key results and findings of the DA 1 were:

- The campaigning in the Peitsari demonstration area was successful: the proportion of bio-waste in mixed household waste decreased from 35% (year 2020) to 27% (year 2021) during the demonstration. At the same time (2020-2021), the amount of separately collected bio-waste increased by 53 % based on monitoring rounds of waste amounts. During 2021-2023, the amount of separately collected bio-waste increased by an average of 47 % per inhabitant compared to the baseline (2020) based on monitoring rounds.
- Bioplastic bio-waste bags usually used in Finland cause problems at the biogas plant by tangling in the mixing system. Advising consumers is important in order to switch from bioplastic bio-waste bags to paper bio-waste bags, which are more degradable in biogas plant. Campaigning and advising consumers as well as distribution of free paper bio-waste bags increase the separate collection of bio-waste.
- When developing waste collection in the urban area, it is important that the residents, the waste management company as well as the property owner are involved in the promotion campaign.
- The key findings of the business cases concerning the demonstration 1:
    - Lack of information and motivation is the main obstacle of separate bio-waste collection. Conventional information campaigning is not very affective, so more creative and unconventional information campaigning should be implemented

- In bio-waste collection, the form of living and the density of living have a great influence on what kind of bio-waste collection model would be best suited for the resident. In the area of apartment buildings, bio-waste collection is generally handled in a resource smart way.
- In densely populated residential areas, it would be advisable to organise block collection points for bio-waste and other recyclable materials especially for the detached houses. This is an affordable collection service for residents as well as cost-effective for the waste company.
- In sparsely populated areas, in addition to own a composter, a good bio-waste collection model would be shared neighbourhood bio-waste collection bin. This is suitable for those locations where the detached houses are located a short distance away from each other. A multi-compartment waste collection may be an option where there are no neighbours close by but requires larger investments in bio-waste containers as well as the collection equipment.

4.2. Results of Demonstration 2

This demonstration action (DA2) explored new processing and end-product optimization techniques in a laboratory- and pilot-scale for the production of biogas as fuel for vehicles from bio-waste, and the production of soil amendments from the nutrients present in the digestate, residual streams from the biogas production. The goal was to biogas process and to establish at least two innovative nutrition extraction and product creation technologies, along with related business models in collaboration with local companies.

In DA2, an increase in biogas production from bio-waste collected in Mikkeli has led to emissions savings as expected. The question that remains in DA2 is whether the end-product optimization techniques being tested are technically and financially viable enough to make replication on a larger scale worthwhile and to induce external stakeholders to adopt them. This issue will be followed up in the final evaluation report.

The key results and findings of the DA 2 were:

- The material flows fed to biogas reactor should be optimised so that the process remains balanced, and the biogas production can be maximised. For example, materials that inhibit the process (like citrus fruits) should not be fed into the reactor too much at the same time. It is good to have storage facilities at the plant so that the process can be controlled.
- The pre-treatment of bio-waste in the biogas plant enhance the biogas process and the quality of the final products. However, the experiments showed that the digestate still

requires processing for final product optimization. For example, the digestate should be crushed before pelletizing.

- According to our experiments, the tests showed that the liquid fraction of the digestate of the biogas reactor is a very challenging matrix in terms of struvite precipitation compared to, for example, fractions from the mining industry, where the method has been used more. In our experiments, there were many factors interfering the chemical reactions in the complex matrix, so many pre-treatment steps were required to precipitate struvite. Obviously, this is a challenge for a cost-effective full-scale process. A lot of useful information was obtained from the laboratory scale demonstration experiments, but the method still requires a lot of development work and optimization in laboratory, pilot and demonstration scale to be suitable for bio-waste digestate in a full-scale commercial process.
- Biochar addition in the biogas process prevented the effects of harmful or inhibiting materials and improved the quality of biogas. The amount of biochar addition must be carefully optimised, e.g., in the biogas process, more than 1% biochar addition mixed the process. Attention must also be paid to the quality of biochar. Biochar's raw material and pyrolysis conditions play an important role in the quality of biochar and its functionality in different applications. The birch-based biochar used in the demonstration tests had good quality based on analyses and ecotoxicity tests.

- Poor separate collection of bio-waste causes annually approximately 3500 tons of loss of recyclable bio-waste
- The value of the 3,500 tons of bio-waste potential that ends up in household mixed waste, is worth around 700,000 Euros when processed into transport fuel.
- This transport biomethane would replace approximately one million Euros worth of fossil fuels.

In terms of nutrients, the potential of this mass of bio-waste that ends up in mixed waste is about 22,000 kg of nitrogen and 4,500 kg of phosphorus and 9,500 kg of potassium. The value of these fertilisers is growing sharply in the markets. (Source: Mikkeli's climate program 2022–2035).

5. Economic analysis

5.1. Business cases: Collection and logistics system

Alongside the demonstration actions and stakeholder dialogues, an analysis of the business cases underlying different separated collection and logistics systems was conducted. Two variables were particularly relevant:

- The potential of nutrient recovery based on the current estimated volumes of bio-waste in mixed household waste, bio-waste specifically for nitrogen, phosphorus and potassium bio-waste, which has an impact on the amount of soil improvers produced. Moreover, the production of biogas is highly relevant, which is dependent on the amount of bio-waste collected. The amounts produced of both will have an impact on the economic benefits that can be obtained.
- Other aspects related to the profitability of bio-waste collection, such as logistics and separated collection systems in sparsely populated areas, as well as possible barriers to separate collection (e.g., legislation related to collection and treatment, citizen engagement).

This analysis utilises information from various sources, including literature, interviews with experts and the workshop on collection and sorting through service design. It also draws on the discussions with the stakeholders described above (chapter 3.1.2)

Analysis of nutrient recovery potential

According to the household mixed waste composition study conducted in Mikkeli Peitsari demonstration area (2020), up to 35% of bio-waste ended up in the mixed waste bins because of poor separate collection. This bio-waste potential scaled to Mikkeli city area is approximately 3500 tons of bio-waste annually. The bio-waste is transported along with mixed waste to be incinerated at the utility power plants in Kotka and Leppävirta, affecting the plants' processes and energy production. Having bio-waste within the mixed household waste causes unnecessary waste transports of about two cargo containers per day, equivalent to approximately 80 000 kg CO_2e emissions, and around 400,000 Euros/year (Figure 19).

In Mikkeli's climate program 2022–2035 the value of about 3,500 tons of bio-waste that ends up in mixed household waste yearly in Mikkeli, is estimated to be worth around 700,000 Euros when processed into transport biomethane. This transport biomethane would replace approximately one million Euros worth of fossil fuels. In terms of nutrients, the potential of this mass of bio-waste that ends up in mixed waste is about 22,000 kg of nitrogen and 4,500 kg of phosphorus and 9,500 kg of potassium. The value of these fertilisers is growing sharply.

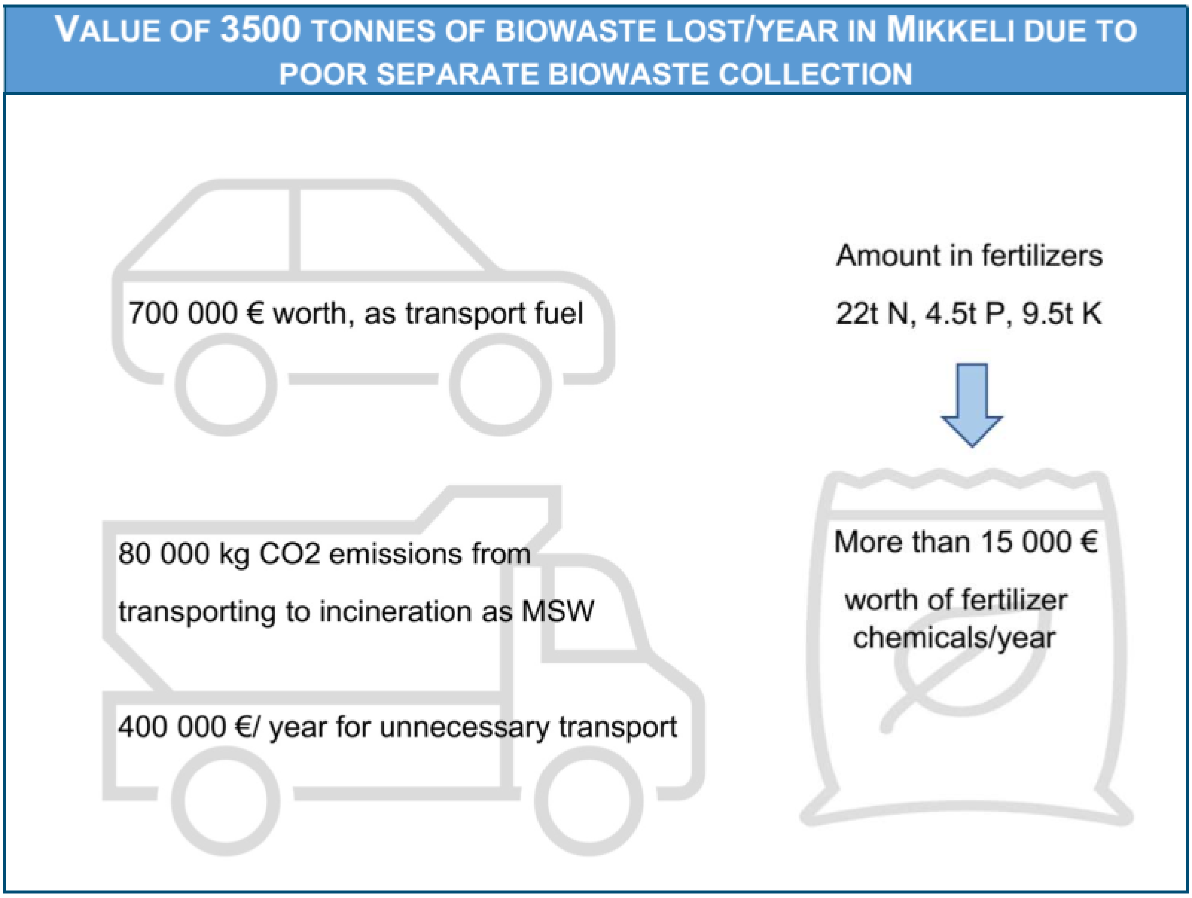


Figure 19. Information on the value of the bio-waste yearly lost to incineration because of poor separate bio-waste collection in Mikkeli was obtained through literary studies.

