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Results and experiences from the Circwaste project

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Abstract

Executing circular economy strategies in practice in Finland
Results and experiences from the Circwaste project

A Europe-wide circular economy policy was launched in 2014 when the European Commission published the first strategic policy programme for circular economy. It was compiled to provide very comprehensive impacts and dimensions of sustainable development: sustainable growth and a climate neutral, resource efficient and competitive economy. The targets of a circular economy are that the value of products, materials and resources is maintained in the economy for as long as possible, economic growth is decoupled from resource use, generation of waste and environmental loads are minimised, and pressure on the Earth's resources and biodiversity is minimised.

The European Union is supporting the sustainability transition with research and development funding. In Finland, Circwaste – Towards Circular Economy is one of the biggest development projects accelerating the transition to a circular economy. During the period 2016–2020, the project has produced monitoring data on the development of circular economy and the sustainability of waste management, highlighted the circular economy concept, promoted stakeholder collaboration, supported strategic national processes, strengthened know-how and mainstreamed and concretised circular economy thinking. This interim report presents all the relevant results so far.

It is crucial that data is produced from different angles on implementing the circular economy. More information is needed both to support decision making and on connections between and reflections on different factors. The key figures for Finland show quite clear coupling of the use of natural resources, waste amounts and economic growth. The circular material use rate is ca. 7%, which can be considered quite modest. Quantitative national targets for decreasing the use of natural resources are needed. Instead of country comparisons, the focus should be on trends in order to learn from the past and to identify the policy instruments needed to achieve the level aspired to.

One of the key findings is the need for regional indicators and data for decision-making. The work done within Circwaste is the first effort towards a systematic monitoring scheme for monitoring circular economy regionally. The study showed that the production of regional waste data is challenging, that the estimated recycling rates have not increased adequately to reach the EU targets and that there could therefore be a need for municipal-level recycling targets.

The transition to a circular economy also causes fundamental social changes in society. In the project, new indicators were developed for measuring social impacts: circular economy employment, education and employment for vulnerable groups, publicly shared resources, accessibility of recycling services and sustainable vehicle fuels. The first baseline data show advances towards the circular economy: the accessibility of waste management services has improved, the Finnish educational system has been able to respond quickly to the need for circular economy education, circular economy activities have potential for the employment of vulnerable groups and economic activities related to recycling, repair and reuse have grown. The regions and municipalities emerge as key actors in facilitating a socially just transition towards a circular economy.

The study on innovative material processing technologies gathered data on technologies for elemental recycling, especially for plastic waste but also for making new fibres from textiles waste. Financial issues are key to the survival of these technologies and there is a need for governmental financial support.

Public procurers can be considered key players in the circular economy, creating demand for more sustainable products and services. Implementing circular economy in municipalities requires commitment, financial planning, interaction with regional actors and inclusion of circular economy in financial rules. The construction sector is a major consumer of natural resources, but the municipalities can make construction more sustainable through public procurements and planning. As buyers, they can require the use of recycled raw materials and soils in construction projects. Obligations for ecological compensation and goals of no net loss of biodiversity would decrease the pressure on natural resources. To support municipalities in their work, a national organisation for providing municipal auditing, development, education and business support services could be established. Employing circular economy experts in each municipality to work as cross-administrative coordinators could enhance the transition.

The project has created a lot of political, theoretical and practical content on the concept and field of circular economy. The next steps are to further develop and widen, as well as deepen, the results and to provide national support in searching for answers and solutions for decreasing the use of natural resources, achieving the MSW recycling targets and creating a more sustainable society.

Keywords: circular economy, waste, sustainability, indicators, sustainable development, natural resources

Sammandrag

Praktisk implementering av strategier för cirkulär ekonomi i Finland
Resultat och erfarenheter från Circwaste-projektet

Den europeiska politiken som förs för cirkulär ekonomi kom igång år 2014 i samband med att Europeiska kommissionen lade fram det första politiska programmet för cirkulär ekonomi. Programmet innehåller en omfattande lista med mål för hållbar utveckling: hållbar ekonomisk tillväxt och en klimatneutral, resurseffektiv och konkurrenskraftig ekonomi. Målsättningarna för den cirkulära ekonomin är att värdet på produkter, material och övriga resurser består inom ekonomin så länge som möjligt, att bryta sambandet mellan ekonomisk tillväxt och resursanvändning, att minska mängden avfall, att skydda globala resurser och biologisk mångfald samt att minska miljöbelastningen.
Europeiska unionen stöder hållbarhetsomställningen genom att finansiera forsknings- och utvecklingsarbete. Projektet Circwaste - Mot en cirkulär ekonomi är ett av de största utvecklingsprojekten som verkställer mål för cirkulär ekonomi i Finland. Under åren 2016 - 2020 har projektet producerat uppföljningsuppgifter om framgångarna inom cirkularitet och inom hållbar avfallshantering, gett mer synlighet för begreppet cirkulär ekonomi, främjat samarbetet mellan olika intressentgrupper, stött nationella strategiska processer, stärkt kompetens och integrerat och preciserat tänkandet kring cirkulär ekonomi. Denna rapport presenterar de mest märkvärda resultaten som man hittills uppnått.
Det är väldigt viktigt att producera information om hur den cirkulära ekonomin verkställs ur olika synpunkter. Ytterligare information behövs både som stöd för beslutsfattandet och om sambandet mellan och konsekvenser av olika aktörer. Indikationer när det gäller Finland visar fortfarande ett klart samband mellan utnyttjandet av naturresurser, mängden avfall och ekonomiska indikationer. Materialets användningsgrad är 7 %, vilken är en relativt låg grad. För att ändra riktningen behövs kvantitativa mål för att minska användningen av naturresurser. I stället för en jämförelse mellan länder borde förståelsen om processer vara i fokus för att vi ska lära oss av det förflutna och att kan identifiera åtgärder som måste tas för att nå den eftersträvade nivån.

Ett av de viktigaste resultaten är att det behövs regionala indikatorer som stöd för beslutsfattandet. Arbetet inom projektet Circwaste är det första försöket att förverkliga en systematisk metod för att regionalt övervaka den cirkulär ekonomin. Resultaten visar att det är utmanande att producera regional information, att återvinningsgraden inte har ökat tillräckligt för att nå de sameuropeiska målen, och att därför skulle det finnas behov för återvinningsmål på kommunalnivå.

En övergång till cirkulär ekonomi orsakar även grundläggande sociala förändringar inom samhället. Inom projektet utvecklades det nya mätare för att mäta sociala effekter: hur den cirkulära ekonomin påverkar anställning, utbildning, sysselsättningsgraden hos mindre gynnade grupper, resurser som tilldelas offentligt, tillgänglighet av återvinningstjänster och hållbara bränslen. De första resultaten påvisar den cirkulära ekonomins nyttor: tillgänglighet av avfallstjänster har förbättrats, det finska utbildningssystemet har kunnat reagera snabbt på utbildningbehov när det gäller cirkulär ekonomi, funktioner som berör cirkulär ekonomi kan anställa de mindre gynnade och att affärsverksamheten inom återvinning, reparation och återbruk har ökat. Regionerna och kommunerna är nyckelaktörer som möjliggör en socialt jämlik övergång till cirkulär ekonomi.

I utredningen, som handlade om innovativa lösningar för behandling av olika material, hittades många tekniker för materialåtervinning på kongennivå, särskilt för plastavfall, men även för att tillverka nya fibrer ut av textilavfall. Ekonomiska faktorer spelar huvudrollen för att dessa tekniker blir vanligare och det finns behov för statlig finansiering.

Offentliga upphandlingar kan ses som nyckelfaktorer eftersom de skapar efterfrågan för mer hållbara produkter och tjänster. Genomförande av cirkulär ekonomi kräver engagemang och ekonomisk planering inom kommunerna samt samarbete mellan regionala aktörer och att kommunerna inkluderar

cirkulär ekonomi i sina arbetsordningar. Byggnadssektorn konsumerar en märkvärd mängd naturresursser, men kommunerna kan se till att det blir hållbarare genom offentliga upphandlingar och planläggning. Som köpare kan kommunerna kräva att återvinnings- och jordmaterial används i sina byggprojekt. Förpliktelser för ekologiska kompensationer och mål för att stoppa nettoförluster av naturens mångfald skulle minska trycket på användningen av naturresurser. För att stöda kommunernas uppgifter skulle en nationell organisation som skulle erbjuder revisions-, utvecklings- och utbildningstjänster samt tjänster för att stödja affärsverksamhet kunna grundas. Omställning skulle kunna stödas även genom att anställa experter inom cirkulär ekonomi till varje kommun för att agera som tväradministrativa koordinatorer.

Inom projektet har det producerats mycket politisk, teoretisk och praktisk information om cirkulär ekonomi. Till näst kommer arbetet att utvidgas och fördjupas och projektet kommer också i fortsättningen att erbjuda nationellt stöd för att söka efter svar och lösningar för att minska förbrukningen av naturresurser, nå återvinningsmålet för hushållsavfall och bygga ett mer hållbart samhälle.

Nyckelord: cirkulär ekonomi, avfall, hållbarhet, indikatorer, hållbar utväckling, naturresurser

Tiivistelmä

Kiertotalouden toteuttaminen käytännössä Suomessa
Tuloksia ja kokemuksia Circwaste-hankkeesta

Euroopan laajuinen kiertotalouspolitiikka käynnistyi vuonna 2014 Euroopan komission julkaiseman ensimmäisen kiertotalouden poliittisen ohjelman myötä. Se sisältää hyvin kattavasti kestävän kehityksen tavoitteita: kestävää kasvua ja ilmastoneutraalia, resurssitehokasta ja kilpailukykyistä taloutta. Kiertotalouden tavoitteita ovat tuotteiden, materiaalien ja muiden resurssien arvon säilyminen taloudessa mahdollisimman pitkään, taloudellisen kasvun irtikytkentä materiaalien käytöstä, jätemäärien vähentäminen, maapallon resurssien ja biodiversiteetin säästäminen ja ympäristökuormituksen vähentäminen.
Euroopan unioni tukee kestävyysmurrosta tutkimus- ja kehitysrahoituksen avulla. Suomessa Circwaste – Kohti kiertotaloutta -hanke on yksi suurimmista kiertotalouden tavoitteita toimeenpanevista kehittämishankkeista. Vuosien 2016 – 2020 aikana hanke on tuottanut seurantatietoa kiertotalouden edistymisestä ja jätehuollon kestävyyden kehittymisestä, tehnyt näkyväksi kiertotalouden käsitettä, edistänyt eri sidosryhmien välistä yhteistyötä, tukenut kansallisia strategisia prosesseja, vahvistanut osaamista ja valtavirtaistanut ja konkretisoinut kiertotalousajattelua. Tässä väliraportissa esitellään merkittävimmät tähän mennessä saadut tulokset.
On erittäin tärkeää tuottaa tietoa kiertotalouden toteutumisesta eri näkökulmista. Lisätietoa tarvitaan sekä päätöksen teon tueksi että eri tekijöiden välisistä yhteyksistä ja seurauksista. Suomelle lasketut tunnusluvut osoittavat yhä varsin selkeää luonnonvarojen käytön, jätemäärien ja talouden tunnuslukujen kytkeytymistä toisiinsa. Materiaalien kiertotalousaste on 2 %, eli varsin matala. Suunnan muuttamiseksi tarvitaan määrällisiä tavoitteita luonnonvarojen käytön vähentämiselle. Seurannassa pääpainon tulisi kuitenkin olla kehityskulkujen ymmärtämisessä maavertailujen sijaan, jotta opitaan menneestä ja tunnistetaan ohjauskeinot tavoitetasolle pääsemiseksi.

Yksi avaintuloksista on, että päätöksenteon tueksi tarvitaan alueellisia indikaattoreita. Circwaste-hankkeessa tehty työ on ensimmäinen yritys toteuttaa järjestelmällinen menetelmä kiertotalouden alueellisen seurantaan. Tulokset osoittavat, että alueellisen tiedon tuottaminen on haasteellista, kierrätysasteet eivät ole kasvaneet riittävästi, jotta saavutettaisiin Europanlaajuiset tavoitteet ja että sen vuoksi voisi olla tarvetta kuntatason kierrätystavoitteille.

Siirtyminen kiertotalouteen aiheuttaa yhteiskunnassa myös perustavanlaatuisia sosiaalisia muutoksia. Hankkeessa kehitettiin uusia mittareita sosiaalisten vaikutusten seurantaan: kiertotalouden työllistävyys, koulutus, heikommassa asemassa olevien työllisyys, julkisesti jaetut resurssit, kierrätyspalveluiden ja kestävien liikennepolttoaineiden saavutettavuus. Ensimmäiset tulokset osoittavat kiertotalouden hyötyjä: jätehuoltopalveluiden saavutettavuus on parantunut, Suomen koulutusjärjestelmä on pystynyt nopeasti reagoimaan kiertotalouden koulutustarpeisiin, kiertotalouden toiminnot pystyvät työllistämään heikommassa asemassa olevia ja kierrätykseen, korjaukseen ja uudelleenkäyttöön kytkeytyvä liiketoiminta on kasvanut. Alueet ja kunnat ovat avaintoimijoita, jotka mahdollistavat sosiaalisesti oikeudenmukaisen siirtymisen kiertotalouteen.

Innovatiivisia materiaalien käsittelymenetelmiä käsittelevässä selvityksessä löytyi useita tekniikoita yhdistetason materiaalikierrätykseen, etenkin muovijätteille, mutta myös uusien kuitujen valmistamiseen tekstiilijätteistä. Taloudelliset tekijät ovat avainasemassa näiden tekniikoiden yleistymisessä ja tarvetta olisi valtion rahalliselle tuelle.

Julkisia hankintoja voidaan pitää kiertotalouden avaintekijänä, koska ne luovat kysyntää kestävämmille tuotteille ja palveluille. Kiertotalouden toteuttaminen vaatii kunnissa sitoutumista, taloussuunnittelua, yhteistyötä alueellisten toimijoiden kanssa ja kiertotalouden sisällyttämistä taloussääntöihin. Rakennussektorilla käytetään huomattava määrä luonnonvaroja, mutta kunnat voivat tehdä siitä kestävämmän julkisten hankintojen ja kaavoituksen avulla. Ostajina he voivat vaatia kierrätysmateriaalien ja maaainesten käyttöä rakennushankkeissa. Velvoitteet ekologisiin kompensaatioihin ja luonnon monimuotoisuuden nettohävikin pysäyttämiseen liittyvät tavoitteet vähentäisivät luonnonvarojen käyttöön kohdistuvia paineita. Kuntien tehtävien tukemiseksi voitaisiin perustaa kansallinen organisaatio, joka tarjoaisi auditointi-, kehitys-, koulutus- ja liiketoiminnan tukipalveluita. Muutosta voitaisiin tukea myös palkkaamalla kiertotalouden asiantuntijoita joka kuntaan toimimaan poikkihallinnollisina koordinaattoreina.