In table 1 below, the March 2022 price for different fertiliser nutrients is shown on the World Bank's website. These products are not exactly the same as nutrients derived from bio-waste but can nevertheless give an indication of what their global market value is.

Table 1. The value of nutrients from bio-waste based on the World Bank operator's commodity market in March 2022 (World Bank, 1 April 2022).

Fertilisers	Price/t, March 2022	3500 t of bio-waste	Estimated value, (products are not exactly the same)
DAP (Diammonium phosphate)	875€/t	4.5 t phosphate	3937€
Potassium chloride	524€/t	9.5 t potassium	4978€

Urea (contains nitrogen 40 %, this is accounted for in calculations)	1526€/t (pure nitrogen)	4.5 t nitrogen	6867€
		Total:	15782€

The Peitsari demonstration sites results were promising. A hypothetical study in the chart below (table 2) was made, based on the amount of bio-waste collected in the Peitsari demonstration area in the year 2020 and in year 2021.

The percentage of bio-waste within the household mixed waste in 2020 was 35% which would account for approximately 3772 tonnes of bio-waste going to incineration in the city scale. In 2021 the percentage of bio-waste within the municipal solid waste was 27% which would account for approximately 3273 tonnes of bio-waste going to incineration in Mikkeli. Additionally, the monetary gains from the production of fertilisers, and the CO_2 emissions saved from the substitution of biogas instead of fossil fuels, is included in the table.

Table 2. The potential and monetary value of 8% increase in better collection of bio-waste within the Mikkeli city (World Bank 2022).

The potential in results of the Peitsari demonstration site upscaled to Mikkeli City -area with 8% better collection of bio-waste.			
Indicator	Year 2020	Year 2021	Result
Estimated amount of bio-waste within MSW (Mixed household waste) in Mikkeli	3772 tonnes	3273 tonnes	8% increase of separately collecting bio-waste=499 tonnes bio-waste salvaged from Mixed waste
Estimated monetary value as transport fuel	754400€	654600€	money saved by producing more biogas from salvaged bio-waste=99800€
Estimated potential as soil products and its monetary value	2886 t of soil products*15.50e/t=4473€	2504 t of soil products*15.50€/t=3881 €	Money saved by producing more soil products from salvaged bio-waste=5923€
Estimated amount of fertiliser	24.34 t of nitrogen	21.12 t of nitrogen	Monetary value of salvaged bio-waste

chemicals in bio-waste/saved amount of virgin chemicals	2.78 t of phosphorus 10.23 t of potassium monetary value=9166€	2.4 t of phosphorus 8.9 t of potassium monetary value=7953€	as fertiliser chemicals= 1213€
Estimated amount of CO_2 when producing and using of biogas instead of fossil fuels	1314116 kg CO_2	1140271 kg CO_2	173845 kg CO_2 saved from atmosphere when producing and using salvaged bio-waste as biofuel in vehicles.

Factors affecting profitability of bio-waste collection through logistics and separate collection systems

To conduct the analysis of different factors affecting the profitability of the bio-waste collection, data was collected from literary studies and benchmarking with other waste-related projects. Additionally, a workshop on separate bio-waste collection was held in Mikkeli to identify the barriers that hinder effective bio-waste collection.

The decision on what bio-waste collection model is more suitable for the residents, largely depends on population density and their form of housing, which will consequently impact the costs of waste collection for the waste company. In the area of apartment buildings, bio-waste collection is generally handled efficiently. However, the lessons learned from the workshop indicated that the lack of knowledge and motivation, as well as inadequate access to apartment-specific bio-waste bins and waste bags, hindered adequate separate bio-waste collection.

To improve the separate collection of bio-waste, residents need to be educated and motivated to recycle. A good way of doing this is by instilling recycling habits from the moment they move in, so that it becomes a part of their lifestyle. Providing residents with bio-waste collection bags and instructions for recycling can contribute creating permanent and desired recycling habits. This method has been successfully tested in the Peitsari demonstration area, yielding to good results.

Regarding the area of detached houses, one of the most affordable bio-waste collection models is for residents to have their own bio-waste composter. However, the initial investment for a composter might be up to 500 Euros and proper handling of compost also requires familiarization, constant monitoring, and maintenance to ensure its function. Nevertheless, the investment of a composter can pay for itself within 3 years, when compared to the fees for separate collection bio-waste containers from the municipal waste company. Because it would be more costly and logistically inefficient, the waste company has decided not to collect bio-waste separately in certain sparsely populated areas in Mikkeli. In these cases, the bio-waste composter is the best way to recycle bio-waste in households. In densely populated residential areas, it is recommended to set up block collection points for bio-waste and other recyclable materials. This is an affordable collection service for the residents as well as cost-effective for the waste company.

Table 3 provides details of different services available for the separate collection of bio-waste in Mikkeli area.

Table 3 The services of the municipal waste company in Mikkeli on separate bio-waste collection

Separate collection	collective collection/ regional collection	Shared bio-waste bin
	Service	
The BW container is for the property's own use. The owner of the property purchases the container. The cost of the collection of BW consists of the fees for emptying the bin.	The co-collection is for household bio-waste. BW is collected at ecopoints in lockable collection containers.	The BW bin is shared between neighbouring properties. The cost of emptying the bin is shared. A group manager must be appointed to manage the collection. The group will provide a BW container. The cost of collecting BW consists of the fees for emptying the container.
	Price	
140 litre container, 6.71 €/empty. 240 litre container, 8.51 €/empty.	€94.97/year/household	140 litre container, 6.71 €/empty. 240 litre container, 8.51 €/empty.
	Area	
Mikkeli city centre area	shared collection bins at ecopoints.	Mikkeli city centre area
	To be noted	
In sparsely populated areas one should consult the waste management company separately to determine whether separate collection is possible in the area.	The co-collection of bio-waste is intended for household bio-waste. It is not allowed to collect garden waste or large quantities of apples. The frequency of emptying the bio-waste bin is no more than every 2 weeks in summer and no more than every 4 weeks in winter.	In sparsely populated areas separate agreement with the waste management company on whether separate collection is possible in the area. According to the regulations of the city, bio-waste must be sorted separately from mixed waste also in private households.

In sparsely populated areas, in addition to own a composter, a good bio-waste collection model would be shared neighbourhood bio-waste collection bins. This option is however suitable only in those cases where the detached houses are located in close proximity to each other. However, establishing shared bio-waste collection requires an active bin host who takes care of the bio-waste container and its surroundings.

Through interviews with some users of this collection method, it was learned that the role of the bin host can seem cumbersome, therefore it would be beneficial to transfer more responsibility and managing the affairs of the waste collection to the waste company by developing a clear service package and operating instructions for all co-owners.

Another option would be the multi-compartment collection. According to the literature, this collection system requires larger investments in bio-waste containers as well as the collection equipment. The slower collection of multi-compartment containers and the resulting labour time costs must also be considered, which makes this option less suitable for sparsely populated areas compared to more populates ones.

On the other hand, multi-compartment collection has the advantage of being able to easily collect multiple waste fractions as well, eliminating the need for residents to transport them to recycling points. A customised waste collection solution tailored to the different areas would bring savings to both the resident and the service provider. (Hedman Å. Hoang H. et al 2018)

OW QUALITY ASSESSMENT AND BUSINESS CASES

A workshop on bio-waste collection and sorting was held in 16.11.2021 using the service design method. Project stakeholders and Mikkeli residents were involved in identifying potential barriers to separate bio-waste collection.

The aims of the workshop were to identify which collecting methods would most efficient and work best for the residents and the waste company. For this, residents with different types of personalities, families and housing in the Mikkeli region were considered, including the ones living in sparsely populated areas.

Service design is the activity of planning and arranging people, infrastructure, communication and material components of a service in order to improve its quality, and the interaction between the service provider and its users. Service design may function as a way to inform changes to an existing service or create a new service.

Lessons learned

One conclusion of the workshop was that in most cases, lack of information and motivation is the main obstacle of separate bio-waste collection. Conventional information campaigning does not have much impact and has a low attention value. To address this problem, more creative and unconventional information campaigning should be implemented to get the message through. This method was successfully accomplished in the events held for the families in the Hulivili carnival. By experiencing the separate bio-waste collection through fun and games, it makes longer lasting and a more positive impact on the people.

<Link to instrument>

Xamk and Miksei 2023a: Implementation of Demonstration 1.

5.2. Business cases: Valorisation pathways

MikseiMikkeli has produced market analysis on the valorisation of bio-waste. This business case analysis focuses on three types of end product:

- Transport biomethane, produced by the new biogas plant BioSairila
- Fertiliser, produced as a by-product of biomethane production
- Soil improvement products, produced as a by-product of biomethane production

This business case analysis examines the viability of these products and the economic factors involved. The work is carried out in collaboration with the ***New treatment and final product/stakeholder group***, consisting of Metsäsairila Ltd. (municipal waste company), BioSairila (biogas plant) and Etelä-Savon Energia (distributor of biogas in Mikkeli), and managed by MikseiMikkeli.

The analysis utilises information obtained from literature, looking into the main factors influencing the developed products such as markets, EU directives and law as well as municipal decision making. Through interviewing stakeholders involved, more information about the local markets, manufacturing processes, volumes, obstacles and uncertainties of the businesses is attained. An economic evaluation is made for the different valorisation options for the region of Mikkeli.

Refining bio-waste into transport biomethane is profitable both from an environmental point of view and also from an economic point of view. In composting, the energy bound to bio-waste is converted into heat, water vapor and carbon dioxide, but these by-products are not utilised. When bio-waste is converted into biogas, energy is recovered and converted to be suitable for its use as vehicle fuel, thus replacing expensive imported gasoline. Also, from the by-product dry- and wet digestate of the biogas production, soil improvers, fertilisers and other soil products may be manufactured. (Rajantie 2014)

Locally produced transport biomethane also benefits the municipality from a regional economic point of view, as the revenue remains in the local economy, unlike with the imported fuel. Locally produced transport biomethane is also a product in line with the production of renewable energy sources, and its carbon footprint is significantly smaller than imported fuels´. As transportation fuel, the monetary value of biogas is greater compared to its conversion into heat or electricity. (Rajantie 2014)

In Finland, the production and use of biogas is supported with various energy- and investment subsidies (Mutikainen et al. 2016, 4). In the summer of 2021, the parliament has approved the promotion of the use of biofuels in traffic by amending the Distribution Obligation Act. This law provides for the extension of the scope of the national distribution obligation for transport fuels to biogas and renewable liquid and gaseous fuels of non-biological origin.

Additionally, the EU's renewed RED II directive now also takes into account the share limitations of biofuels, biogas and bioliquids produced from certain raw materials, as well as the criteria for reducing greenhouse gas emissions for non-biological renewable liquid and gaseous transport fuels. Decisions regarding the distribution obligation will affect the market for biogas for transportation. Its inclusion in the distribution obligation is believed to increase the profitability of biogas in the long term. (Ministry of Labor and the Economy, 2021)

The biogas plant's income consists of bio-waste reception fees (50–100 €/t, depending on the material and market price) and the sale of biomethane (1.9 €/kg, depending on the market price). The profitability of a biogas plant is a challenging equation, further analysis and new the assessment of different business models should be evaluated.

The profitability of the biogas plant is affected by the following points (Biovoima 2019):

- Bio-waste reception fees/gate fees
- Utilization rate of the capacity of the biogas plant and adequacy of raw material
- Savings in handling costs/transportation costs/etc.
- The method of gas utilization and its income streams
- Income streams and/or savings from products created from side streams
- The technology used and the plant's energy efficiency

Mikkeli's biogas production process is described in Figure 20. With BioSairila´s biorefinery completed in 2020, Metsäsairila´s bio-waste processing capacity will gradually increase to 19500 t/year. The material flows processed in previous years, e.g., in addition to separately collected bio-waste and garden waste, the biogas plant will now also accept sewage sludge, commercial and industrial bio-waste, agricultural by-product streams and separately collected bio-waste from nearby municipalities. In total, the amount of biofractions received by Metsäsairila Ltd. and processed by BioSairila Ltd. will increase more than sixfold.

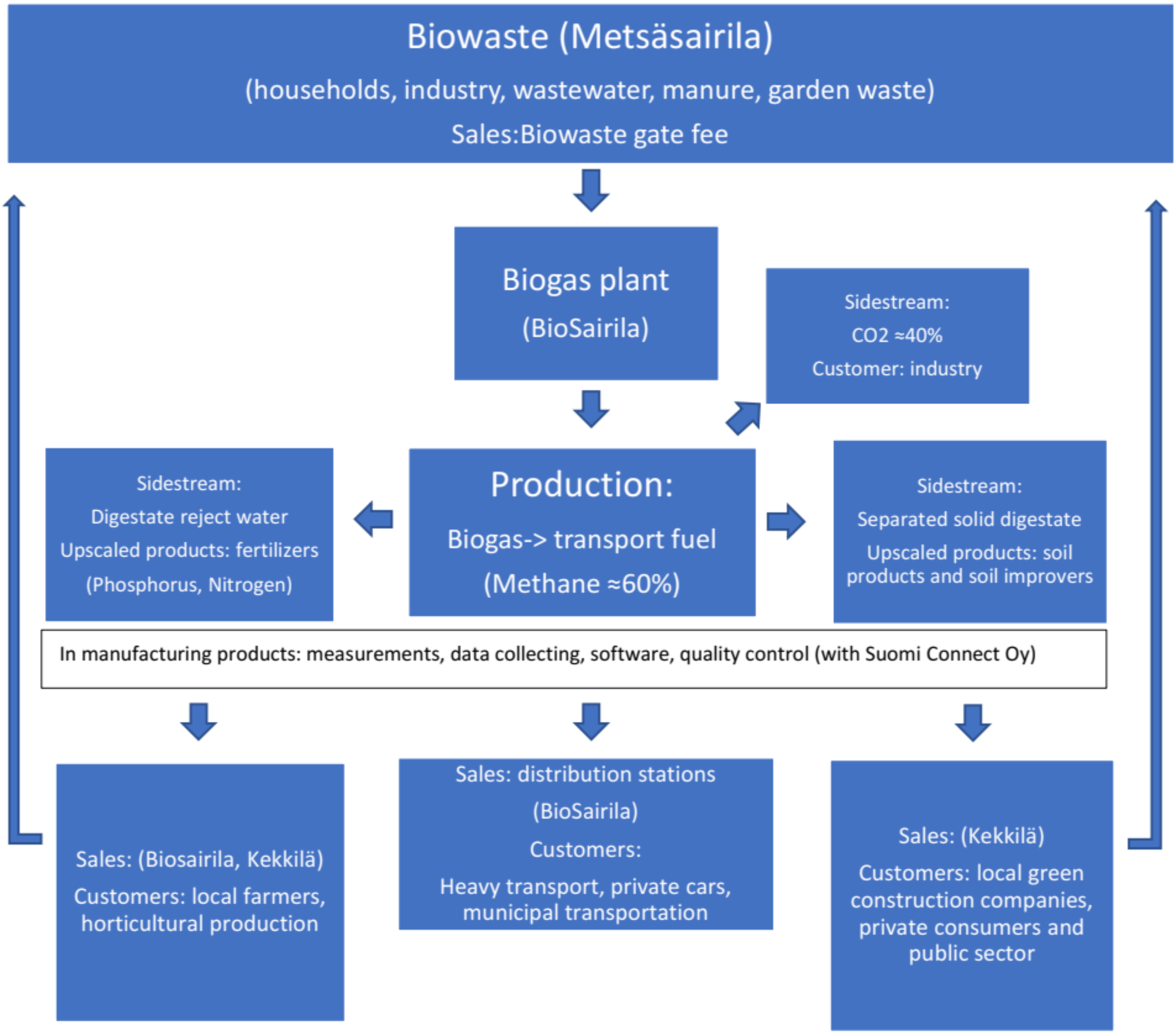


Figure 20. Utilization of bio-waste in different products, its circulation in the production process and in the city of Mikkeli.

BioSairila biogas plant produces about 1.5 Mm^3 (1000 tons, 15 GWh) of traffic biofuel, which corresponds to the annual consumption of about 2000 passenger cars. In Mikkeli, transport biomethane is distributed to consumers at three distribution stations in Graani, Tusku and Haukivuori. The Kuortti distribution station outside Mikkeli, opened in the summer of 2021, also distributes liquid biogas. Etelä-Savon Energia Ltd. has been responsible for distribution and development of the distribution network, but since 2022, these tasks have been transferred to BioSairila Ltd. Gas is sold from distribution stations to all motorists.

In Mikkeli, methods are being developed to promote the use of biogas in the city's procurement and tendering in its own operations, such as public transport and waste transport. This customership is a good way to increase the use of biogas in the region and move towards new markets, for example in heavy duty vehicles.

For heavy duty vehicles, biogas has been an excellent alternative to non-fossil fuels. In trucking, electrification has not yet been a good option since the batteries are too heavy for the needed range for driving and recharging has taken too much time from the total delivery time. For this reason, targeting marketing to this sector, especially in the early stages of the biogas plant's operation has been crucial. To strengthen the demand for the product locally, the markets should have focused first on heavy duty vehicle customers and logistical businesses and after that, on the private markets and personal cars. Personal cars in Finland are mainly shifting towards electric cars, since the infrastructure of biogas stations is still scarce. However, the recommendation for marketing biofuels to heavy duty vehicles should only be considered until 2035, as logistics companies are likely to stop investing in new combustion engine vehicles much earlier in response to the possible changes brought about by the Fit for 55 packages.