Hankkeessa on tuotettu paljon poliittista, teoreettista ja käytännön tietoa kiertotaloudesta. Seuraavaksi työtä sekä laajennetaan että syvennetään ja hanke tarjoaa jatkossakin kansallista tukea etsimään vastauksia ja ratkaisuja luonnonvarojen käytön vähentämiseen, yhdyskuntajätteen kierrätystavoitteiden saavuttamiseen ja kestävämmän yhteiskunnan rakentamiseen.

Asiasanat: kiertotalous, jäte, kestävyys, indikaattorit, kestävä kehitys, luonnonvarat

Preface

The European Commission launched its circular economy strategy in 2015 with a proposal for the first Circular Economy package, 'Closing the loop – An EU action plan for the Circular Economy'. The plan was to support circular economy related research and innovation with several funds and financing programmes. The project 'Circwaste – Towards Circular Economy' was created for the LIFE IP programme, which provided financing for implementing a national waste plan. In the project, circular economy targets were merged with targets for waste prevention and recycling. This successful combination was granted financing in 2016.

The Circwaste project aims at minimising the use of natural resources and advancing the efficient use of material flows, waste prevention and new resource and waste management concepts, directing Finland towards a circular economy. The seven-year long project has been granted financing until the end of 2023 and is a versatile combination of over 20 partners inclusively representing Finnish society: research institutes, universities, universities of applied sciences, companies, waste management organisations, municipalities and regional councils. The Finnish Environment Institute (SYKE) is the project coordinator and the comprehensive list of associated partners involved in the project in alphabetic order is: Business Joensuu, Central Finland Health Care District, the City of Jyväskylä, the City of Pori, the Council of Tampere Region, Digipolis Ltd, GS1 Finland, Karelia University of Applied Sciences, Kiertomaa Ltd, Lappeenranta-Lahti Technical University, Motiva Ltd, the Natural Resources Institute Finland (LUKE), Pikes Ltd, Puhas Ltd, Ramboll Finland Ltd, the Regional Council of Southwest Finland, the Regional Council of Central Finland, the Regional Council of North Karelia and Turku University of Applied Sciences.

The EU LIFE IP programme is the largest financier of the consortium budget, which totals EUR 18 million. There are nine additional funding organisations: the Ministry of the Environment, the Ministry of Agriculture and Forestry, the Finnish Innovation Fund SITRA, Pirteä Porsas Oy, Future Fund of North Karelia, Mustankorkea, Sammakkokangas, Gasum Ltd, Rauman Biovoima and the Finnish Transport Infrastructure Agency.

In this report, using the experiences from the Circwaste project as an example, SYKE has described the means and possibilities for implementing circular economy strategies and targets in practice. The process and measures in the project have been documented, and the factors influencing the successes and challenges have been analysed. Furthermore, the main results have been reported. They include the development work on assessing the indicators suitable for measuring circular economy and all the sustainability dimensions in general. Additionally, the development of circular economy in Finland and regionally is discussed. Moreover, the environmental impacts of circular economy development and different policy actions are assessed by using Life Cycle Assessment methods (LCA) and input-output methodology. The report also includes a detailed literature review examining potential treatment methods for producing elementary level raw materials from waste. We believe this report will be beneficial for experts, decision makers and other stakeholders in Finland and all over the world who are interested in measures that promote circular economy with concrete actions and, for example, with a large-scale project like Circwaste.

The materials presented in this report were prepared by Tuuli Myllymaa, Kati Pitkänen, Tiina Karppinen, Hanna Savolahti, Helena Dahlbo, Jachym Judl, Jouni Neuvonen, Hannele Ahponen, Katja Lepistö, Hannu Savolainen, Aino Ukkonen, Antti Rehunen, Kimmo Nurmio, Santtu Karhinen, Katriina Alhola, Petrus Kautto, Hanna Salmenperä, Teija Haavisto, Anne Holma, Ida Mönkkönen, Riina Antikainen (passed away in April 2020), Kaarina Kaminen, Sara Turunen, Sami Alt and Camilla Sederholm, who all work at SYKE.

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Helsinki, February 2021

The authors

Contents

1 Circular economy in Finland

The European Commission launched its first circular economy package in 2015. A carbon-neutral circular economy has become one of the leading topics in environmental policy and an instrument for implementing sustainable development.

1.1 **The circular economy concept**

1.1.1 The foundation of EU circular economy policy

The strategic history of circular economy policy in Europe began in 2015, when the European Commission proposal, the first circular economy package, 'Closing the loop – An EU action plan for the Circular Economy' (European Commission 2015), was introduced. The Commission had originally presented proposals for new waste rules a year before, in 2014, in the communication paper 'Towards a circular economy: A zero waste programme for Europe' (European Commission 2014). However, these targets were replaced by new and more ambitious ones, accompanied by concrete measures, in 2015 as part of the Circular Economy agenda of the Juncker Commission.

With this plan in 2015, the European Commission outlined its aim to support the EU's transition to a sustainable, low carbon, resource efficient and competitive economy (European Commission 2015). The circularity of economy was defined as "economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised" (European Commission 2015).

The expected benefits from implementing the circular economy were multiform (European Commission 2015):

Economic targets included boosting the EU's competitiveness and growth, creating jobs at all skill levels, creating new business opportunities and establishing innovative and more efficient ways of producing and consuming. Environmental targets set by the plan include protecting the Earth's resources, climate and biodiversity; saving energy; and reducing carbon dioxide emissions and air, soil and water pollution. The expected social impacts included social integration and cohesion.

With the first circular economy package, the European Commission is also aiming to increase policy coherence and implementation of the UN 2030 Agenda for Sustainable Development and the G7 Alliance on Resource Efficiency. The targets and expectations for circular economy represent the dimensions of sustainable development and the action plan has been mentioned as instrumental in achieving the Sustainable Development Goals (SDGs) by 2030, particularly Goal 12 of ensuring sustainable consumption and production patterns. (European Commission 2015)

The new regulatory framework set by the action plan was focused on revising the waste management directives. Targets included clarifying rules on by-products to facilitate industrial symbiosis and higher recycling targets for municipal and packaging waste. These were expected to help both in closing the material cycles and encouraging better product design.

Moreover, a set of incentives was provided in the action plan for key activities and sectors (as expressed by the European Commission 2015):

Promoting sustainable product design (ecodesign) to increase the reparability, upgradability, availability of spare parts, repair information, durability and recyclability of products, in general and specifically for electrical and electronic products, in future working plans and when updating the Ecodesign Directive.

Promoting environmentally and socially sustainable production, commitments and cooperation within the industry through policy dialogues, partnerships, trade and best available technique reference documents (BREFs) and the EU Eco-Management and Audit Scheme (EMAS).

Promoting sustainable consumption by prioritising quality and the amount of information available to consumers, supporting new business and consumption models financially, and providing economic incentives. The Product Environmental Footprint (PEF) methodology will be further developed and the effectiveness of the EU Ecolabel and Energy Labelling will be increased to cover, i.a. product durability and repairability. Circular economy criteria will be emphasised in Green Public Procurement (GPP). Member States are encouraged to provide incentives to implement economic instruments, such as taxation, to better reflect environmental costs in product prices. Horizon 2020 funding is used to support the creation of new business, e.g. sharing products and infrastructure.

Promotion of sustainable waste management is realised by sending long-term signals on prioritising prevention and reuse, increasing recycling by setting new recycling targets and producer responsibility schemes and returning waste back to the economy as valuable materials. All waste – whether generated by households, businesses, industry or mining – is taken into account.

Boosting the market for secondary raw materials and water reuse by improving knowledge on the quality of and possible impurities or chemicals of concern in secondary raw materials and their suitability for recycling. These targets are being worked towards by launching EU-wide work on quality standards for secondary raw materials (in particular for plastics), revising regulations on fertilisers, developing the Raw Materials Information System, supporting EU-wide research on raw materials flows, clarifying existing rules on ending the waste status of a waste material, and encouraging industry to make public commitments that ensure a certain level of recycled content in products they put on the market and public authorities to issue procurement policies that emphasise recycled material content. New legislation will be set up for minimum requirements for reused water for irrigation and groundwater recharge.

Priority area 1: Increasing plastic recycling is supported by setting new targets for plastic packaging recycling and by adopting a strategy on plastics, including aspects on recyclability, biodegradability, the presence of hazardous substances and marine litter.

Priority area 2: Avoiding and minimising food waste and the discarding of edible food is being tackled by aiming for the SDG goal set by the United Nations General Assembly of halving per capita food waste amounts and reducing waste in the production and supply chains. To support this goal, coherent monitoring and reporting procedures to measure food waste will be developed, a platform bringing together Member States and actors will be created, the Commission will support awareness-raising campaigns and clarify legislation to facilitate food donation, feed manufacturing and the use and interpretation of the 'best before' label.

Priority area 3: Increasing the recovery of raw materials that are economically important and supply disruptive (=critical) is being encouraged by preparing a report on best practices and options for suitable technologies and information exchange between (electronic product) manufacturers and recyclers. Additionally, landfills containing discarded electronic devices and mining waste are considered potential sources.

Priority area 4: Increasing construction and demolition waste recycling and the environmental performance of buildings is being encouraged through use of a mandatory recycling target, with guidelines on identification of waste that is valuable but also hazardous, separate collection and recovery for demolition sites, and developing indicators to assess environmental performance throughout the life cycle (design, durability and recyclability of components) of a building and promoting use of these indicators for building projects and guidance on GPP.

Priority area 5: Encouraging utilisation of the potential of renewable resources (biomass and bio-based products) is being implemented by setting targets for recycling wood packaging and ensuring the separate collection of biowaste. Biological resources can be used in a variety of applications, from products to energy use. The potential competition arising as a result of multiple use possibilities and the possible increased pressure on land use will be examined, guidance and best practices will be disseminated and the bio-economy strategy will be updated if necessary. A waste hierarchy is to be applied when deciding on the most appropriate utilisation option and order in the use chain.

Innovation, investment and other horizontal measures to promote systemic change require new technologies, processes, services and business models. Hence, research and innovation are being supported with Horizon 2020 funding, Cohesion Policy Funds, programmes like LIFE and COSME, the implementation of the Eco-innovation Action Plan and pilot innovation deals. For companies, the Green Action Plan for SMEs and the European Fund for Strategic Investments (EFSI) can provide support for creation of new business. The Green Employment Initiative will support the educational needs associated with new skills in job creation.

Monitoring of progress towards a circular economy is needed to assess progress towards a more circular economy and the effectiveness of actions. The Resource Efficiency Scoreboard (list of Eurostat (2020) indicators in Attachment 1) and the Raw Materials Scoreboard publication (part of the monitoring and evaluation strategy for the European Innovation Partnership (EIP) on Raw Materials (European Union 2018)) contain relevant indicators, which will be complemented in cooperation with the European Environment Agency (EEA) and member states. Newly developed indicators will encompass at least food waste, key raw materials, repair and reuse, waste generation, waste management, trade in secondary raw materials and the use of recycled materials in products, based on reliable existing data. (European Commission 2015)

1.1.2 Circular Economy Package 2018

In 2018, EU member states approved new measures for the future of circular economy, to prevent waste, increase re-use and increase recycling of municipal and packaging waste. The new measures also aimed at phasing out landfilling and efficiently promoting the use of economic instruments, such as Extended Producer Responsibility schemes. The timeframes for separate collection of hazardous waste, biowaste and textiles were added in the 2018 update, too.

The package published in 2018 also included the first documents promised in the circular economy package in 2015, including the EU Strategy for Plastics in the Circular Economy, a communication on options to address the interface between chemical, product and waste legislation, a monitoring framework on progress towards a circular economy, a report on critical raw materials and the circular economy, and a proposal for a regulation on minimum requirements for water reuse (European Commission 2019).

In 2019, the Commission announced that all the actions under the plan in 2015 have been delivered or were being implemented. In its announcement in March 2019, the European Commission reported that it had completely implemented the first circular economy package and published a comprehensive report on it. The report presented the main achievements and sketched out future challenges to shaping our economy and paving the way towards a climate-neutral, circular economy where pressure on natural and freshwater resources, as well as ecosystems, is minimised (European Commission 2019).

1.1.3 A new Circular Economy Action Plan

The new Circular Economy Action Plan for a Cleaner and More Competitive Europe 2020 is defined as Europe’s new agenda for sustainable growth (European Commission 2020b). Therefore, sustainability remains a strategic policy target in the EU. In the Plan (European Commission 2020a) is stated that half of all greenhouse gas emissions and more than 90% of biodiversity loss and water stress are as a result of resource extraction and processing. The European Green Deal aims to be a concerted strategy for a climate-neutral, resource-efficient and competitive economy. “Scaling up the circular economy from front-runners to the mainstream economic players will make a decisive contribution to achieving climate neutrality by 2050 and decoupling economic growth from resource use, while ensuring the long-term competitiveness of the EU and leaving no one behind” (European Commission 2020a). The goal is to have a regenerative growth model that gives back to the planet more than it takes, keeping its resource consumption within planetary boundaries by reducing the consumption footprint and doubling the circular material use rate by 2030 (European Commission 2020a). The need for a transition to a circular economy is defined as "systemic, deep and transformative, in the EU and beyond" but also disruptive at times, "so it has to be fair" (European Commission 2020a). Hence, in parallel with decreasing environmental impacts and aiming for sustainable economic growth, the need to control social impacts is therefore included in the main goals.

The new Action Plan 2020 presents possibilities, measures and actions for businesses and citizens.

The new Action Plan announces initiatives throughout the entire life cycle of products, targeting, for example, their design, promoting circular economy processes, fostering sustainable consumption, and aiming to ensure that the resources used are kept in the EU economy for as long as possible (European Commission 2020b).