In 14.2.2023 the EU parliament approved the new targets of CO_2 emissions reduction for new passenger cars and light commercial vehicles as part of the “Fit for 55” package. This would mean that no new cars or vans with combustion engines will be produced from year 2035 forward in EU. (European parliament news 2023) This would have meant that producing biomethane as a fuel for cars and trucks would not have a future. Germany has voted to change this target and wanted to add e-fuels (synthetic fuels) to the allowed fuels. If this proposal was accepted, some combustion engines would be allowed after all in the future. Would that also mean, that biomethane would be allowed as a sustainable fuel for cars and trucks? This remains unconcluded.

Biogas production produces a digestion residue that can be separated into a dry and liquid fraction. Soil and soil improvement products can be made from the phosphorus-rich dry fraction, and nutrient or fertiliser products can be further processed from the liquid fraction. The dry fraction is not composted further unless more organic material is added to it. It is safe to use in soil improvement and mulch products, as it is sanitised during the digestion process, destroying weeds and pathogens to a large extent.

Metsäsairila Ltd. has annually produced approximately 6,000 tons of finished soil and green construction products, adding soil, sand, and other raw materials to the biomass. Metsäsairila estimates that 6,000 tons of soil products correspond to about 40% of the regional market for similar products. The customers who buy soil products are mainly green construction contractors. They transport the products directly to end customers, either to city construction sites, or to private construction sites for yard construction. The biogas plant however produces a growing amount of digestion residue, that needs even more resources to be productised and sold.

Metsäsairila Ltd. has been selling three different products: Lawn soil, planting soil and green soil. The price for these products is on average around €15/t. On average, an income of 50 €/t has been received as bio waste gate fees. Metsäsairila Ltd. has formed just recently (year

2022) a contract with Kekkilä Ltd. to operate and productise the sidestream materials from the biogas plant. In this way, they can concentrate on their main product which is the transport biomethane.

The digestate liquid from the biorefinery plant in Mikkeli is very nutrient intense. Struvite, a crystallised form of fertilizing chemicals such as phosphate (main fertiliser chemical), ammonium nitrogen and magnesium can be recovered from the digestate using an electrochemical method. Struvite could be used as phosphate fertiliser product in agriculture.

According to CityLoops studies in demonstration 2, from 1000 litres of digestate, 2.7kg of crystallised struvite can be made. In comparison, there has been laboratory scale tests on wastewater, where 1kg of struvite can be made of 100 000 litres of wastewater (Shu et al. 2005). Comparing to this study, the digestate from the biorefinery-plant in Mikkeli is about 270 times more potent in producing phosphate rich struvite, than from wastewater. Some studies show (Zheng et al. 2004, European Fertiliser Manufacturers Association 2000), that 2.7kg of struvite could fertilise around 192 m^2 of land with an application rate of 40 kg phosphorus as P_2O_5/ha/year (Shu et al. 2005).

Replacing mined phosphorus with digestate derived phosphate, negative environmental impacts are reduced, and better European self-sufficiency of the fertiliser is gained. The natural resource of phosphorus is mainly found in the bedrocks of Marocco, China and the USA. In Europe, there is only a little phosphorus found in Finland. (European Sustainable Phosphorus Platform 2011-2023) The demand of the fertiliser is growing, but at the same time the worlds resources on phosphorus-rich rock are running out. There is a crisis building up on the scarcity of phosphate for the use of agriculture. This fertiliser is essential for the food security of the world.

One solution of this problem would be to recover all phosphate possible from the municipal-wastewaters and biowaste streams. As mentioned in the paragraph 3.2.1, testing electrochemical methods the extraction methods of phosphate from material streams such as liquid digestate from biorefineries are not yet established. This needs further studies and testing of different methods. Also, more accurate calculations on the viability of the struvite as a product need to be done. For this report, it is however not possible, considering the wide range of influencing factors to be taken to account. It is still safe to say that struvite made from liquid digestate of biorefineries is a growing possibility as a viable product due to the world situation on the supply and demand of the phosphate rich fertiliser.

OW QUALITY ASSESSMENT AND BUSINESS CASES
Informational events: Biokaasusta vauhtia Etelä-Savoon! -webinar (A Boost from Biogas to the South-Savo Region) Local operators have been encouraged to organise informative seminars about the possibilities of biogas use in logistics. Sharing the latest information about the distribution infrastructure, incentives and subsidies for the purchase or leasing of gas cars is needed. The price of biogas and its profitability in logistics, as well

as its climate effects compared to other transport fuels could promote the demand for the product. City officials and decision-makers may be challenged at such events to increase the city's logistics for biogas. The increased utilization of biogas has contributed to the city's environmental goals, and it has been a good strategy to promote it. Possible new EU directives should be closely followed, as any changes to these related to combustion engines and biofuels, will need new city strategies.
Lessons learned The world is changing very rapidly when it comes to fuels, energy, and their use. It is hard to keep up with all the new directives, laws, subsidies, and the latest technology related to transportation. More information is needed and preferably at least once a year to keep up with the changes at hand. The biogas webinar (Biokaasusta vauhtia Etelä-Savoon) held 22.2.2022 was a success and a well needed event. Now even more important, would be to share information on the EU decisions and goals related to the Fit for 55-package, what it may mean in practice for the transportation- and logistics industry and firms. What instance will take the role for this in Mikkeli, is yet to be seen. New long-term strategies may be needed in Mikkeli concerning bio-waste recycling, the production and use of biogas as well as the cities´ own environmental strategy. These need to be updated according to the directives and laws to be.
<Link to instrument> Xamk and Miksei 2023b: Implementation of Demonstration 2

Economic evaluation of demonstration 2

Demonstration 2 laboratory experiments and procurement activities have required a lot of working time. Equipment and supplies as well as analysis services from accredited laboratories have also been purchased.

The business cases have been implemented through studies of literature, interviewing experts and the organisation of events such as workshops and webinars. The business cases have also been drawn from the discussions within the stakeholder activities. These activities have very little economic impacts, other than possible fees of event speakers, marketing costs and facilitation of events.

6. Lessons learned

5.1 Implementation of actions

Demonstration 1 was targeted to citizens to promote sorting of bio-waste. The demonstration was very successful and the residents of the Peitsari demonstration area were activated to recycle their bio-waste.

Drivers

- Key drivers were versatile communication methods. Organizing residential events was quite easy and a simple way to activate people and similar events could be repeated with the same formula several times. In the final event mould for flower planting was offered as thanks for the resident's participation in the project.
- The most effective measure was certainly the distribution of free bio-waste bags to residents. The bags were offered by the waste management company Metsäsairila Ltd. free of charge. Each resident participating in these events, received bags for about a year's worth of use. This also rewarded residents for sorting.
- In addition to the demonstration area, sorting of bio-waste was promoted at several other events throughout the Mikkeli area. Good experiences were gained from the face-to-face discussions, as the challenges and benefits related to the sorting of bio-waste could be discussed personally. Participating in bigger events was an effective way to reach people. For example, even thousands of people were reached at the children´s Hulivili carnival.
- Imagination, creativity and visuality were felt to be important in the events. Project team dressed up at children´s events into fairy tale characters and exciting games were organised for the children. In this way, the message about sorting bio-waste could be shared in an inspiring way. One good example of this is the “Biofairy” video informing small children about recycling bio-waste. In all events, paper bio-waste bags were distributed to people which was a nice and practical way to convey the message.

Barriers

- All residents of Peitsari pilot area were not reached in the events. However, information was provided also on the bulletin board of the houses and in the resident magazine. Bio-waste bags and brochures were distributed directly to each apartment before the events, which also reached the people who did not participate in the events.
- The biggest barrier in the demonstration was the corona situation, which prevented organizing events for residents at the beginning of the demonstration. Due to the restrictions, residents could not be involved in planning of demonstration activities as much as would have been desired.

Demonstration 2 was targeted to industries that process bio-waste and the end products of biogas plant. Laboratory experiments yielded new information about the digestion of bio-waste, the effects of biochar in the process and the functionality of the digestate in the final product. This information can be used in optimizing the full-scale plant process. However, the bio-waste and digestates are complicated matrices and development of cost-efficient methods to recover nutrients and to produce good quality end products are slow processes. Tested methods still need further development and commercialization of new methods can take several years.

In the business cases it was learned that there are rapid changes in the EU directives, laws, subsidies and in technology, related to transportation, energy, and fuels. Information about these changes is greatly needed. Since it might not be in the interest of the local companies that sell and market the products to give out this information considering all aspects, a neutral actor could preferably take this role. These changes should also be followed by the city and taken into accordance in the city procurement actions and environmental- and other city strategies.