It introduces legislative and non-legislative measures targeting areas where action at EU level brings real added value. The new Circular Economy Action presents the following measures (as expressed by the European Commission 2020a):

- **Designing sustainable products**
  Up to 80% of products' environmental impacts are determined at the design phase. In order to make products more sustainable in the future, the legislative initiative is to widen the Ecodesign Directive beyond energy-related products. The Commission will also establish a common European Dataspace for Smart Circular Applications. Sustainability principles and other appropriate means will be used to regulate improved product durability; reusability; upgradeability; reparability; resource efficiency; recycled material content; remanufacturability; recyclability; and decreased use of hazardous chemicals, carbon and environmental footprints, single-use, premature obsolescence and destruction of unsold durable goods. A further target is to incentivise product-as-a-service or other models where producers retain ownership of the product throughout its life cycle and mobilise the digitalisation of product information (digital passports, tagging and watermarks). Priority products are electronics, ICT, textiles, furniture, steel, cement and chemicals. (European Commission 2020a)
- **Empowering consumers and public buyers with sustainability information**
  To enhance the participation of consumers in the circular economy, the Commission will ensure that consumers receive trustworthy and relevant information on products and their lifespan and repairability. New minimum requirements are being set for the use of sustainability labels/logos and information tools such as the Environmental Footprint and EU Ecolabel. The Commission will also propose minimum mandatory green public procurement (GPP) criteria, targets and monitoring in sectoral legislation. Public authorities' purchasing power represents 14% of gross domestic product (GDP) in the EU and can serve as a powerful driver of demand for sustainable products. (European Commission 2020a)
- **Promoting circularity in production processes**
  The Commission aims to facilitate greater circularity in industry in the context of the Industrial Emissions Directive and Best Available Techniques reference documents, by developing an industry-led reporting and certification system, and promoting the use of digital technologies for mapping resources and verifying technologies. (European Commission 2020a)
- **Focusing actions on the most resource intensive sectors with the greatest circularity potential**: **electronics and ICT** – new regulatory measures to facilitate durability, reparability, upgradability, maintenance, reuse and recycling, as well as facilitating a common charger and restricting hazardous substances;

Batteries – rules on recycled content, transparency of carbon footprint, ethics, supply security of raw material sourcing, and facilitating reuse and recycling.
Vehicles – linking design issues to end-of-life processing, considering mandatory recycled content, promoting product-as-service solutions.
Packaging – target setting and other waste prevention measures, driving design for reuse, recyclability and reducing the complexity of materials and material variation, assessing the feasibility of EU-wide recycling labelling, promoting use of tap water.
Plastics – consumption is expected to double by 2040. Considering mandatory recycled content, reducing littering and microplastics by developing labelling, standardisation, capture and measuring, and assessing the sustainability of alternative materials like bio-plastics.
Textiles – the fourth highest-pressure category of primary raw materials and water and the fifth for greenhouse gas (GHG) emissions, recycling rate < 1%. New strategy for textiles, strengthening the EU's competitiveness and sustainable and circular textiles. Developing ecodesign, uptake of secondary raw materials, avoiding hazardous chemicals, supporting product-as-service models, circular materials and production processes, boosting sorting, re-use and recycling and producer responsibility schemes.
Construction and buildings – accounts for about 50% of all extracted material, over 35% of the EU's total waste and 5–12% of country-specific GHG emissions. New regulation on construction products and recycled content. Promoting digital logbooks for buildings, integrating LCA into public procurement, assessing carbon reduction target setting, revising material recovery targets and excavated soil utilisation.
Food, water and nutrients – circular economy can contribute to restoring biodiversity and natural capital. It is estimated that approximately 20% of the total food produced is lost or wasted in the EU. New targets for food waste reduction, regulation encouraging reuse of water in agriculture and industrial processes and stimulating recovered nutrients markets. (European Commission 2020a)

- **Minimisation of waste amounts and hazardousness –** Amounts of waste are growing and decoupling waste generation from economic growth requires considerable efforts. The implementation of modernised EU waste laws must be strengthened, new reduction targets will be set, and separation and collection systems harmonised. Efforts will be made through information campaigns etc. to support member states in reducing waste amounts and toxicity. Developing sorting and data tracking systems in synergy with the ECHA, i.a. in the forthcoming Chemical Strategy for Sustainability. (European Commission 2020a)
- **Creating a secondary raw material markets** – Measures for overcoming challenges to compete with primary raw materials in safety, performance, availability and costs: requiring recycled content in products, developing EU-wide end-of-waste and by-product criteria and standardisation, making 'recycled in the EU' a benchmark for qualitative secondary materials and restricting exports of harmful waste outside the EU. (European Commission 2020a)
- **Make circularity work for people, regions and cities –** Between 2012 and 2018 the number of jobs linked to the circular economy in the EU grew by 5% to around 4 million. Circularity can have positive net effects on job creation, if workers have the skills required for the green transition. New plans – the Skills Agenda, the Pact for Skills and the Action Plan for Social Economy – and the European Social Fund Plus will ensure the transition to a circular economy. Regions are supported with Cohesion Policy funds to implement circular economy strategies and carry out awareness-raising, cooperation and capacity building and reinforce value chains. Funds are also

harnessed to support necessary investments and projects. The European Circular Economy Stakeholder Platform will offer stakeholders a place to exchange information and the Circular Cities and Regions Initiative will assist in this. (European Commission 2020a)

- **Political coherence on sustainability – circularity, climate neutrality and economy** – In order to achieve climate neutrality, the Commission will analyse how to measure and model the impacts and benefits of circularity on GHG emissions and mitigation and adaptation measures and strengthen the role of circularity in relevant climate policies. Moreover, the regulatory framework of carbon removal actions, accounting and monitoring will be developed to increase carbon circularity, in full respect of biodiversity objectives. (European Commission 2020a)
  To support sustainable economy and more sustainable production and consumption patterns, the Commission has included a circular economy objective in the EU Taxonomy Regulation, prepared EU Ecolabel criteria for financial products and offered SME guarantees to mobilise financing in support of the circular economy. In the future, companies will be encouraged to transparently publish environmental data and environmental accounting on circular economy performance and to integrate sustainability criteria into business strategies. Member states are encouraged to apply environmental taxation measures, such as value added tax (VAT), to activate circular economy business that targets final consumers, especially repair services. (European Commission 2020a)
- **Leading global efforts on circular economy** – the circular policy will be a success only if its efforts also drive the global transition to a just, climate-neutral, resource-efficient and circular economy. To support a global shift, the Commission will build the European Plastic Strategy, propose a Global Circular Economy Alliance to identify knowledge and governance gaps, define a 'Safe Operating Space' and launch an international agreement for use of natural resources. (European Commission 2020a)
- **Monitoring progress** – the Commission will reinforce the monitoring of national plans and measures to accelerate the transition to a circular economy and integrate a stronger sustainability dimension. The Commission will update the Monitoring Framework for the Circular Economy. New indicators will take into account the previously mentioned focus areas and interlinkages between circularity, climate neutrality and the zero-pollution ambition. Indicators on resource use, including consumption and material footprints will be further developed and linked to assess the progress towards decoupling economic growth from resource use and its impacts in the EU and beyond. (European Commission 2020a)

In the 2020 Circular Economy Action Plan, the European Commission encourages all EU institutions and bodies to actively contribute to the implementation of the Action Plan and to adopt and update national circular economy strategies, plans and measures (European Commission 2020b). This report gives an example of its implementation at in the regional level.

1.2 Strategic implementation in Finland

1.2.1 Leading the cycle – the Finnish road map to a circular economy 2016–2025

Work on implementing the circular economy policy and actions in Finland started in 2016. The work was coordinated by the Finnish Innovation Fund Sitra but was carried out in close co-operation with the relevant ministries – the Ministry of the Environment, the Ministry of Agriculture and Forestry and the Ministry of Economic Affairs and Employment – as well as with the business sector and other key stakeholders. This cooperation has resulted in what has become known as the world's first national circular economy road map.

Leading the cycle – the Finnish road map to a circular economy 2016–2025 aimed at the kind of substance that is needed to consolidate a new concept. Finland's circular economy road map states that it describes the concrete actions that can accelerate the transfer to a competitive circular economy in Finland. It highlights best practices and pilots that are easily replicable and provide added value on a national scale. (SITRA 2016a) The first roadmap highlights in particular the economic potential of circular economy policies: "Tangible actions for growth, investments and exports are emphasised" (SITRA 2016a) and with this policy, creating tens of thousands of new jobs and generating billions of euros in added value each year are considered achievable (SITRA 2016b). "The driving force for the circular economy road map work was to turn the circular economy into a driver of growth, investment and export for Finland." (SITRA 2016a)

The vision and the upper-level targets of the road map are summarised as follows:

Economy: The circular economy will be a new cornerstone of the Finnish economy. The circular economy will improve competitiveness; create new business, companies, export and jobs; increase turnover and lead to new innovations. This change will be supported by public procurement, new private and public sector co-operation and financing instruments. The state of the environment will also be improved.

Environment: Finland as a model country for the challenge of scarcity. Resource efficiency will improve, material cycles will become more efficient, non-renewable natural resources will be replaced by renewables, and society will approach a carbon neutral and waste-free state. Ecological sustainability will be improved, and emissions decreased.

Society: From adapter to pioneer. The circular economy is taken into account when planning social actions. Strong cooperation between the public, private and third sectors (public-private partnerships, PPP). A bold and enabling trial-oriented approach will be adopted and investments made in education. Circular economy will create well-being in Finland and promote the transition to a service and sharing economy. Consumers will give rise to renewal of domestic market demand for circular economy products and services, including shared and recycling services.

Key policy actions and targets were formulated for five focus areas, based on Finland's traditional strengths. The key areas were chosen from the ideas collected from Finns representing many different sectors – trade unions, organisations and the corporate field, ministries and research organisations, environmental organisations, consumers and other stakeholders – during the road map process. The need for co-operation across sectoral and industrial boundaries was underlined in the roadmap process by bringing together over 1,000 participants at stakeholder events.

The actions in the different focus areas are divided into three levels: policy actions, key projects and pilots. The road map is designed to be agile and develop over time, focusing on practical actions and continuous systemic change. The content will be monitored, developed and updated during the process. The five interlinked focus areas are: 1) a sustainable food system, 2) forest-based loops, 3) technical loops, 4) transport and logistics, and 5) joint actions. Policy actions related to these focus areas include (SITRA 2016a):

For a **sustainable food system**, the key policy actions identified include creating a market for organic recycled nutrients, minimising food waste by eliminating barriers and creating incentives, and supporting biogas systems and other renewable energy solutions to replace fossil fuels in agriculture.

In **forest based loops**, the policy actions include making the main target of the national forest strategy the overall value of Finnish forest-based products and services, rather than maximising the amount of wood; encouraging the use of wood-based and other products made from renewables in public procurements; supporting investments aimed at demonstrating bioproducts and bioservices on a commercial basis; creating incentives to develop Finnish wooden construction and the wooden design furniture and interior design sector.

The **technical loops** focus area has several policy actions: Promoting the use of secondary raw materials, incorporation of waste act interpretation and streamlining the environmental permit procedure. The goal must lie in utilising secondary raw materials, such as industrial side streams, as effectively as possible by actively seeking uses for side streams instead of allowing them to become waste. Use of the side streams produced during the project, such as surplus soil, should be planned and described in the environmental impact assessment and environmental permit processes. Ecodesign requirements should also be included in product design and construction and in the material development phase.

In the **transport and logistics** focus area, the policy actions needed include: Developing incentives and policy instruments to accelerate a radical change towards a more service-based transport system. Developing tax and other steering to support the end of fossil fuel use in private cars by 2040. Promoting the implementation of biofuels produced in a sustainable manner.

The common **joint actions** identified include the following policy actions: Public procurements should focus on purchasing new solutions and products that support the circular economy. An education and research policy that facilitates the circular economy. Dismantling regulation barriers and creating incentives. Changing the focus of taxation. Guidelines and synergies with initiatives in other parts of administration. A digital and service-centred circular economy. Circular economy indicators. (SITRA 2016a)

The communication style used in launching the circular economy strategy in Finland was new. The targets behind the strategy are implementing the EU policy to tackle severe and critical threats in terms of sustainability loss, climate change and overusing natural resources, but the messages were presented in a positive and uplifting style and by exploiting social media to create the phenomenon ‘positive buzz’. Emphasis was placed on good opportunities and good news and the messages were also formed into a (success) story: Finland as a forerunner and Finland as the first creator of the Circular Economy Roadmap. “The target of the Finnish government and the road map is to make Finland a global leader in the circular economy by 2025.” (SITRA 2016a) The target of making Finland a bio and circular economy and cleantech forerunner was also a strategic target set by Juha Sipilä’s Government in 2015. So there was a clear difference compared to, for example, the dominant climate change policy reportage that was fact and anxiety oriented and producing serious messages on rising temperatures and sea levels. Probably due to the wide-ranging cooperation work and strong visibility work, the Circular Economy Roadmap has become a very well-known and much-discussed national tool, both in Finland and abroad, making it highly successful in fulfilling the expectations for implementing an EU strategy.

1.2.2 Finland’s road map to a circular economy 2.0

The Circular Economy Roadmap was planned in an agile manner and the work on updating the Circular Economy Roadmap of Finland continued in autumn 2018. The target set was to update the steps towards a carbon neutral circular economy. The aim was to raise the level of the targets and ambitiousness, strengthen Finland’s international role as a forerunner, identify long term needs and means for change, and introduce new measures for different actors and sectors for promoting circular economy. (SITRA 2019a)

The results of the updating process gave four strategic targets:

1) **Renewal of the foundations of competitiveness and vitality**, to bring the circular economy solutions into the centre of competitiveness and economic growth strategy.

2) **Transition to low-carbon energy and raising the level of ambition** in climate and energy policy.

3) **Natural resources are regarded as scarcities.** To achieve the targets of the Paris Climate Agreement, Finnish consumption and production cannot be based on unlimited use of natural resources.

4) **Everyday decisions working as a driving force for change.** Cutting our carbon footprint by half by 2030 from the level in 2010 requires a new attitude towards ownership, in culture, taxonomy and income distribution.

The New Circular Economy Roadmap – 'The critical move – Finland's road map to the circular economy 2.0' is a wide-ranging and updated document that provides challenges and stimulation for both the public and private sector as well as citizens. (SITRA 2019a) The examples are divided into different categories: for municipalities and regions, the government, companies and citizens. The aim of the new circular economy road map is to emphasise that each of us is responsible and part of the solution and can influence achievement of circular economy targets.

The updated Circular Economy Roadmap 2.0 also introduces how advances made in the circular economy can be monitored. As stated in the report, many circular economy phenomena take place within enterprises, outside the old systems and at interfaces or between individual citizens. Therefore, no data has been gathered on all sub-areas of the circular economy.

Monitoring of circular economy is a challenge that has also been worked on in the EU. The EU has grouped the actions into four phases of circularity: production and consumption, waste management, secondary raw materials, and competitiveness and innovation (SITRA 2019a).

As part of its 2018 Circular Economy Package, the Commission published a set of circular economy indicators, which extensively describe the transition towards a circular economy within the EU. The objective is that the indicators mainly provide information on the developments taking place in the maintenance of the financial value of products, materials and resources and the generation of waste. The European Statistical Office Eurostat updates and publishes the indicators on a regular basis and continues to develop them in collaboration with other EU institutions and member states. (SITRA 2019a)

The roadmap includes also proposals for indicators, based on previous work on key indicators for green growth (SITRA 2019a):

- the proportion of national added value related to circular economy business
- monitoring of patent applications related to the circular economy
- monitoring the resource productivity or the added value obtained through the expenditure of unit resource (comparing the GDP to national material consumption)
- total raw material consumption (RMC) by material categories and the proportion renewable raw materials account for of total consumption
- the volumes and reuse of industrial, construction and municipal waste
- the proportion renewable and low-carbon energy account for of final use and
- monitoring the carbon footprint of the average Finn.

1.2.3 Scientific policy discussion on demand for quantitative goals

The policy brief published by SYKE on circular economy (Berg et al. 2019) represents the national activity in Finland for implementing the circular economy. In the policy brief, SYKE is particularly keen on the establishment of quantitative targets for reducing the use of natural resources. It is also suggested that such targets are aimed in particular at branches of industry that consume large amounts of natural resources, such as construction, the process industries, and the food chain. Berg et al. also demand that it is established which industries could be required to use more recycled material than they do now. In particular, industries using rare and critical metals, such as the electrical and electronics and battery industries, should undergo a transition to circular economy. Although the larger resource users are known, more information is needed on material flows and material stocks, as well as the ecological, economic, and social effects of a circular economy. The goals could be measured through, for example, the ratio of raw material consumption to GDP, the proportion of circular-based economy of the entire national economy, and the proportion recycled raw materials account for all raw materials used in industries that consume large amounts of natural resources and critical natural resources. Because the transition to a circular economy requires extensive structural changes, it is important to assess the effectiveness, economy and social aspects of policy instruments as a whole – the benefits must be shared fairly in Finland and globally. As circular economy is linked with the community structure and land use, the impact of circular economy on biodiversity needs to be assessed too. High-quality and open data reserves are required for the management of a circular economy, as well as research on information on consumer needs and circularity characteristics of products. (Berg et al. 2019)

One of the key suggestions is to establish a deposit fee system based on voluntary agreements for key material flows and product groups, such as electronics industry products. Moreover, legislation could be used to promote a longer operational life for products in the form of longer warranty periods and quality standards on easier product repairability and updatability. (Berg et al. 2019)

Public procurers are seen as key players in the transition to a circular economy: Public procurers can serve as circular economy pioneers and developers and offer companies opportunities to test circular economy solutions. Stronger commitments to procurements that advance a circular economy are required. (Berg et al. 2019)

1.2.4 Promoting circular economy in industry and commerce

Sitra published the Circular Economy Playbook (SITRA 2018) on circular economy business models for Finnish SMEs in the manufacturing industries in 2018. Firstly, the book seeks to understand the advantages and value potential that the supporting circular economy has – for example exchanging the direct and indirect use of non-renewable and fossil materials for renewable or bio-based alternatives, increasing operating hours or utilising full product functionality, exploiting potential for repair and maintenance, increasing the material recovery of disposable materials and focusing on solving customer problems and engaging with them throughout the product life cycle. The book guides companies in identifying and prioritising suitable circular business models, the organisational capabilities required, and customer-centric and sustainable design. (SITRA 2018)

SITRA has also listed the most interesting initiatives taken by municipalities to support the circular economy (SITRA 2018b). The work is similar to the work of EIT Climate-KIC (2018), aiming to give visibility to municipality-led success stories. SITRA's list presents examples for all the municipalities in Finland, with these examples gathered through a competition. The initiatives included reusing furniture, donating food to social work initiatives and the unemployed, the ecopass for pupils for documenting sustainable everyday life examples, citizen-based strategy development and circular economy-oriented planning and construction.

In 2020, a broad-based working group entitled the Strategic Programme for Promoting the Circular Economy was coordinated by the Ministry of Environment together with SITRA. This work was established by Prime Minister Sanna Marin's Government with the goal of strengthening Finland's role as a trailblazer in the circular economy with concrete measures during 2020. The vision of the programme is for the economic success of Finland in 2035 to be founded on a carbon-neutral circular economy society. "The strategic programme to promote a circular economy sets out objectives for the use of natural resources. It sets the objectives and indicators, specifies the measures to be taken and allocates the resources needed to promote the circular economy and achieve systemic change." (Ministry of the Environment 2021). The programme was prepared as a collaborative effort between ministries, research institutes, the Finnish Innovation Fund Sitra, Business Finland, and several companies and municipalities, committing the main operators and industries in Finland to its objectives. The work was completed and published in January 2021. The programme includes the following three steps and targets for Finland (Valtioneuvosto 2021):

- By 2035 the use of primary domestic raw materials will not exceed the level of 2015.
- Resources productivity will double by 2035 compared to 2015.
- The circular material use rate (CMU) will double by 2025.

1.3 The National Waste Plan (NWP) and the circular economy

The Finnish NWP, ‘From Recycling to a Circular Economy – National Waste Plan to 2023’, includes both the Waste Plan as required by article 28 of the Waste framework Directive 2008/98 and the Waste Prevention Programme as requested by article 29 (Ministry of Environment 2018).

As the NWP points out, the plan will steer Finland towards a circular economy only with respect to waste management. Therefore, it is evident that measures far beyond those presented in the Plan will also be required to achieve a circular economy. By developing waste management practices, the outermost value circle, recycling, of the well-known circular economy system diagram (Ellen MacArthur Foundation 2017a) can be optimised. Additionally, the core principles and targets of a circular economy – to avoid use of natural resources and create value added from services – at the same time help to put into practice the core target of the waste legislation: preventing waste.

In Finland, the target defined for 2030 in waste management and in reducing the quantity and harmfulness of waste includes seven goals:

1. High-standard waste management is part of a sustainable circular economy.
2. Material-efficient production and consumption save natural resources and mitigate climate change.
3. Volumes of waste have decreased from the present. Reuse and recycling have risen to new levels.
4. The recycling market works well. Reuse and recycling create new jobs.
5. Valuable raw materials present at low levels are also recovered from recycled materials.
6. Material cycles do not cause harm and less and less hazardous substances are used in production.
7. In the waste sector high-quality research and experiments are underway and competence in waste issues is at a high level.

The four key waste streams in Finland’s NWP for 2023 are construction and demolition waste (C&DW), biodegradable waste, municipal solid waste (MSW), and waste electrical and electronic equipment (WEEE). These were selected due to the particular challenges in reducing the quantity and harmfulness of waste and in promoting recycling in the coming years. Packaging waste is addressed as a part of MSW. Additionally, prevention of litter pollution has been included in the NWP to cover important topics in the EU’s Circular Economy Package.

Finland’s NWP aims at increased sustainable and safe use of resources and the advancement of environmental protection. The implementation of the plan has been evaluated as having a positive effect in terms of decreasing waste volumes and increasing the level of recycling. The measures in the NWP will promote environmental awareness and expertise relating to the circular economy and waste. Realisation of the plan will also create conditions and opportunities for introducing new circular economy approaches and economically viable business concepts. (Ministry of Environment 2018). The plan will be updated in 2021.

2 Framework of the Circwaste project: cooperation for implementing circular economy

Essential requirements for implementing the circular economy through a project include long-term commitment and financing and comprehensive cooperation and information dissemination and exchange in order to achieve system-level changes.

Circwaste is a SYKE-coordinated seven-year LIFE IP project that promotes circular economy and aims to implement the NWP. It also aims to minimise the use of natural resources and advance the efficient use of material flows, waste prevention and new resource and waste management concepts. In the consortium, over 20 partners are executing the project to achieve the targets. On top of that, networks outside the core consortium, namely a project advisory group, forerunner municipalities network and complementary action cooperation are supporting achievement of the targets. The project has been structured to maximise information exchange and the effectiveness of sharing the results and best practices nationally and internationally. An expert network lead by SYKE is guiding the activities. The expert network, project management group and regional coordination in each project area are important parts of the project methodology and have occupied a key role in facilitating interactions between partners and regions and enhancing capacity building. Communication and dissemination activities play a very significant role in identifying relevant data and organising and scheduling the distribution of the information. The framework for executing a circular economy with a project is described in Figure 1.

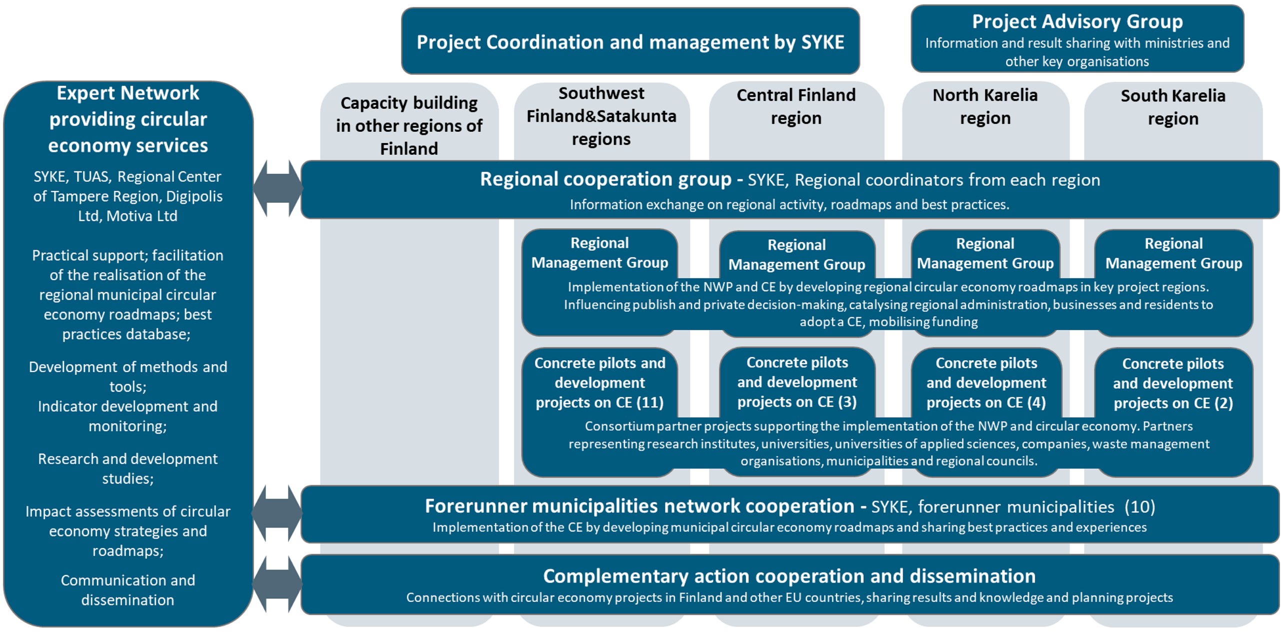


Figure 1. Framework of the circular economy implementation project Circwaste.

2.1 Expert network on circular economy

In order to support the circular economy and implementation of the NWP, an expert network on circular economy has been formed by SYKE together with partners specialising in public procurement, facilitation of events and networking with circular economy related companies: Turku University of Applied Sciences (TUAS), the Council of Tampere Region (CTR) and Digipolis Ltd. The expert network is focused on disseminating the results and analysing the development and impacts nationally and caused by the project itself. The network provides expert services and spreads information on successful solutions. In practice, the network offers practical support and tools for assessing environmental impacts and cost effects (including life cycle assessment (LCA) and input-output-models) and develops indicators. The network identifies, collects and shares good circular economy practices from the regions, shares information on current activities and answers questions related to facilitation of the roadmap process. Facilitation includes support through the whole process, from the beginning to finishing the roadmaps. The expert network also provides information regarding factors such as material-efficient procurement, hazardous substances, industrial symbiosis, and finding funding for new initiatives – all key elements also identified by the EU action plan.

2.2 Regional cooperation and regional road maps

The Circwaste project has placed the operational emphasis on five geographical regions that have committed to implementing the circular economy. These regions are Southwest Finland, Satakunta, Central Finland, North Karelia and South Karelia. In these areas, the regional coordinators have brought together key regional stakeholders and formed cooperation groups that are working to implement circular economy and the NWP at a regional level.

The regional groups have created circular economy roadmaps that set the goals and necessary activities for decreasing amounts of waste, improving material efficiency, utilising industrial by-products, etc. Most importantly, the groups are catalysing new actions and R&D projects as well as activating and supporting locals in establishing the most effective activities and reducing waste.

The aim of the regional road maps is to identify regional needs, know-how and the relevant actors and to introduce measures related to the circular economy, considering the special features of the region, as identified by the actors in the region. Both the NWP and the roadmap were used to support the selection of priorities and objectives. One of the purposes of the regional roadmap was to implement the objectives of the NWP. Regional roadmap work highlights and generates new best practices and pilots, as well as disseminating information on existing ones.

The regional coordinators were responsible for preparing each roadmap. The regional co-operation group acted as a steering group for the preparation, with experts from the Circwaste Expert Network supporting regional groups in preparing roadmaps and also later in assessing impacts.

The expert network on circular economy facilitated building the regional road maps by offering:

- design assistance for the roadmap work process
- gathering of regional data
- facilitation of workshops and conferences
- on-the-spot expert assistance and facilitation
- support and feedback on written road map drafts
- networking and mediating on the flow of information between regions
- communicating roadmap work to the public.

The work phases of the regional circular economy road map can be divided into background work, preparation of the target, and measures. The proposal for the rough implementation of the work steps and content are presented in Figure 2 below. Formation of objectives and measures are interlinked, and measures were identified during the selection of objectives and vice versa.

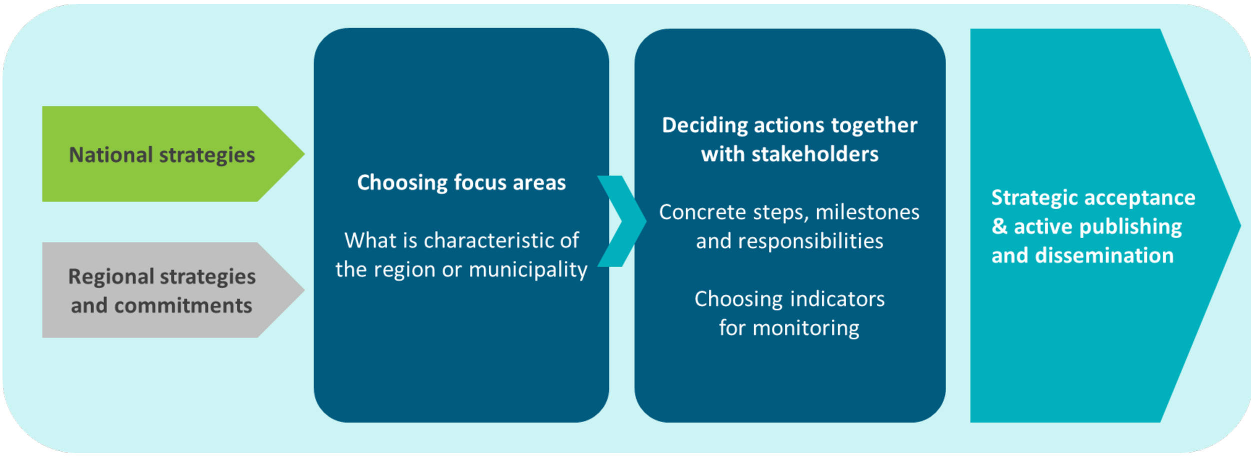


Figure 2. Process for formulating the Circular economy roadmap.