5.2. Stakeholder engagement

Stakeholder engagement has been a key aspect of the project's successful implementation. Two demonstration actions had very different target audiences. Demonstration 1 was targeted to citizens and demonstration 2 to industries. Two separate stakeholder groups were formed for each demonstration, with events, activities and experiments planned collaboratively with them. A city-owned rental housing company Mikalo Ltd has helped inform residents. Waste-management company Metsäsairila (also city-owned company) has offered free bio-waste bags to people and has participated in communication events. The BioSairila biogas plant and energy company Etelä-Savon Energy Ltd have contributed with their expertise in the planning and implementation of laboratory experiments, with their input incorporated into the experiments on bio-waste treatment and final product optimization. Stakeholders have also participated in CityLoops' international meetings and provided valuable feedback on the reports.

To reach to a wider range of stakeholders and promote bio-waste recycling by sharing the project's results, a general "bio-waste stakeholder group" was also established. Moreover, thematic stakeholder groups and regular online meetings (even short ones) were effective on maintaining engagement and commitment to the project among participants. Stakeholders have found the demonstrations to be important and beneficial to them.

5.2. Procurement

Procurement guides related to biogas and bio-waste have been produced as a result of the project. In Mikkeli, important purchases promoting the circular economy of bio-waste have already been made, e.g., procurements related to biogas-powered buses and waste trucks. These case studies are very important in future procurements, and support documents to be used as model examples have been prepared from the successful procurement cases as a result of the project. These documents help implement circular economy aspects described in the procurement guide in future procurements.

When preparing procurements, it is important to first cooperate with experts, so that the substance and goals relevant to the procurement are first well understood. Only after this should the procurement process be started with the procurement manager.

5.3 Organisational changes

Xamk and MikseiMikkeli are partially city-owned organizations, but not part of the city organization, and therefore cannot do organizational adjustments in the city. With CityLoops demonstrations, Xamk and MikseiMikkeli have brought new information and operating models to the city. For example, the procurement guidelines related to the bio-waste sector concerning circular economy aspects, have been drawn up in direct cooperation with the city's procurement unit, and after the city's approval, they will be implemented in the city's procurements. The project has also influenced, for example, the climate program of the city and the operation of companies (Chapter 2.3).

5.4 Data collection and monitoring

Data was collected to monitor the efficiency of bio-waste sorting and impacts of demonstration 1:

- A municipal solid waste composition study was carried out to measure the share of bio-waste in the household mixed waste. However, composition study requires resources and labour, which may limit data collection if resources are not budgeted. In the CityLoops project, the composition study was carried out twice in 2020 and 2021 but share of bio-waste in household mixed waste could not be measured in the later phase of the project. The following composition studies will be carried out in the regional Biovirtaa spin-off project, which enable to obtain valuable data on the sorting of bio-waste after the CityLoops project. The instructions and reports produced in the CityLoops help the implementation of studies in the future.

- Separately ordered waste collection and weighing rounds were used to monitor the change in the amounts of separately collected bio-waste and household mixed waste
- Both methods provided important information about the effects of the demonstration, and these methods could be used to measure the efficiency of bio-waste sorting in the future as well.

Data on bio-waste streams in the City of Mikkeli were collected for the evaluation of circular transition:

- Evaluation work of the project has been labour intensive. Choosing and modifying the correct indicators was a difficult task that required deep insight and collaboration of all project workers. However, different tools provided by the project partners (ICLEI, NRI etc.) and consistent work on data collection and understanding of the data needed for all indicators has produced a coherent evaluation of the project and the demonstration actions.
- The evaluation showed how important indicators and data availability are in measuring the achievement of the city's circular economy goals. Without indicators and statistics, progress in the circular economy cannot be reliably proved. Good statistics, on the other hand, acts as tool in decision-making and enhance the city's vitality, when the progress in circular economy and sustainability can be utilised in the city's image.

7. Future perspectives

6.1 Future activities

In Mikkeli, the situation in the circular economy of the bio-waste sector is quite good. A new biogas plant has been built in the city and the city has invested, for example, in purchasing buses and waste trucks that run on biogas. In Mikkeli's climate program, significant goals have been set for the sorting and collection of bio-waste, as well as the utilization of biogas and nutrients.

Future activities that follow up for demonstration 1:

- The campaigning started in CityLoops to activate citizens in the sorting of bio-waste is continued in the regional spin-off project Biovirtaa and will also be upscaled to a wider area. Monitoring of the amount of separately collected bio-waste and composition studies will also be continued, which enable the evaluation of the circular transition in the city in the future.

Future activities that follow up for demonstration 2:

- Xamk has a regional spin-off project, BioCir underway with BioSairila biogas refinery, where the optimization of the biogas process is continued. The BioLuuppi pilot environment has been built on Metsäsairila waste management area, where biogas experiments can be done on a larger scale.
- An investment in the testing of final products from digestates is coming to the Metsäsairila area.
- Laboratory tests conducted in the CityLoops project did not unfortunately achieve full-scale commercial products. However, the valuable research data obtained in the project can be further used in these future projects and pilot environments. Especially the use of biochar as an additive to enhance biogas process could be upscaled on a larger scale. At the same time biochar can also be used as CO_2 adsorbent.

During the replication phase, the results of CityLoops demonstrations have been disseminated in the Mikkeli region and other cities and dissemination of the results continue until the end of the project. Discussion will be continued with stakeholders on how bio-waste recycling can be promoted in Mikkeli after CityLoops.

6.2 Recommendations for replicators

Many tools and activities demonstrated in Mikkeli can be easily replicated in any other city. For example, the campaigning implemented in the Peitsari area can be used as a model in other areas. The impacts can be measured with composition studies and by monitoring the amount of waste amounts in a similar way that was implemented in Mikkeli. Laboratory testing methods can be replicated in other laboratories. Workshops implemented in Mikkeli can also be organised with the same formula in other regions. Reports are available on how each event was organised and held. Procurement guides and support documents for Mikkeli can give ideas for other cities on how to consider the circular economy in procurements. However, the procurement guides need always to be adjusted city specific. All the activities and methods used in Mikkeli have been documented for replication (Xamk and Miksei 2023a: Implementation of Demonstration 1 and Xamk and Miksei 2023b: Implementation of Demonstration 2).

5.3.1. Recommendations for Demonstration 1

1. Learning about baseline and establishing stakeholder cooperation.
   - **What is the baseline?** Before implementing a demonstration, it is important to carefully establish the baseline situation: e.g., waste volumes at city level, available statistics, reports from previous studies such as waste composition studies or waste monitoring.

The challenges of sorting bio-waste can be explored by interviewing experts and citizens.

- **Commence stakeholder activities.** The best way to improve sorting and collection of bio-waste is to work closely with a wide range of stakeholders. Before starting the demonstration actions, it is important to identify the stakeholders that should be involved (e.g., waste management companies, property representatives, residents, waste transporters, waste processors such as biogas plants and proper public authorities).

2. Strategic planning in collaboration with stakeholders
   - **Stakeholder groups.** Once a clear picture of the baseline situation has been established and stakeholders have been identified, the planning of the demonstration activities can begin. This should be done in consultation with stakeholders. In Mikkeli, it was found to be good practice to form stakeholder groups that met regularly (e.g., once a month) throughout the demonstration.
   - **Workshop on bio-waste sorting challenges and finding solutions.** The service design workshop for residents and stakeholders worked well. The aim was to identify barriers/challenges to sorting and solutions to these that can be taken into account at the demonstration site and in the city context.
   - **Choosing the demonstration site.** The demonstration area should be chosen, e.g., a district or a residential area. On a smaller scale, it is easier to implement some of the measures (e.g., distribute bio-waste bags, carry out monitoring and composition studies) and to see how the measures actually affect the sorting of bio-waste. At the same time, it is worth planning how to promote and inform about bio-waste sorting on a city-wide scale.
   - **Planning for monitoring/measuring the impact of the demonstration area.** The impact of the campaign can be measured by carrying out mixed waste composition studies, which will provide information on how much bio-waste ends up in the mixed waste stream. It is also recommended to monitor the quantities of separately collected bio-waste and mixed waste. The first compositional study and monitoring of waste quantities should be carried out before the start of the information campaign. The composition study will be repeated after the information campaign. Monitoring of waste quantities can be carried out throughout the demonstration. A more detailed description of how these were carried out in Mikkeli can be found in a separate report (Malk et al. 2023). Data collection is important for measuring and evaluating the impact of actions.
   - **Other ways to measure impact.** The effects of the demonstrations can also be explored through discussions with residents and stakeholders. This can be done through surveys or meetings.
   - **Events, information and distribution of paper bio-waste bags in the demonstration area.** Planning the information campaigns in the demonstration area should be done in cooperation with stakeholders. Events held in the demonstration areas in Mikkeli promoted the separate collection bio-waste, the use of paper bio-waste bags for collecting bio-waste in households, and the use of bio-waste for nutrient and

energy recovery in the city. In Mikkeli the campaign included the distribution of paper bio-waste bags and sorting instructions delivered directly to residents' letterboxes and holding residential events in the area. It is important to organise events systematically in the area and to meet residents face-to-face on several occasions.