Regional road maps follow a specific framework (target status, objectives, measures), but may differ, for example, in terms of priority areas. Regions will update their road maps during the project by adding new themes and actions. Road maps also contain visions for the development beyond the project timeframe, ensuring long-term effectiveness. The focus areas and key objectives of the four regional road maps are presented in chapter 3.4.

2.3 Concrete regional pilots

The Circwaste project puts into practice demonstrations and pilot plants and carries out studies and trials. The nature of the project actions varies from development, testing, preparatory studies, demonstrations, pilots and diffusion of policy and management approaches to best practices and solutions to tackle the short- and long-term challenges of the implementation of the circular economy and the NWP.

Each of these actions bring concrete results, such as decreasing the amount of waste or used material flows, setting up new equipment or intelligent management systems and creating new practices. There are seven key target sectors in the project: agriculture, construction, large-scale food production, wood and metal industry, SMEs, services, households, earthwork and the public sector (namely municipalities/cities and development companies, regional councils and hospitals). Project actions have been divided into six thematic focus areas: resource efficiency in construction, utilisation of industrial waste and side streams, utilisation of biodegradable waste, utilisation of soils, digitality and logistics, and regional and strategic co-operation. In the actions, the targets are to recycle and reuse plastics, increase material efficiency in hospitals, increase biogas production, promote nutrient recycling, increase soil reuse, prevent surplus food, productise food industry waste, develop innovative waste collection systems to increase recycling, develop digital storage management systems to prevent material losses, etc. Some actions include counselling and education and facilitating the creation of industrial symbiosis, for example. Concrete pilots and their description are described in Table 1.

Table 1. Regional pilot projects and the benefiting industry, project description, and the executing partners and the regions.

Benefiting industry	Project description and objectives	Partner sector/Target region
Construction	Developing resource-efficient construction and housing that takes into consideration all phases of building of a new residential area.	Municipality/Southwest Finland
	Developing sorting and recycling of construction and demolition waste at construction sites.	Municipal waste company/North Karelia
Earthwork	Developing a soil recycling park and regional operations in soil recycling.	Municipality/Southwest Finland
	Testing use of industrial waste and contaminated sediments in the construction of a coastal bay.	Consultant/Southwest Finland
	Developing the use of recycled materials in highway construction.	Consultant/Southwest Finland
	Building test fields for infrastructure application for foundry sand waste.	Municipality/Southwest Finland
Large-scale food, wood and metal industry	Developing and piloting resource-efficient production, distribution and use of food and minimising food waste.	Research institute/Finland
	Developing improved distribution and rechannelling of food to reduce food waste.	Research institute/Finland
	Demonstrating applicable technologies for utilisation of by-products in vegetable processing.	Research institute/Finland
	Searching for, modelling and testing sustainable utilisation methods for wood-based, agricultural, metal industry and food industry by-products.	Municipal development company/North Karelia
Agriculture	Promoting biogas production from organic by-products and improving nutrient recycling in the food system.	Research institute/Finland
	Developing tools and supporting farmers in establishing farm-scale biogas plants and promoting recycling.	University of applied sciences/Southwest Finland
	Description of a regional waste system and creating utilisation scenarios for plastic granules and pellets.	University of technology/North Karelia
Creating new circular economy SMEs	Promoting new circular economy business opportunities and supporting circular economy start-ups in regionally identified key sectors.	Municipal development company/North Karelia
	Building a pilot plant for waste fraction composite manufacturing and developing the business idea.	Company/South Karelia
	Demonstrating of separation of magnets from scrap metal and production of recycled magnets.	Municipal development company/Southwest Finland
Services	Creating a digital management ecosystem for decreasing waste and material losses throughout the fast-moving consumer goods storage and supply chain.	Company/Finland
Public sector (municipalities/cities and development companies, regional councils and hospitals).	Designing and building smart waste collection solutions in urban areas.	Municipality/Central Finland
	Creating an 'expert and advisory network' to enhance circular economy among NGOs, companies, public administration, schools and residents.	Municipality/Southwest Finland
	Collecting ideas from citizens and carrying out practical experiments to enhance municipal waste prevention, recycling and other aims of circular economy.	Municipality/Central Finland
	Planning resource efficient waste management in hospitals.	Municipality/Central Finland
	Facilitating the advanced use of regional biowaste streams by increasing awareness of novel waste management practices.	Regional council/Central Finland

2.4 **Forerunner municipality network and road maps**

The most important stakeholder network is formed by the project are the forerunner municipalities. Municipalities are powerful partners with huge potential to implement effective measures to increase circular economy activity and waste recycling.

With strategic commitments, the municipalities have engaged in ambitious and concrete efforts in their regions and aiming to regionally achieve the goals of the NWP by recycling at least 55% of municipal waste, using at least 70% of construction and demolition waste for material recovery and reducing the overall waste volume.

Municipalities have committed to a wide range of means to promote the circular economy, such as establishing new business operations, activating residents in the area and forging new cooperation arrangements with a variety of operators.

The pioneer municipalities will also plan and publish municipal road maps to a circular economy. Some of these municipality road maps are already finished, some are still under construction. In road map work, it is important to identify local strengths, special characteristics and challenges, as well as to activate the residents of the area.

Road maps specify the municipality's circular economy goals and the practical measures for achieving them. The municipalities invest in practical measures such as resource efficiency in construction, waste management counselling and reduction of food waste. This type of work can create new circular business opportunities for the municipality while building new types of partnerships with various operators and promoting the social well-being of the municipal residents as the opportunities provided by the sharing economy increase, for example.

In the Circwaste project, ten Finnish municipalities form the forerunner municipality network: Ii, Jyväskylä, Kuopio, Lahti, Lappeenranta, Porvoo, Riihimäki, Rovaniemi, Turku and Vantaa.

There was a public application procedure for the forerunner network and the pioneer municipalities were selected from among some 20 applicants. The choice was made based on the commitments (chapter 3.2.3) that the municipalities made in the application phase and the measures undertaken so far.

2.5 **Complementary projects and municipalities**

Exchange of information and experiences amongst research and development projects is highly important as the number of projects increases and more funding is directed to research on this topic. Ensuring the spread and exploitation of all relevant knowledge and information produced is a challenge, but also a huge opportunity.

A large national project, such as Circwaste, can act as a platform for sharing information. Similar projects may be running in different parts of the country, yet connections between the projects may remain remote. A large project can contribute to the publicising of knowledge by gathering information on different projects nationally, as well as internationally, and inviting different researchers to come together at events to present their results and to create new connections.

Since the beginning of the project in 2016, over one hundred circular economy research and development projects have been launched in Finland, with the total budget exceeding EUR 81 million (for more information on this, see Chapter 4.4.2). Most of the projects are thematically broad and touch on several aspects, and some of these projects have been directly inspired by Circwaste.

The municipal authorities are working together with research institutes and experts to devise and tailor new, cost-effective solutions. The expert network facilitates knowledge exchange in particular regarding good practices in circular economy, decreasing the amount of waste or materials used, setting up intelligent management systems and creating new practices and strategies. Information about new tools and ideas is promoted in Finland and internationally.

The municipalities promote circular economy in their regions. They establish new business operations, activate residents in the area and initiate new cooperation between different operators.

2.6 Communication and dissemination work

Good and active dissemination and communication might be the most important task when the target is to achieve system-level changes by influencing and providing data to policy makers, municipalities, citizens, the education sector and industry. This ambitious level of communication is realisable in wide-ranging and long-term projects like Circwaste. Dozens of partners and actions are involved, producing interesting new results from different areas of circular economy. Disseminating these results nationally and within the consortium gives meaning and volume to this valuable research work. The consortium also benefits from receiving information that is as up-to-date as possible on activities and results of other projects in Finland.

One of the main tasks of the Circwaste project has been to define the communicative objectives and to build a sustainable communicative infrastructure, along with the content production processes. Partners' own communications play a vital role in supporting the dissemination and the circulation of the messages.

The entire communicative infrastructure of the Circwaste project functions as a comprehensive system, with each communication product being considered part of an overall concept, with several channels. These channels and their target groups and follower activity are listed in Table 2. The core of the communication infrastructure is the www.materiaalitkiertoon.fi and www.circwaste.fi websites, which is used to present actions, general circular economy content and activity in Finland in general. The webpage is the most important way for the expert network to disseminate the latest news and studies on circular economy, information on upcoming events and funding opportunities. It also supports the expert network's sub-action. All the results, tools, infographics and other project materials can be found through the webpage. The Materiaalitkiertoon.fi webpage also collects and presents information from outside the project.

Social media channels such as Twitter and Facebook can be used for teasers and incentives to get to know the online service where all the communication materials produced in the project are collated.

The Circwaste regions have created wide-ranging networks during the project. They have arranged a lot of activities in the form of events, seminars and workshops and therefore also reached citizens and circular economy operators in the region. Every region has created their own strengths and dissemination focuses and the aim for project communications is to maintain a constant flow of news to keep all followers interested.

Table 2. List of communication products and target groups.

Communication product	Target group	Followers	How to find it?
The project's webpage materiaalitkiertoon.fi	The Circwaste consortium, experts on circular economy, policymakers, municipalities, regions	13,000 visitors/year	https://materiaalitkiertoon.fi/en-US
Newsletter CIRCnews	Citizens and all those interested in the circular economy	530	https://materiaalitkiertoon.fi/fi-FI/Ajankohtaista/Tilaa_Circnews/Uutiskirjeet
Circblog	The Circwaste consortium, experts on circular economy, municipalities, regions	on average 100–150	https://materiaalitkiertoon.fi/en-US/Current/Circblog

Communication product	Target group	Followers	How to find it?
Circwaste magazine I	The Circwaste consortium, experts of circular economy, regions	5,655	https://epaper.fi/read/3640/28ce64JP
Circwaste magazine II	Companies and municipalities	133,000	https://issuu.com/suomenympar-istokeskus/docs/web_lehti_circwaste_eng_2020?fr=sMmNjZDE5MDcyMDU
Resource wisdom Facebook page	Citizens and all those interested in the circular economy	1,400 (in December 2020)	https://www.facebook.com/Resurssiviisaus
Twitter @circwaste	Experts, policymakers and the media	1,700 (in December 2020)	@circwaste

3 Results from cooperation with municipalities and regions

Municipalities are key when it comes to implementing a circular economy.
The best examples and actions can be carried out with circular procurements.

3.1 **Distributing good practices with the Energy and Material Leap online service**

One of the most effective ways of bringing best practices into use is to learn from others. In the project, best practices are collected and distributed in various ways. The main idea is to make them easily available for everyone – not just municipalities but also citizens and entrepreneurs.

The Material Leap platform (materiaalitkiertoon.fi; Figure 3) for documenting good practices has been online since November 2017 and publicly accessible since August 2018. The Material Leap platform is a website/portal for gathering and sharing best practices in energy and material efficiency and circular economy. The portal implements the aims of Finland’s NWP and catalyses the sharing of best practice case examples more efficiently. The portal is implemented and maintained in cooperation with several projects in SYKE to maximise the distribution and audience of the data included. Other projects involve gathering good practices, for example from climate change prevention activities.

The Material Leap platform is designed to be as open as possible and relies on the power of good examples: anyone can add their good examples to the service. When you talk about your own leap to the users of this service or to your neighbours, friends and colleagues, it encourages others to take action and our journey towards a carbon-neutral and material-efficient society will be shortened.

The platform has been designed with special attention paid to making it as social media friendly as possible, allowing, for example, for each article to be shared widely on different platforms and in different forms. Additionally, users can embed a plugin of their articles on their own websites. In terms of continuity, the Material Leap platform is designed to work independently of projects. As such, its life beyond Circwaste is certain.

The platform and its cases have been translated into English to maximise the potential audience, both nationally and internationally, allowing for Finnish best practices to be spread abroad.

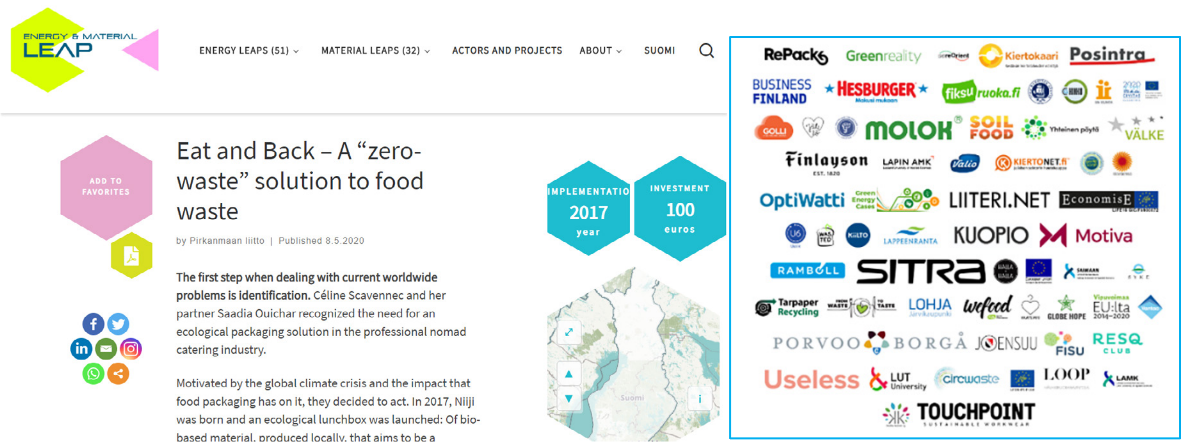


Figure 3. The open Energy and Material Leap database showcases good circular economy practices in Finland and abroad.

This Finnish platform and its purpose are similar to the Good Practices platform established by the EU (European Union 2019). The EU platform includes relevant practices, innovative processes and 'learning from experience' examples. All information is provided by the stakeholders themselves, but the practices published (371 in 2020) are selected by the platform secretariat (European Union 2019). There are also other similar platforms, such as the one managed by SITRA (SITRA 2019b), and others described in EREK (2018), the Ellen MacArthur Foundation (2017b) and Zero Waste Europe (2020). The existence of several services with similar ideologies is slightly confusing, but on the other hand it is supported by the assumption that the context motivates the users.

3.2 **Circular public procurement**

3.2.1 Potential of public procurement to promote a carbon-neutral circular economy

Public procurement has been identified as an important means to promote low carbon and circular society as it covers around 16% of the GDP at EU level and nationally. It has been noted that municipalities play a key role in promoting circular solutions through public procurement (SITRA 2019a). In 2015, public procurement was responsible for one fifth (i.e. 8.3 Mt CO_2ekv) of the consumption-based carbon footprint in Finland. Municipalities and federations of municipalities accounted for almost 80% of the carbon footprint of public procurement, in which 42–43% of emissions were caused by the procurement of services and 52% by procurement of goods. In addition to this, the carbon footprint of investments made by public organisations amounted to 2.7 Mt CO_2ekv and the raw material requirement of the public sector was 19.5 Mt in 2015 (Nissinen & Savolainen 2019; Table 3).

Table 3. Volume of public procurement, greenhouse gas emissions, and raw material requirements in 2015 (Nissinen & Savolainen 2019).

	Expenditure million euro	**Greenhouse gas emissions** million kg CO_2e	**Raw material requirements** million kg
State	4,850	1,780	6,690
Municipalities	10,160	4,730	9,910
Federations of municipalities	4,930	1,790	2,930
Total	19,950	8,300	19,530

Currently, the EU supports the uptake of sustainable public procurement (SPP) and green public procurement (GPP), also highlighting the circular nature of public procurement. For example, the EU's GPP criteria, as well as many national green procurement criteria, already set targets for circular aspects, e.g. criteria for buying products with a higher percentage of recycled content, and products and parts that could be better recycled (Alhola et al. 2019; Alhola & Salmenperä 2019). Criteria include also actions higher in the waste hierarchy, such as criteria for reuse and refurbishment. In addition to this, different business models, such as product–service systems, i.e. buying services instead of products, could encourage 'closed-loop' production and consumption cycles (UNEP 2015).

3.2.2 From strategic aim to local practices and networking

In the Circwaste project, the aim has been to promote the adoption of circular solutions in public procurement. The work has focused on capacity building, i.e. educating procurers and creating understanding about the strategic view of circular procurement, and highlighting the importance of networking and co-operation.

Public procurement offers many possibilities for implementing the circular targets set at global, EU and national level. In Circwaste municipalities these aims have been communicated in the procurement strategies and alignments at municipal level, which may include, for example, the following:

- Environmental aspects and possibilities to use green procurement criteria should be considered in all procurement, especially those related to reduced energy consumption (electricity, heat and water) and emissions (CO_2 emissions and particles), recyclability, extension of lifespan, material selection, use of recycled materials and prevention of waste.
- Possibilities for buying second-hand products and products made of recycled materials should be considered.
- Products being procured should be recyclable and sent for re-use or recycling after use.
- Life cycle costs should be considered in procurement. This allows procurers to choose the most economically advantageous option on a life cycle basis.
- Resource efficient procurement options should be considered. These include procuring services instead of products, optional types of ownership and reuse of products.
- Eco-label criteria can be used in the formulation of criteria in calls for tender.

The Circwaste project has gathered good examples and practices in circular procurement. Best practices and good examples, as well as exchange of knowledge, have been gained through networking and in close co-operation with ongoing circular public procurement projects and the KEINO competence centre (www.hankintakeino.fi/en). Several projects that focus on circular public procurement, such as CircularPP (http://circularpp.eu/), have provided international examples and knowledge of circular procurement as well as related business models. Circular public procurement has been realised in different forms and different sectors, such as construction, transport, waste management, food and catering and certain product groups, such as furniture, textiles and IT equipment (Alhola & Salmenperä 2019; KEINO 2020). Good examples have also been spread and discussed through Circwaste education events and webinars.

3.2.3 Challenges and solutions for circular public procurement

The main challenges and hindrances to sustainable public procurement in municipalities have been identified by Alhola & Kaljonen (2017) and KEINO (2018). They relate to loose strategic commitment and a lack of resources and procurement capabilities in municipalities. In addition to this, there is a lack of opportunities for new circular solutions on the market, as well as insufficient knowledge about new circular business models. Municipalities benefit from discussing the challenges and the solutions, and events have been arranged to facilitate this. Based on a workshop held on 25 August 2020, several suggestions for promoting circular procurement in municipalities and related activities were identified:

1. Strategic objectives and strong commitment from management are needed:
    - Clear objectives and alignments should be set at management level.
    - Education and training for the decision makers in municipalities should be organised.
    - Visits to realised circular procurement cases should be organised.

2. A sufficient amount of resources for public procurement operations should be guaranteed:
    - Co-operation in terms of joint procurement and common market dialogue events could be utilised.
    - Learning from others, sharing experiences and mentoring should be used more.

3. Capacity building in practical procurement is needed:
   - Available guidance and related services (e.g. the KEINO competence centre) should be utilised.
   - Co-operation should be highlighted, e.g. learning from others, sharing experiences and mentoring.
   - Existing best and good practice examples should be utilised in the planning of procurement.

4. Market dialogue should be increased, and market information should be utilised:
   - Co-operation in organising market dialogue events is recommended, e.g. general level discussions with market representatives (not necessarily related to a certain call for tender).
   - Requests for information and other tools for gathering market supplier information should be used.

It was agreed that a commitment from management and decision makers is needed in order to boost circular public procurement in municipalities. However, there are also many opportunities that the procurers and specialists have available to them. They can, for example, deliver information and good examples within the organisation, connect different departments and sectors in round table discussions, and consider possibilities for implementing a procurement in a circular way.

3.3 Criteria for choosing forerunner municipalities

The forerunner municipality network is a vital essential element in executing the circular economy at national level. The municipalities involved will serve as examples for other municipalities and provide their knowledge and solutions to be copied and utilised in other Finnish regions, too. Forerunner municipalities will also prepare a circular economy road map, which will give them a regional tool for target setting and committing regional operators. Therefore, it is appropriate to bring together the forerunner municipalities that have the motivation and capability to operate in the desired role. A set of criteria was created to test the relevant elements (Table 4) and these criteria formed the application form for the forerunner municipality network. In the application form, justifications were also required for the answers.

The circular economy expert network selected the forerunner municipalities from among some 20 applicants. The choice was influenced by the commitments that the municipalities made in the application phase and the measures they had taken so far.

In the Circwaste project, ten municipalities were chosen for the forerunner municipality network: Ii, Jyväskylä, Kuopio, Lahti, Lappeenranta, Porvoo, Riihimäki, Rovaniemi, Turku and Vantaa.

Table 4. Commitment criteria for choosing the forerunner municipalities network.

Sector of municipal operation	Criteria for proving circular economy supporting activity
Commitment to goals that support the circular economy in general	• Eco-labelled products are used in construction procurement. • The use of recycled building materials is a procurement criterion in public procurements. • Building resilience, recyclability, demolition and reusability of building materials is taken into account. • The criteria of the Green Public Procurement Guide are used in construction projects. • The municipality will sign Society's Commitment to Sustainable Development. • Committing to increasing the number of industrial symbioses in the region. • Committing to increasing the level of material efficiency in region businesses. • Separately collected municipal biowaste generated in the area is utilised in the production of biogas, bioethanol or biodiesel. • Committing to expanding the distribution network for the biogas. • Committing to increasing the number of environmental systems (ISO, EMAS, LEED) in production industry companies. • The Guide to Responsible Food Procurement is in use to promote the circular economy in the region. • Committing to increasing the number of environmental business in the municipality. • Committing to increasing the amount of regional development funding allocated to projects promoting the circular economy.
Commitment to NWP targets – actions to achieve the municipal waste recycling targets	• Committing to introducing stricter separate collection obligations in the municipal waste management regulations for recyclable waste. • Committing to introducing Pay as you throw systems that encourage sorting. • Committing to increasing waste advising resources. • Committing to implementing composition studies on mixed waste and studying proportions of recyclable waste fractions. • Creating conditions and opportunities for introducing new and innovative collection systems (For example waste containers that are equipped with digital capabilities to indicate that they are full, multi-compartment waste containers, pipeline-based waste collection system). • Fertiliser products from biological waste treatment are utilised in farming, soil enrichment or landscaping. • Committed to developing biowaste home composting in sparsely populated areas. • Committed to increasing the number of different recyclables collected from properties.
Commitment to NWP targets – raising the material recovery rate of construction and demolition waste to 70%	• Committed to developing and intensifying the activities of recycling centres for construction products and components in municipalities. • Committed to increasing the use of demolished concrete and other C&D wastes in soil construction. • Committed to encouraging C&D companies to increase the source separation of waste types. • Committed to increasing the recycling of gypsum waste from demolition. • Committed to increasing the recycling of roofing felt waste in the production of new asphalt. • Introducing pilot conveyance deals encouraging sustainable construction.
Introducing the requirements of the circular economy in urban planning in a way that promotes use of recyclables, long lifespans of buildings, recyclability of building materials and reuse of building materials. Targets: Volumes of waste have decreased from the present. Re-use and recycling have risen to new levels.	• Committed to organising leftover lunch experiments in municipalities' own institutions. • Committed to promoting reuse and efficient use of products in their procurements. • Material efficient methods are tested in public repair construction projects. • Committed to developing recycling centres in the municipality. • Committed to developing sharing models suitable for municipalities.

3.4 **Regional road maps**

A road map is an efficient strategic implementation tool for regions, too. In the Circwaste project, four regional circular economy road maps have been compiled to engage all regional key operators to strive for efficient use and looping of materials. The road maps were structured around the areal characters and needs and therefore they are unique and diverse.

In Southwest Finland, the road map 'From recycling to circular economy' promotes the objectives and measures of the NWP. The themes of this road map are 1) construction and demolition waste, 2) biodegradable wastes and nutrient cycles and 3) municipal waste. The road map is linked to many regional strategies and programmes, especially the previous work with the circular economy road map for the southwest region. (Circular economy road map of southwest Finland 2018)

In Central Finland, the Circwaste road map for the region considers local factors and strengths. The road map has four main themes: 1) construction and demolition waste, 2) biodegradable waste, biogas and nutrient recirculation, 3) plastics and 4) WEEE. The themes, targets and measures are in accordance with the NWP. In addition to this, the theme 'Biodegradable waste, biogas and nutrient recycling' pays particular attention to broader aspects than are included in the NWP. This means promotion of biogas production from other waste materials and side streams as mentioned in the NWP and promotion of biogas consumption as traffic fuel. (Circular economy roadmap of Central Finland 2018)

'Circular economy roadmap, South Karelia' includes goals for 2030 such as: 1) sustainable welfare, no emissions and zero waste, 2) employment and business growth and 3) growth of environmental and circular economy expertise and education. Furthermore, factors facilitating circular economy, e.g. participation of citizens, research co-operation and public procurements, were examined in every focus area. (Circular economy roadmap of South Karelia 2018)

The North Karelia region's roadmap defines the goals for circular economy as follows: 1) to promote the material and energy efficiency of the region and the sustainable and optimal use of natural resources, 2) to make the circular economy an integral part of the activities of various sectors and to strengthen the cooperation network of the region's circular economy and 3) to strengthen and create new business in the circular economy and develop new technical solutions and know-how for the region. (Circular economy roadmap of North Karelia 2018)

3.5 **Circular economy checklist for municipalities**

As part of the Strategic circular economy promotion programme, a subgroup on municipalities and regions has been working to identify the most efficient means for implementing a circular economy (Myllymaa et al. 2020). As the background information for their work, data was produced on advisable practices for implementing circular economy. The desired topics for the work were three: public infrastructure and investments, business and innovation politics and citizens in circular economy.

3.5.1 Public infrastructure and investments

In a study on public infrastructure and investments, strengths, development needs and suggested actions were identified for eight topics (Myllymaa et al. 2020): 1. circular economy leadership and strategic commitment, 2. sharing economy solutions and products as services for infrastructure development in municipalities, 3. including a circular economy perspective in investments and their financing, 4. public procurements supporting circular economy – increasing know-how on public procurements, 5. construction procurements promoting a circular economy – new construction production, demolition and infrastructure construction, 6. planning and land use at all levels, 7. waste management and recycling and 8. energy solutions that save natural resources. The results are presented in Table 5.

Table 5. Strengths, development needs and suggested actions for municipalities to implement a circular economy in public infrastructure and investments.

Public infrastructure and investments (Myllymaa et al. 2020)		
Strengths in the present state	**Development needs**	**Suggested actions**
1. Circular economy leadership and strategic commitment		
- Several municipalities have already made commitments to circular economy or resource efficiency with strategic implementation plans or roadmaps and defined the actions and responsible parties.	- Committing private actors, companies and citizens to the actions is needed. - Strengthening experimentation culture and copying and mainstreaming successful pilots executed in other municipalities. - Maintaining a systemic, reiterative operating model in planning and decision making. - Branding circular economy-based decision making strongly as a cross-administrative strategy and as part of regional vitality development.	- A national organisation must be established for providing municipalities with audit, development, education and business support services. - Circular economy experts should be recruited to each municipality to work as cross-administrative experts and coordinators – and governmental support should be available for this. - Circular economy, sustainable development and resource efficiency should be included in financial rules in the financial management and decision making in municipalities.
2. Sharing economy solutions and 'products as services' for development in municipalities		
- New services and digital platforms have been put into operation in municipalities, for example, shared use electric cars and loan services for different equipment have become common. - Spaces/facilities have been designed to be versatile and suitable for a variety of services (sports, celebrations, concerts etc.) - A diverse selection of products has been made available in libraries. - Municipalities have been utilising private electronic flea markets and auctions. - Giving citizens the opportunity to use public facilities has become a customary activity.	- Easily accessible regional information should be gathered on available sharing and repairing services. - Promoting acquisition of services instead of products. - Identifying the possibilities offered by digitalisation and artificial intelligence. - Much wider accessibility of public facilities could be achieved by extending the use of digital services (such as fingerprint, library card, etc. identification.)	- Loaning services could be extended to new product categories. - Governmental support is needed to increase the availability of open access data. - More cooperation with companies and third sector actors in exploiting underutilised facilities.
3. Including a circular economy perspective in investments and their financing		
- Municipalities are carrying out large infrastructure and construction investments where there is huge potential for making the circular economy a primary target. - Municipalities can set obligations and incentives for procurements and investments to promote the use of recycled raw materials (and promote market dialogue on the availability of these products).	- There is inadequate awareness of supporting instruments for circular economy investments (for example, green loans) and their possibilities. - The benefits of solutions that support the circular economy are assessed as being too short-sighted or the benefits have not been identified at all in investment calculations. - There is still inadequate knowledge of the use of sustainability criteria in investments. - Circular economy criteria might be used in singular investments, when their impact on systemic change is minor; investments should be planned so that the circular economy is the central target. - A circular economy perspective should be included in investment planning from the early stages.	- Open national level information must be produced on the benefits and cost efficiency of circular economy solutions, and information should be included in investment planning tools. - Municipalities should be provided with support in strategic investment planning. - Green financing instruments should be developed to more strongly include circular economy and resource efficiency perspectives.