- **Planning promotional events at city level.**
  The planning should take into account different age groups, e.g., children, youth, working people, elderly people. Events should promote the sorting of bio-waste, the use of paper bags for bio-waste collecting, the purpose of separate bio-waste collection for nutrient and energy recovery. In Mikkeli, for example, the complex messages of separate bio-waste collection and production of local biofuel from the bio-waste, was eased by developing a game for the children and a bio-fairy character for promotional purposes. Also, abling the children to get acquainted and visit a waste truck and learn about waste collecting system. These means were used at a large children's carnival event and were received well by the children and their parents.
- **Planning communications at city level. In** Mikkeli, communication was done for example by writing articles for the residents' magazine and by presenting the project at joint residents' events organised by the rental housing associations. Events were promoted on social media and the sorting of bio-waste was emphasised. A video was made for children in which a bio fairy teaches how to sort bio-waste and explains how this is turned into biogas to fuel cars.

3. Implementation

   The timeline in Figure 21 summaries the steps to implement the demonstration. For example, in Mikkeli, baseline studies including a first compositional study and monitoring of waste volumes were carried out in 2020. The actual information campaign to improve the sorting of bio-waste started in 2021 and a second composition study to measure the impact of the measures was carried out in late 2021. Information and events as well as waste monitoring have been organised in the demonstration area for a further two years between 2022 and 2023.

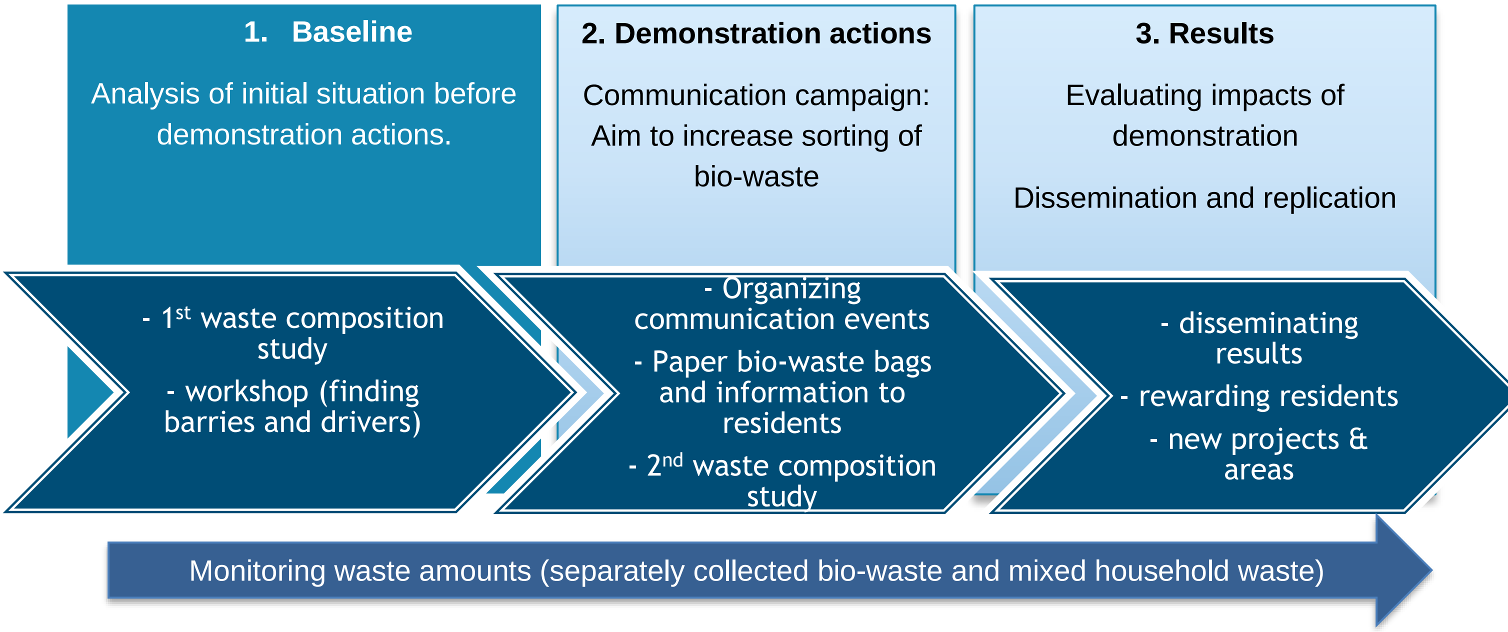


Figure 21. Timeline for actions to increase sorting of bio-waste in demonstration area.

4. Evaluating results, communicating/disseminating, planning follow-up actions
   - **Evaluating results.** At the end of the demonstration actions, the success and impact of the measures will be evaluated on the basis of compositional studies, waste monitoring results and feedback from residents and stakeholders.
   - **Publication of results and reporting to residents.** Residents should be thanked for their cooperation and rewarded for improved bio-waste sorting, which creates a positive attitude to it. In Mikkeli, for example, we will organise a final event where we will thank residents for their cooperation and improved sorting of bio-waste by offering them mulch made from bio-waste and seedlings for planting flowers.
   - **Upscaling and planning of resources.** Based on experiences, plans will be made to scale up the measures from the demonstration site to the whole city or to other areas of the city. This will require an assessment of resources. Can the demonstration measures be transferred to normal practice in the regions and are there resources to continue this? For example, by the distribution of bio-waste bags? Can the promotion of bio-waste sorting be continued in new projects? In Mikkeli, for example, the measures will be continued and replicated regionally in a spin-off project.
   - **Networking and replication.** It is recommended to disseminate results and experiences through networking and cooperation with other cities and projects.

5.3.2. Recommendations for demonstration 2

1. Learning about baseline and establishing stakeholder cooperation.
   - **Determining the baseline.** Before implementing a demonstration, it is important to carefully establish the baseline situation: It is necessary to describe the city's current bio-waste treatment methods and to identify future visions (e.g., increasing the amount of biogas produced and improving nutrient recovery). At the same time, there is a need to identify the needed process developments and efficiency improvements. Analysing existing business models and benchmarking best practices elsewhere will help find a suitable model for the city. Pre-testing of laboratory and pilot-scale methods will further sharpen the goals for further studies on production and processes.
   - **Commence stakeholder activities.** The best way to improve bio-waste treatment is to work closely with a wide range of stakeholders. Before starting the demonstration actions, it is important to identify the stakeholders that should be involved (e.g., waste management companies, waste processors such as biogas plant/biorefinery, energy company and the further processors of possible any by-products such as the digestate. These producers could be producers of fertilisers, or mulch/soil improvements. Also, there is a need to involve the municipality and other proper public authorities as well as procurement experts in promoting the use of these locally produced products in the city.

2. Planning implementation together with stakeholders
   - **Stakeholder groups.** Once a clear picture of the baseline situation has been established and stakeholders have been identified, the planning of the demonstration activities can begin in cooperation with the stakeholders. In Mikkeli, committing the stakeholder groups to the project was done through regular meetings and active dialogue, noting the stakeholders' interests and needs throughout the process.
   - **Planning of the laboratory- and pilot tests.** On a smaller scale, it is easier to implement methods such as testing new materials and techniques for the removal of harmful substances. Laboratory and pilot-scale trials also have lower financial risks and are cheaper and easier to conduct. Subsequently, new promising methods can be then tested in a full-scale process.
   - **Planning for monitoring/measuring the impact of the demonstration actions.** It is important to identify the most relevant indicators for assessing the results of the demonstrations. The economic impacts of the demonstrations can be assessed for example by measuring the amount of biogas produced or sold. The climate impacts can be measured by calculating amounts saved in virgin materials and carbon dioxide emissions. These indicators and impacts are important for helping reach the carbon neutrality and sustainability targets in municipalities. The impact of laboratory or pilot-scale experiments can be assessed by scaling up the results to a larger scale, e.g., the enhanced biogas production potential or the amount of nutrient potential recovered or the inhibition of harmful substances that may be used in process optimization and assessing product safety.

- **Other ways to measure impact.** The effects of the demonstrations can also be explored through discussions with residents and stakeholders. This can be done through surveys, meetings or events. The project objectives in municipal procurement could be measured for example in the number of municipal vehicles running on biofuels. Also, for procurement, the number of public tenders that have made use of circular economy criteria and the use of procurement guides that advise towards sustainability could be accounted for as impact.
- **Planning communications and events at city level.** In Mikkeli, project communication was done for example through stakeholder group dialogue, writing articles and organizing a webinar for local companies, decision makers and officials. This webinar's purpose was to give out information about the distribution infrastructure of biofuels, incentives and subsidies for the purchase or leasing of biofueled vehicles as well as the economics of biofuel driven vehicles in businesses. For promotional incentives, information and comparison of biofuels versus fossil fuels and their climate effects where presented. City officials and decision-makers may be challenged at such events to increase the city's logistics towards biofuels. In connection with demonstration 1, promotional work towards the public was made in connecting separate bio-waste collection to the concrete results of this in production of local and environmentally friendly products such as biofuels, fertilisers, and soil products.

3. Implementation
   - **Product testing, designing and process optimization for full scale production.** Laboratory and pilot-scale experiments can be used to design operations of the full-scale facility. Testing on how to run the plant's various processes, for example in alloying ratios and achieving the best optimum efficiency to produce the maximum amount of gas. The experiments need to be designed in cooperation with the processing plants (biogas plant) and other city group companies. Laboratory and pilot-scale tests are needed to introduce new openings and products to the market or to raise the TRL level of a product or process. In Mikkeli, for example, a local birch-based biochar was tested as an additive component in biogas process and in soil improvement products.