Public infrastructure and investments (Myllymaa et al. 2020)		
Strengths in the present state	**Development needs**	**Suggested actions**
4. Public procurements supporting a circular economy – increasing know-how on public procurements		
- Municipalities have used circular economy criteria in public procurements, for example in the construction sector. - The government is strongly supporting the promotion of circular economy in public procurements. - Interest in circular procurements and learning more about them has grown.	- National targets on promoting procurements that support the circular economy are not being systematically implemented in municipalities yet. - There is not necessarily enough information on possible circular economy concepts. - Knowledge on procurements is at times considered insufficient. -There should be regularly set circular economy and other environmental targets for procurements.	- Financing of the Competence Centre for Sustainable and Innovative public procurement (KEINO) should be continued. - Municipalities should be provided with information on good examples of procurements, criteria and agreement conditions including a circular economy perspective. - Buyer-supplier dialogue should be included in planning circular economy procurements. - It should be possible to define targets for sustainable procurements and find representative indicators and monitoring methods. - The relevance of measuring and impact assessment is growing.
5. Construction projects that promote the circular economy – construction and demolition of buildings and construction of infrastructure		
- Municipalities are a significant actor in infrastructure construction, and their example has great importance. - Municipalities have good experience of contaminated soil (PIMA) treatment. - Use of safe recycled aggregates and other materials is taking place in earthworks.	- In infrastructure construction, there is often a need to use new rock material for timing reasons. -The planning of contaminated soil treatment also suffers from tight scheduling.	- In infrastructure construction procurements, the municipalities should, as the orderer/buyer, preferably prioritise the use of recycled soil materials; a circular economy coordinator could help in implementing this.
- In the circular economy procurement of new construction production, municipalities can, as the orderer, require a longer service time for buildings, longer guarantees, repairability and upgradability, as well as modifiability and versatility of spaces.	- Assessing renovation possibilities before making a decision on demolition and new construction production. - Sometimes transferable buildings and spaces without walls are needed. - Thinking of buildings as material banks is needed. - Quality management and control on construction sites to prevent material losses and mishandling. - The municipality as the buyer should require waste plans for construction sites in which the targets and requirements for sorting, reuse and recycling and documentation of demolition material composition are clearly set out.	- Municipalities should require, as orderers, the use of recycled raw materials in their construction projects as well as the documentation of material composition (incl. hazardous substances). - Municipalities should require actors to commit to voluntary agreements on recycled raw material use and decreasing the use of natural resources.

Public infrastructure and investments (Myllymaa et al. 2020)		
Strengths in the present state	**Development needs**	**Suggested actions**
- There was fresh guidance published by the Ministry of the Environment in 2019 on demolition work (Lehtonen 2019), on pre-demolition audits (Wahlström et al. 2019) and a guide for procurement of demolition work (Kuittinen 2019). - There are already business concepts that utilise demolition materials and surplus materials from construction work.	- The orderer/buyer could offer training to the contractor employees to help them commit to the relevant goals and, for example, ensure the necessary collection/sorting bins for construction materials at construction sites. - To create a commitment in earthwork contracts to utilise recycled materials. - There is relatively little reuse of materials coming from demolition sites.	- Balancing the use of new construction production and renovation and using careful evaluation before demolition. - There is a need for regional sorting centres for construction and demolition materials and material banks for reselling the materials (see also recycling centres).
6. Regional planning and land use		
- Placing industrial activities in **regional planning regulations** (*kaavamääräys*) to support circular economy activities and logistics. - Studies on greenery networks have been used in **regional planning** and **regional plans (*maakuntakaava*)** to support the integration of different land use needs.	- The actions that support circular economy and what is allowed if defined as a circular economy region should be defined more precisely. - Integration of land use needs and simultaneously securing carbon sequestration, ecosystem functionality, ecosystem services and sustainable nutrient and water cycles.	- Use of and instruction on circular economy plan notations (*kaavamerkintä*). - Development of new plan notations and instructions.
- Sustainable soil management and identification of suitable intermediate depots and final disposal sites on **master plans (*yleiskaava*), component master plans (*osayleiskaava*) and interim town plans (*kaavarunko*)**.	- Taking contaminated soil treatment needs and need forecasting better into account (in master, component master and interim town plans).	- Co-operation with different sectors. - Sharing of good examples and experiences in municipality networks. - Obligations for ecologic compensation; quantitative no net loss goals for biodiversity. - Quantitative targets for reducing the use of natural resources. - Quantitative targets for land use that will be adopted for built-up environments "Määrälliset tavoitteet rakennetun maa-alan käyttöönotolle".
- A **zoning plan** (*asemakaava*) is the key land use planning tool for circular economy action implementation. - Directive (*ohjeellinen*) or determining measures for promoting circular economy. - Including circular economy requirements in the instructions of construction methods (*rakennustapaohjeet*) and plot allocation conditions. - Utilisation of the green factor tool.	- More detailed placing of circular economy actions and highlighting enough spaces for storage and treatment operations in **zoning plans**. - Bringing more versatile circular economy goals and life cycle thinking to zoning.	- Comprehensive examinations of circular economy and life cycle sustainability assessments to support decision making. - Development of new plan notations (*kaavamerintä*) that are linked to circular economy, and formulating appropriate guidance. - Enough space reservations for circular economy business and activities. - New circular economy obligations needed for plot allocation conditions (*tontinluovutusehdot*) or instructions on construction methods.

Public infrastructure and investments (Myllymaa et al. 2020)		
Strengths in the present state	**Development needs**	**Suggested actions**
		- Circular economy strategies and targets should be implemented at all plan levels: in regional plans, master plans, component master plans, interim town plans and zoning plans. - Including circular economy targets in the **building code** (*rakennusjärjestys*). - Enabling landowners, too, to participate in building code planning.
7. Waste management and recycling		
- Municipalities are responsible for consumer instruction, including waste prevention and recycling. - Municipalities have created strong operative collaboration organisations, which create a good basis for development and knowledge. - In the municipalities, innovative separate collection pilots have been realised and restricted separate collection obligation limits for biowaste, for example, have been applied. - Citizens are ready for change; they are expecting better services and might also be ready to pay more for these services.	- Even more cooperation on waste management is needed between municipalities. - Providing versatile separate collection services, taking into account different types of residential area. - Investing in waste counselling. - New waste act proposal: municipalities in charge of packaging waste collection from households.	- Preparation in municipalities of more ambitious and possibly more costly waste management services and wider cooperation with all the actors in municipal waste management. - Employing a land mass / circular economy coordinator as an additional own or shared (with several municipalities) resource. - Ending the burning of recyclable waste. - Instead of collecting energy waste fractions, homogenous plastic, fibre and wood waste should be recycled. - Utilisation of services that upgrade the refining level of recycling.
8. Energy solutions that save natural resources		
- Increasing number of innovative projects on geothermic energy, heat recovery from wastewater, waste heat utilisation, and other innovative energy sources. - Use of locally produced biogas in local transport, for example.	- Compensating for burning-based energy production with emission-free electricity, waste heat, heat pump technology and energy savings. - Increasing biogas production where possible.	- Producing cost efficiency information on different energy producing technologies (best practices) and applicable planning tools. - Using a municipality owner policy for influencing energy companies. - Cost-saving energy updates will soon be phased out; national energy support will be needed in the future to produce climate and raw-material neutral geothermal heat and sustainable electricity.

3.5.2 Business and innovation politics

On the theme 'business and innovation policies', strengths, development needs, and suggested actions were identified in two topics (Myllymaa et al. 2020): 1. co-operation with companies and 2. pilots and research (Table 6).

Table 6. Strengths, development needs and suggested actions for municipalities to implement circular economy in business and innovation policy.

Business and innovation policies (Myllymaa et al. 2020)		
Strengths in the present state	**Development needs**	**Suggested actions**
1. Co-operation with companies		
- Municipalities have long-term experience of business cooperation and big data. - The material market (Materiaalitori.fi service) brings municipalities and companies to the same platform. - Companies have solutions and development ideas for promoting circular economy.	- A lack of resources is slowing down cooperation. - Proactive dialogue with municipalities, companies and different actors is needed to bring together circular economy know-how and business.	- Legislation is needed to set goals for decreasing the use of natural resources - Governmental support is needed to establish a national organisation: auditing, developing and business subsidy services for municipalities. - Active marketing of the material market portal (Materiaalitori) for companies. - Municipalities can work as circular economy concept references for companies.
2. Pilots and research		
- New treatment technologies are a possibility: producing elemental level substances for industry. - There are circular economy projects and pilots in municipalities.	- Limited resources in municipalities for piloting.	- Governmental financing instruments are needed to support innovative technology pilot plants. - Municipalities could provide pilot platforms for companies, for example to pilot new technologies. - Governmental support is needed for municipalities, for example: composter renting/management business activities from 2023.

3.5.3 Citizens in circular economy

The theme of 'citizens in circular economy' includes strengths, development needs and suggested actions for municipalities on six topics (Myllymaa et al. 2020): 1. providing reuse centre services, 2. nature as a natural resource, 3. dissemination and communication, 4. offering food waste products, 5. pilots in transportation and 6. circular economy indicators and monitoring (Table 7).

Table 7. Strengths, development needs and suggested actions for municipalities to implement circular economy in citizen interaction.

Citizens in circular economy (Myllymaa et al. 2020)		
Strengths in the present state	**Development needs**	**Suggested actions**
1. Providing Reuse centre services (*Kierrätyskeskus*) for citizens		
- Products and appliances can find new life at reuse centres. - Provide jobs for third sector operators and those who are disadvantaged. - Facilitates availability of reasonably-priced products.	- Not a very common service in municipalities. - Often the location is not easily accessible. - Not all cooperation opportunities have been utilised.	- Establishing more reuse centres in central locations, in cooperation with waste management companies, municipalities and associations. - Expanding the reuse centre concept into a 'citizens' shared living room'. - Establishing pop-up reuse-centres.
2. Nature as a natural resource, source of wellbeing and preserving biodiversity		
- Wide selection of outdoor areas and hiking routes. - Stronger natural connections in-crease wellbeing and offer alternative action for a consumption-centric society.	- There are only a few expansive regions in their natural state or they are not accessible with public transport.	- More efficient utilisation of nature-based solutions and services.
3. Dissemination and communication, citizen engagement and instruction		
- Long experience of citizen communications. - Good experiences, such as the citizen emission trade pilot and cooperation with schools. - Competitions and campaigns are attracting positive attention. - Environmental education is an important form of cooperation with schools and academies.	- Engagement of all demographic groups is challenging.	- Positive branding with the help of dissemination, communication, campaigns and drives. - Cooperation with the third sector in communicating. - Circular economy should be included as part of the degree in every sector.
4. Offering food waste products		
- Many municipalities are decreasing food waste by selling or donating surplus food. - Digital solutions have been applied to minimise food waste.	- Efficient ways of minimising food waste through effective use (e.g. stor-ing, preparation, recipe development). - Feasibility in exceptional times (e.g. COVID19 pandemic) is problematic.	- Food waste models to be adopted in municipalities.
5. Pilots in transportation		
- Successful pilots and actions, especially in biogas buses and free public transport.	- So far only in a few municipalities.	- Efficient communication on lessons from transport pilots. - Bold pilots and actions.
6. Circular economy indicators and monitoring		
- In Finland, many things are already monitored, so there is relatively good readiness for data production. - There are initiatives and develop-ment work underway for circular economy measurement.	- The broadness of the definition of the circular economy concept and insufficient sources do not support monitoring of circular economy progress. - There is demand for regional data, but a lack of data sources.	- Municipalities should measure the waste amounts, recycling rates and material use in their own operations. - It should be required in legislation that municipalities gather data on circular economy progress and impact monitoring as municipality specific and regional data. - Digitalisation will make monitoring and data management easier.

4 Circular economy indicators for analysing national and regional development

Indicators are needed to measure development and to understand all the possible impacts of the system-level change.

4.1 Initiatives for measuring circular economy in Europe

Implementing a circular economy requires a systematic change in society. As efforts to increase circularity are enforced, the need for monitoring the change as well as its effects is also emphasised (Saidani et al. 2019). Furthermore, the European Commission has recognised the need for monitoring and originally established a Monitoring Framework for the Circular Economy in 2018. The framework was updated in 2020 (European Commission 2020a).

The need for monitoring the implementation of circular economy and predominant societal courses of development is crucial, because the estimated trends are predicting manifold growth in global use of materials within the next decades (OECD 2019), caused by factors such as population and economic growth. According to estimates calculated by the OECD (2019), construction materials dominate total materials use now and will continue to do so in 2060 (Figure 4).