4. Evaluating results, communicating/disseminating, planning follow-up actions
   - **Evaluating results.** At the end of the demonstration actions, the success and impact of the measures will be evaluated through various indicators set for the project and through feedback from the residents and stakeholders.
   - **Publication of results.** As an EU funded project, the results will be widely available for regional, national, and international use.
   - **Upscaling and planning of resources.** Further testing and application of the methods tested in laboratory and pilot scale will be implemented towards a full-scale facility. For example, in Mikkeli, testing will be continued in a new larger-scale demonstration environment as part of a national project. The results will provide a basis for generating

new business activities in productization. The new procurement guidelines and practices can also be used and replicated in other cities and organizations to promote their circular transition.

- **Networking and replication.** It is recommended to disseminate results and experiences through networking and cooperation with other cities and projects on regional, national and international level.

References

Biovoima, Biokaasulaitos. 2019. WWW-dokumentti. Saatavissa: Biokaasulaitos – orgaaniset jätteet ja sivuvirrat tuotoiksi - Biovoima [viitattu 3.2.2021]

Da Ros, C., Libralato, G., Ghirardinia, A.V., Radaelli, M. & Cavinato, C. 2018. Assessing the potential phytotoxicity of digestate from winery wastes. Ecotoxicology and Environmental Safety, 150, 26-33. https://doi.org/10.1016/j.ecoenv.2017.12.029

Dudek M, Świechowski K, Manczarski P, Koziel AJ, Białowiec A. The effect of biochar addition on the biogas production kinetics from the anaerobic digestion of brewers' spent grain. Energies. 2019;12(8). doi: 10.3390/en12081518.

European Parlament News. 2023, Fit for 55: zero CO2 emissions for new cars and vans in 2035. Saatavissa: https://www.europarl.europa.eu/news/en/press-room/20230210IPR74715/fit-for-55-zero-co2-emissions-for-new-cars-and-vans-in-2035 [Viitattu 22.5.2023]

European Sustainable Phosphorus Platform 2011-2023: Phosphorus is essential for worldwide food security Available at: https://www.phosphorusplatform.eu/links-and-resources/p-facts

Hedman Å., Hoang H. et al, 2018, Monilokerokokeilu, Kotitalousjätteen kierrätysasteen nostaminen monilokeroastiapalvelulla Itä-Uudellamaalla vuosina 2017–18. PDF-document

Heinonen, A. 2022. Description of the biogas process of BioSairila Ltd. Information received via e-mail in February-April 2022. Project manager, Metsäsairila Ltd.

HSY (Helsingin seudun ympäristöpalvelut -kuntayhtymä) 2018. Kysely biojätteen lajittelusta. BIORENT project. PDF. Available at: https://vanha.hsy.fi/fi/asiantuntijalle/jatehuolto/tutkimusjakehitys/Documents/kyselytutkimus2018.pdf [referred to 20.11.2020].

Inthapanya S, Preston TR, Leng RA. Biochar increases biogas production in a batch digester charged with cattle manure. Livestock Research for Rural Development. 2012;24:112. https://www.cabdirect.org/cabdirect/abstract/20123413318.

Kabir MM, Rajendran K, Taherzadeh MJ, Sárvári Horváth I. Experimental and economical evaluation of bioconversion of forest residues to biogas using organosolv pretreatment. Bioresource Technology. 2015;178:201-208. doi: https://doi.org/10.1016/j.biortech.2014.07.064.

Mutikainen, M., Sormunen, K., Paavola, H., Haikonen, T. & Väisänen, M. 2016. Biokaasusta kasvua. Sitran selvityksiä 111. PDF-dokumentti. Saatavissa: Selvityksia111-2.pdf (sitra.fi [viitattu 3.2.2021].

Pivato, A., Vanin, S., Raga, R., Lavagnolo, M., Barausse, A., Rieple, A., Alexis Laurent, A. & Cossu, R. 2016. Use of digestate from a decentralised on-farm biogas plant as fertiliser in soils: An ecotoxicological study for future indicators in risk and life cycle assessment. Waste Management 49, 378–389. https://doi.org/10.1016/j.wasman.2015.12.009

Rajantie L. 2014. Kannattaako biojätteestä tehdä kaasua vai multaa? WWW-dokumentti. Saatavilla: https://www.sitra.fi/artikkelit/kannattaako-biojatteesta-tehda-kaasua-vai-multaa/ [Viitattu 11.8.2021]

Shu L., Schneider P., Jegatheesan V., Johnson J., 2005. An economic evaluation of phosphorus recovery as struvite from digester supernatant. https://www.researchgate.net/publication/7405260_An_economical_evaluation_of_phosphorus_as_struvite_from_digester_supernatant

World Bank 2022, Commodity Markets, Annual prices in year 2022. https://www.worldbank.org/en/research/commodity-markets

Zheng, F., Huang, C.H., Norton, L.D., 2004. Effects of near-surface hydraulic gradients on nitrate and phosphorus losses in surface runoff. Journal of Environmental Quality 33 (6), 2174–2182.cEuropean Fertiliser Manufacturers Association, 2000. Phosphorus essential element for food production, pp. 9–10.

Xamk and Miksei 2023a: Implementation of demonstration 1. The report will be published later.

Xamk and Miksei 2023b: Implementation of demonstration 2. The report will be published later.

Annex 1: Impacts

This section summarises the impacts achieved by Mikkeli as measured by the expected outcomes and indicators given in the city's bio-waste Evaluation Plan (D6.2). Intermediate-stage results of the demo actions have previously been discussed in the CityLoops Interim Evaluation Report (D6.3). Final, updated results will be presented in the CityLoops Final Evaluation Report (D6.4).

Demonstration action 1

Planned outcome: Improved interactions in the field of bio-waste collection and sorting between citizens, waste management companies and public authorities, through the establishments of stakeholder groups, i.e., one on bio-waste and one on collection and sorting.

Indicator	Baseline result	Final result
Indicator 6 Circularity-related stakeholder activities	Baseline 0	Number of meetings with Collection and sorting stakeholder group: 24. Number of meetings with Biowaste stakeholder group: 3
Indicator 11. Communication measures on circular transformations and waste prevention	Baseline 0.	All In total around 131600 people reached 1.10.2019-25.5.2023
Outcome review: ● The expected outcome has been achieved. To improve stakeholder interaction, a wide variety of outreach activities have been carried out in accordance with the stakeholder engagement plan developed by the Mikkeli team within CityLoops.		

Planned outcome: New collection and sorting concepts and tools have been tested for bio-waste, leading to improved opportunities in recycling and use of the material flow in Mikkeli.

Indicator	Baseline result	Final result
Indicator 21. New planning instruments/tools for improved circularity: Qualitative description	Baseline 0	Tool 5 OW Quality Assessment and Business Cases - Implementation Plan. Procurement guidelines. Tool 7 New collection and sorting processes for OW

Indicator 22. New planning instruments/tools for improved circularity: Impact	Baseline 0.	Estimated amount of bio-waste within MSW in 2020 (according to the 35 % of bio-waste in MSW in demonstration site waste composition studies) 3772 t. Estimated amount of bio-waste within MSW in 2021 (according to the 27 % of bio-waste in MSW in demonstration site waste composition studies) 3273 t. Procurement guidelines and reports are taken to use in the city.
Outcome review: ● Several collection and sorting concepts have been developed and described. The viability and impact of the concepts and tools are described in this demonstration report and Xamk and in Miksei 2023a: Implementation of demonstration 1, by the end of project.		

Planned outcome: New collection and sorting concepts (i.e. distributing paper bags) for bio-waste tested in the demonstration site.

Indicator	Baseline result	Final result
21. New planning instruments/tools for improved circularity: Qualitative description	Baseline 0	Tool 5 OW Quality Assessment and Business Cases - Implementation Plan published, 20.4.2021. Tool 7 OW Collection and Sorting processes -Implementation plan published 21.4.2021. These plans have been implemented during demonstration phase in co-operation with the stakeholders involved. This demonstration report qualitively describes the actions that have been taken during the project.
22. New planning instruments/tools for improved circularity: Impact	Amount of bio-waste collected in Mikkeli 2019: Compostable separately collected (household) bio-waste (excluding other organic waste material): 2,473 tonnes.	Amount of bio-waste collected in Mikkeli 2020: 2,320 t, 2021: 2,176 t, 2022: 2295t Share of bio-waste within MSW in Demonstration site 2021 = 27%. 1 procurement guideline and 2 case reports. The procurement guide (and case reports) will likely be applied to 2-3 times for city-tenders/year.

	Share of bio-waste within MSW in demonstration site 2020 = 35%. Baseline on procurement guidelines is 0.	
Outcome review: ● The expected outcome at the demonstration site has been achieved. Separate collection of bio-waste has been promoted and the amount of household biowaste has declined within the municipal solid waste (MSW) from 35% to 27%. New procurement guidelines and case reports have been taken to use in the city of Mikkeli.		

Planned outcome: New circular job opportunities created in the area of bio-waste collection and sorting.

Indicator	Baseline result	Final result
Indicator 33. CE-based employment	Metsäsairila and BioSairila average amount of employees in year 2019, 22 people.	Metsäsairila and BioSairila amount of employee's year 2020: 21 people, year 2021: 26, year 2022: 26 people, (18% increase) from year 2019).
Outcome review: ● The expected outcome has been achieved in the sense that the activities of CityLoops have indirectly contributed to 4 new hirings since 2019 at the waste management company Metsäsairila and the biogas plant BioSairila.		

Planned outcome: 15% increased separate collection rate of bio-waste within the demonstration site. MSW (Municipal solid waste) BW (household biowaste).

Indicator	Baseline result	Final result
Indicator 52. Quantity of material subjected to recycling	MSW amount tonnes/week average 1.16 t. BW amount tonnes/week average 0.27 t Average amount of BW within MSW 35%	MSW amount tonnes/week average 0.90 t. MSW percentage change from baseline -22.41%. BW amount tonnes/week average 0.36 t. BW percentage change + 33.33%. Average amount of BW within MSW 27 %. Difference to baseline -8%.

Outcome review:
• Separate collection of bio-waste has increased during the CityLoops project period as evidenced by Mikkeli's calculations, which show that the proportion of bio-waste contained in municipal solid waste (MSW) has decreased from 35% on average at baseline to 27% on average during the project. The average amount of separately collected bio-waste has increased by 33%. It should be noted that there was a decline of 25 occupants in the demonstration area apartments when comparing the baseline year to final evaluation year, so the actual impact has been even greater. Whether the expected outcome has been achieved depends on how the target number of 15% is interpreted and the results accounted for.

Planned outcome: 10% reduction in the amount of organic waste landfilled or incinerated in Mikkeli by the end of project

Indicator	Baseline result	Final result
59. Incineration rate	Estimated percentage and amount of bio-waste incinerated within MSW in 2020=35% (using the results of demonstration site waste composition studies) 3772 tonnes of BW within MSW	Estimated percentage and amount of bio-waste incinerated within MSW in year 2021=27 %. 3273 t of BW within MSW in year 2021.From year 2020 to year 2021 a -13% percentage change decrease in amount of bio-waste going to incineration.
61. Landfilling rate	baseline 0	Landfilling rate 0 in years 2019-2022.
Outcome review: • The expected outcome has been achieved as there has been a 13% reduction in bio-waste going to incineration while the rate of landfilling has stayed constant at 0%.		

Planned outcome: The recycling rate of organic waste has improved, which enables a 15% reduction in the greenhouse gas emissions

Indicator	Baseline result	Final result
85. GHG emissions per year.	Hypothetical amount of emissions saved by collecting bio-waste in the demonstration area. 4.8 t CO2e saved if	6.3 t CO2e saved by producing biogas and using it as transport fuel in year 2022 (biowaste collected at demonstration site and estimated as years collection from weekly weighing tests). The percentual change ≈17

	bio-waste was to be produced as biogas and used as transport fuel in year 2020 (bio-waste collected at demonstration site and estimated as full year in collection from weekly weighing tests)	% increase of saved CO_2e emissions compared to year 2020.
Outcome review: ● Mikkeli's calculations show that the increased collection of bio-waste in the demonstration area has enabled an estimated 17% increase in the amount of CO_2 emissions saved compared to the baseline and thus achieves the planned outcome.		

Demonstration action 2

Planned outcome: Improved interactions in the field of treatment between citizens, waste management companies and public authorities, through the establishment of stakeholder groups, i.e. on treatment and products.

Indicator	Baseline result	Final result
Indicator 6 Circularity-related stakeholder activities	Baseline 0	New treatment and final product group/ (Biogas group) meetings: 10 meetings. Stakeholder Engagement plan published.
Indicator 11. Communication measures on circular transformations and waste prevention	Baseline 0.	All together around 131600 people reached 1.10.2019-25.5.2023 of which 195 are not already accounted for in DA1 ind.11.
Outcome review: ● The expected outcome has been achieved. To improve stakeholder interaction, a wide variety of outreach activities have been carried out in accordance with the stakeholder engagement plan and other promotional events intended for the citizens of the municipality.		

Planned outcome: Promotion of circularity in the bio-waste sector is embedded in Mikkeli's procurement practices.

Indicator	Baseline result	Final result
12. Circularity requirements in procurement beyond existing levels	Emission class number Euro 6. requirements on city procurement in transportation and logistical services are in use in year 2019.	New procurement guideline and case reports are taken to use in Mikkeli´s procurement practices: The guide has been circulated within the city services, mentioned in the municipality's new climate action plan as a lever to achieve climate neutrality. Will likely be applied to 2-3 tenders a year. Official validation by the City of Mikkeli of the Procurement guide for usage of biogas as a motive power in transportation and logistics services.
15. Procurement with circularity requirements beyond existing levels: Impact	Year 2019 0 biogas buses in used in the area of Mikkeli. Also 0 biogas garbage trucks in use in the area of Mikkeli. 0 end product made from biogasplant (not in operation in year 2019)	By 25.5.2023, 5 biogas buses are in use in Mikkeli. Also 5 biogas garbage trucks are in use in Mikkeli and 6 city-owned biogas cars. 9496 t of soil products made for landscaping from Biosairila compostable raw materials in year 2022. Landscaping materials were used and sold both for public and private users.
Outcome review: ● The expected outcome has been achieved in the sense that the newly developed procurement guidelines have been adopted by the city and may also be seen as the usage of biofuel vehicles in the municipality.		

Planned outcome: At least 5 new treatment and product optimization methods/technologies have been tested and evaluated (at demonstration level), considering technical viability, financial viability, and productivity. At least 2 treatment and product optimization methods / technologies will be established.

Indicator	Baseline result	Final result
23. Eco-innovation: Qualitative description	Baseline 0	This Demonstration report adduces the new treatment and product optimization methods their technical and financial viability, business models, -cases and circularity in new products such as biogas, fertilisers and soil products. These are qualitively described in the report. More detailed information in Xamk, Miksei 2023 b, Implementation of Demonstration 2, published by the end of project.
24. Eco-innovation: Impact	Baseline 0.	Soil products sold in year 2021=157697€ (year 2022 not available). Amount of biogas

		sold in year 2022: 532.5t, monetary value in year 2022= 937200 €. 4712 t of bio-waste was used for biogas production. 132 t bio-waste was used for soil products in 2022. The value of nutrients within this 4844 t of biowaste is about 58000 €.

Outcome review:

- All planned 5 new treatment and product optimisation methods have been tested and evaluated at demonstration level. Technical- and financial viability has been evaluated and qualitively described in this Demonstration report and the Xamk, Miksei 2023 b, Implementation of Demonstration 2 report.

Planned outcome: New circular job opportunities created in the biochar, biogas and fertiliser business

Indicator	Baseline result	Final result
Indicator 33. CE-based employment	Metsäsairila and BioSairila average amount of employees in year 2019, 22 people.	Metsäsairila and BioSairila amount of employee's year 2020: 21 people, year 2021: 26, year 2022: 26 people, (18% increase) from year 2019).

Outcome review:

- The expected outcome has been achieved in the sense that the activities of CityLoops have indirectly contributed to 4 new hirings in since baseline year 2019 at the waste management company Metsäsairila and the biogas plant BioSairila.

Planned outcome: Consumption of virgin materials reduced by 5% at city level (compared to the start of the project)

Indicator	Baseline result	Final result
Indicator 35. Domestic material consumption (DMC) of virgin materials	Year 2020 made amount of end-product from the biogas plant 0. Biogas plant began operating at end of year 2020.The amount of virgin fossil fuels saved by producing biogas is	4844 t of biowaste that was used for biogas- and for soil production has a potential of 31.28 t of nitrogen, 3.60 t of phosphorus and 13.08 t of potassium which will save virgin materials from being extracted. 564.3 t of virgin fossil fuels was saved by producing biogas in Mikkeli in year 2022 this is a significant increase to the baseline year.

	4.1 t virgin fossil fuels in year 2020	

Outcome review:

- Biogas production began in 2020. Mikkeli's calculations show that, as biogas production has increased greatly since. The amount of virgin fossil fuels and nutrients saved by producing biogas and soil products have increased enormously in percentage terms over the same period.

Planned outcome: Increase in upcycled amount of organic waste by 50% by end of project (mass, volume or %) in the city of Mikkeli.

Indicator	Baseline result	Final result
Indicator 53. Quantity of material for anaerobic digestion	In year 2020, 0 amount of separated household bio-waste was used when starting up the biorefinery (end of year 2020).	4712 t of collected household biowaste used for anaerobic digestion in Biosairila.

Outcome review:

- The expected outcome has already been achieved as the amount of upcycled organic waste has increased from 0 to 4712 t.

Planned outcome: 10% reduced emissions of CO2 related to reduced transport needs as well as substitution of fossil fuels (trucks) by biogas

Indicator	Baseline result	Final result
85. GHG emissions per year.	Making transport biogas from bio-waste collected in Mikkeli and in using this transport biomethane instead of fossil fuels saved 9.3 t CO2e in emmissions (year2020).	Making transport biomethane from bio-waste collected in Mikkeli and in using this as transport biomethane instead of fossil fuels saved emissions in year 2022, 1085t CO2e. The increase was significant from the baseline year 2020.

Outcome review:

- Mikkeli's data show that biogas production has led to substantial emissions savings compared to the baseline. The data presented do not allow a precise calculation of the overall emissions reduction in percentage terms in the city.

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.