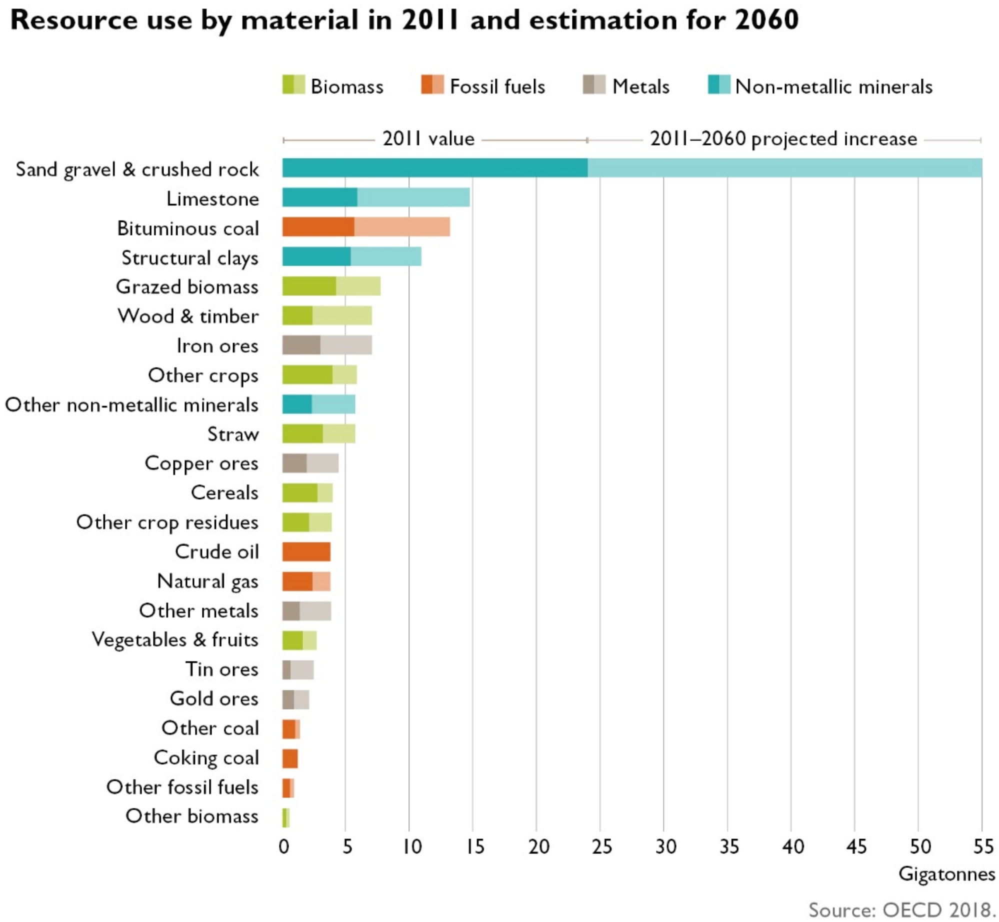


Figure 4. Resource use by material in 2011 and estimation for 2060. Construction materials dominate total material use both in 2011 and 2060 (Redrawn from OECD 2018).

Numerous indicator systems have been developed for the circular economy, both in Europe and globally (Saidani et al. 2019, European Commission 2018, Eurostat 2019a). The connecting feature between these systems is that they produce national-level data. Most of them emphasise waste or material streams. The European Commission (EC) has set up a circular economy monitoring framework that consists of 10 main indicators focusing on production and consumption, waste management, use of secondary raw materials, competitiveness and innovation (Eurostat 2020a, European Commission 2018). The indicators are, as far as is possible, based on existing data, thus limiting the administrative burden. Other selection criteria for the indicators include relevance, acceptance, credibility, ease of use and robustness (European Commission 2018). There is national data available from Finland on waste indicators, investments, employment, value added and number of patents concerning waste or secondary raw materials (Table 8) (Eurostat 2020a).

In addition to this, as a part of the EC's Eco-innovation Action Plan (EcoAP) a set of 14 indicators was chosen to measure the performance of the EU countries in areas that directly or indirectly contribute to the development of the circular economy. These suggested indicators were based on existing indicators and can help measure performance in several areas that directly or indirectly contribute to the development of the circular economy. The indicators were grouped under sustainable resource management, societal behaviour and business operations (European Commission 2020c). They aim to measure and compare the progress of the circular economy in different countries. In comparison to the other indicator sets, the EcoAP also includes indicators that aim to measure citizen awareness, engagement and participation in the circular economy, through looking at people's participation in sharing economy schemes and the coverage of circular economy topics in the mass media.

Previous work on measuring sustainable green growth (Seppälä et al. 2016) has suggested national-level resource efficiency indicators that have similarities to the list used in the Resource Efficiency Scoreboard (Eurostat 2020a, Table 9) and that could also indicate a transition to circular economy. The most relevant indicators include five resource efficiency indicators: the proportion renewable raw materials account for of raw material total consumption (RMC), raw-material intensity (RMC/GDP), total raw material consumption per industry, total raw material consumption per capita, the amount and recovery of municipal solid waste (MSW), and the amount and recovery of industrial and construction waste. The availability of data for the suggested indicators has been assessed to be mainly uncertain, however, for the municipal waste indicators, data is adequately available (Seppälä et al. 2016). The writers particularly emphasise the RMC as a comprehensive measure for green growth.

Table 8. National-level circular economy indicators of the circular economy monitoring framework of the European Commission (European Commission 2018) and resulting values for Finland.

Theme	Indicator Type	Indicator	Results for Finland (most recent value, if data available)
Production and consumption	1. EU self-sufficiency for raw materials		N/A
	2. Green public procurement		N/A
	3. Waste generation	Generation of municipal waste per capita	551 kg, annual data 2014–2018
		Generation of waste excluding major mineral waste per GDP unit	73kg/EUR 1,000, semi-annual data 2008–2016
		Generation of waste excluding major mineral wastes per domestic material consumption	8.2%, semi-annual data 2008–2016
	4. Food waste		N/A

Theme	Indicator Type	Indicator	**Results for Finland** (most recent value, if data available)
Waste management	5. Recycling rates	Recycling rate of municipal waste	42.3%, annual data 2014–2018
		Recycling rate of all waste excluding major mineral waste	37%, semi-annual data 2010–2016
	6. Recycling / recovery for specific waste streams	Recycling rate of overall packaging Recycling rate of plastic packaging Recycling rate of wooden packaging Recycling rate of e-waste Recycling rate of biowaste Recovery rate of construction and demolition waste	65.2%, annual data 2013–2017 26.5%, annual data 2013–2017 14.5%, annual data 2013–2017 48.2%, annual data 2013–2017 72%, annual data 2013–2017 87%, semi-annual data, 2010–2016
Secondary raw materials	7. Contribution of recycled materials to raw materials demand	End-of-Life recycling input rates (EOL-RIR) Circular material use rate (CMU)	N/A 2.2%, annual data 2013–2017 7%, Finnish data on 2018 (Lesonen & Pirtonen 2020)
	8. Trade in recyclable raw materials	Imports from non-EU countries Exports to non-EU countries Intra EU trade	28,449, annual data 2015–2019 304,599, annual data 2015–2019 139,656, annual data 2015–2019
Competitive-ness and innovation	9. Private investments, jobs and gross value added	Gross investment in tangible goods Persons employed Value added at factor cost	0.08% of GDP at current prices, annual data 2014–2017 1.58% of total employment, annual data 2014–2017 0.88% of GDP at current prices, annual data 2014–2017
	10. Patents	Number of patents related to recy-cling and secondary raw materials	16.46, annual data 2011–2015

Table 9. National-level indicators chosen by the Directorate-General for Environment as part of the EcoAP to measure performance in several areas that directly or indirectly contribute to circular economy development (European Commission 2020c).

Theme	Indicator Type	Indicator	**Results from Finland** (data from Finland if available, year of data**)**
Sustainable resources management (European Commission 2020d)	11. Material footprint	Domestic material consumption (DMC), tonnes per capita	30.5 tonnes per capita (data in 2015, European Commission 2020d)
	12. Resources productivity	DMC/GDP or Total amount of materials directly used by an economy (RMC)/GDP	6% positive change in Finland in resources intensity DMC/GDP in 2000–2014 (from data in Seppälä et al. 2016)
	13. Municipal solid waste	Municipal solid waste generation, kg per capita	500 kg per capita (2015 European Commission 2020d)
		Municipal waste recycling, kg per capita.	About 205 kg per capita (calcula-tion with a 41% recycling rate)
Societal behaviours - reflecting citizen awareness, engagement and participation in the circular economy (European Commission 2020e)	14. Citizen behaviour in 2013	Citizens who have chosen alternatives to buying new products: sharing, leasing or buying remanufactured products, percentage of respondents	Used sharing schemes: 59% Used leasing: 25% Buying remanufactured products: 33% None of above: 26% (2013, European Commission 2020e)

Theme	Indicator Type	Indicator	**Results from Finland** (data from Finland if available, year of data**)**
	15. Popularity of circular economy in the mass media in 2016	Coverage of the circular economy topic in electronic mass media in 2016, number of articles published	2,611 articles published (2016, European Commission 2020e)
	16. Repairment of computers and personal goods	Turnover in repair of computers and personal goods	EUR 346 million (2014, European Commission 2020e)
		Number of enterprises and employment in repair of computers and personal and household goods	1,672 enterprises (2014) (-8.5% change 2007–2014) 2,631 employees (2014) (+17% change 2007–2014)(European Commission 2020e)
Business operations – depicting eco-innovation activities toward changing and adapting business models according to the principles of a circular economy (bottom-up indicators) (European Commission 2020f)	17. Difficulties in companies in implementing the circular economy	Difficulties implementing circular economy activities experienced by companies (does not total 100%)	Lack of human resources: 16% (EU 28 average 21%) Lack of circular economy expertise: 26% (EU 28 average 22%) Legal procedures complexity: 33% (EU 28 = 32%) Costs of regulations and standards: 32% (EU 28 = 28%) Financing difficulties: 13% (EU 28 = 25%) Other: 3% (EU 28 = 4%) None: 43% (EU 28 = 42%) Do not know: 1% (EU 28 = 2%) (European Commission 2020f)
	18. Circular economy financing	Financing sources for circular economy activities	Standard bank loan: 5% Green loan: 1% EU related funds: N/A Government grant: 1% Alternative sources: - Self-financed: 84% Other: 3% Do not know: 6% (European Commission 2020f)
		Availability of information that can help promote access to financing for circular economy related activities, as reported by SMEs	Sufficient information readily available: 7% Some information is readily available: 12% Little or no information is readily available: 15% Company has not searched such information: 65% Do not know: 1% (European Commission 2020f)
	19. Companies that execute circular design	Enterprises that extended products' lifespans through more durable products, by innovation	Manufacturing sector: 27.3% (2014, average 16.4%) Service sector: 19.9% (2014, average 11.9%) (European Commission 2020f)
	20. Waste recycling companies	Proportion of enterprises that facilitated recycling of products after use	Manufacturing sector: 23.9% (2014, average 15.2%) Service sector: 17.2% (2014, average 12.0%) (European Commission 2020f)
		Enterprises that recycled waste, water or materials for their own use or sale within the enterprises by innovating	Manufacturing sector: 25.8% (2014, average 20.1%) Service sector: 13.8% (2014, average 13.4%) (European Commission 2020f)

It has been widely acknowledged that the monitoring of the circular economy needs to be developed further (European Environment Agency EEA 2019; Moraga et al. 2019). The European Environment Agency EEA (2019) states that monitoring of the circular economy must be developed, and investments are needed in order to improve the availability of data for monitoring. The EEA has established, in collaboration with the Italian Institute for Environmental Protection and Research (ISPRA) an initiative aiming to “consolidate key principles and areas for future work to improve the monitoring of circular economy” (The Network of the Heads of Environment Agencies (EPA Network), 2020).

The national circular economy indicator values show large variation between countries. For example, the material footprint (domestic material consumption DMC) varies from 8 to 32 tonnes per capita in 2018 (Figure 5) (Eurostat 2019b). DMC is also part of the EU Sustainable Development Goals (SDG) indicator set, indicator 12.2.2. (UN 2019). The comparison between countries is complicated, although the main influencing factors affecting indicators on use of natural resources are the industrial structure and economic conditions. The substantive observation and recommendation on the national indicators is to focus on monitoring national trends rather than comparing countries. National decisions affect national trends. Therefore, the trends should be monitored to learn from the past and to identify the policy instruments needed to achieve the target level. In Figure 6, the national trends in DMC show quite stable development in Finland, as they do in Austria and in the Netherlands. In some countries, the trend is decreasing (Germany, UK, Italy), whereas in others it is clearly increasing (Sweden, Romania, Poland).

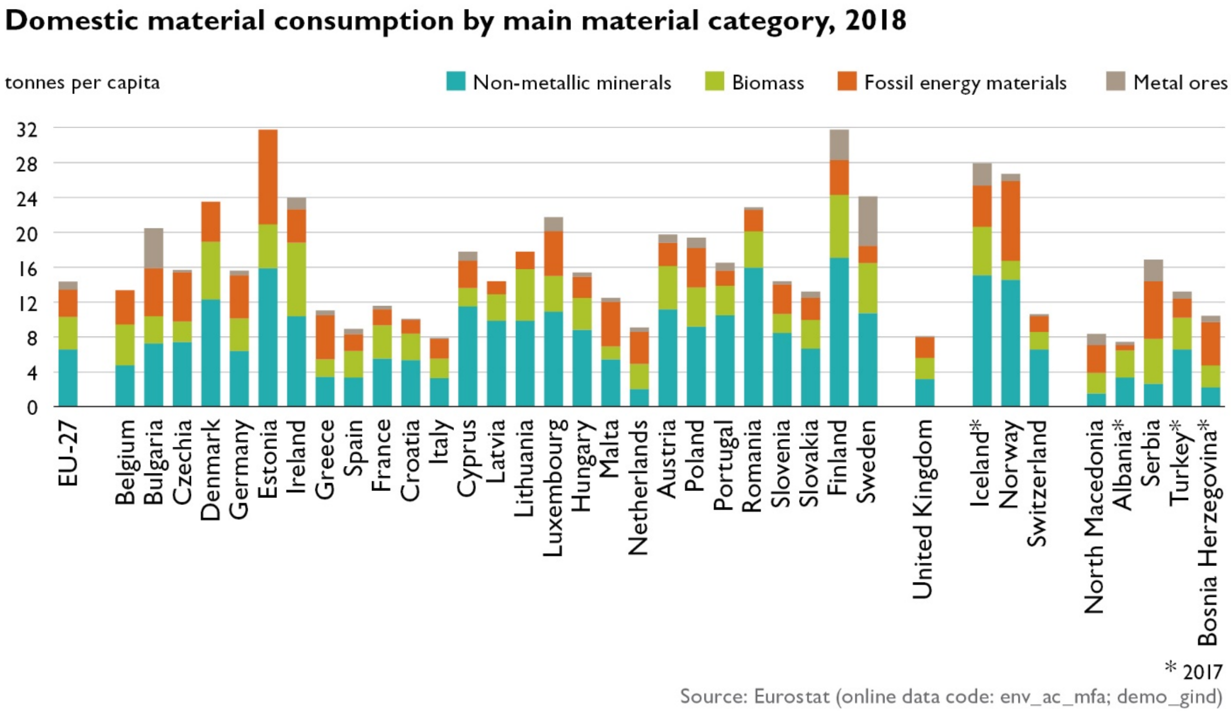


Figure 5. Material footprint or Domestic Material Consumption of non-metallic minerals, biomass, fossil energy materials and metal ores. For 2018, in tonnes per capita (Redrawn from Eurostat 2019b). (DMC = The annual total amount of raw materials used directly by an economy including extracted materials from the domestic territory of the focal economy, plus all physical imports minus all physical exports. Not including upstream flows related to imports and exports of raw materials and products originating outside of the local economy.)

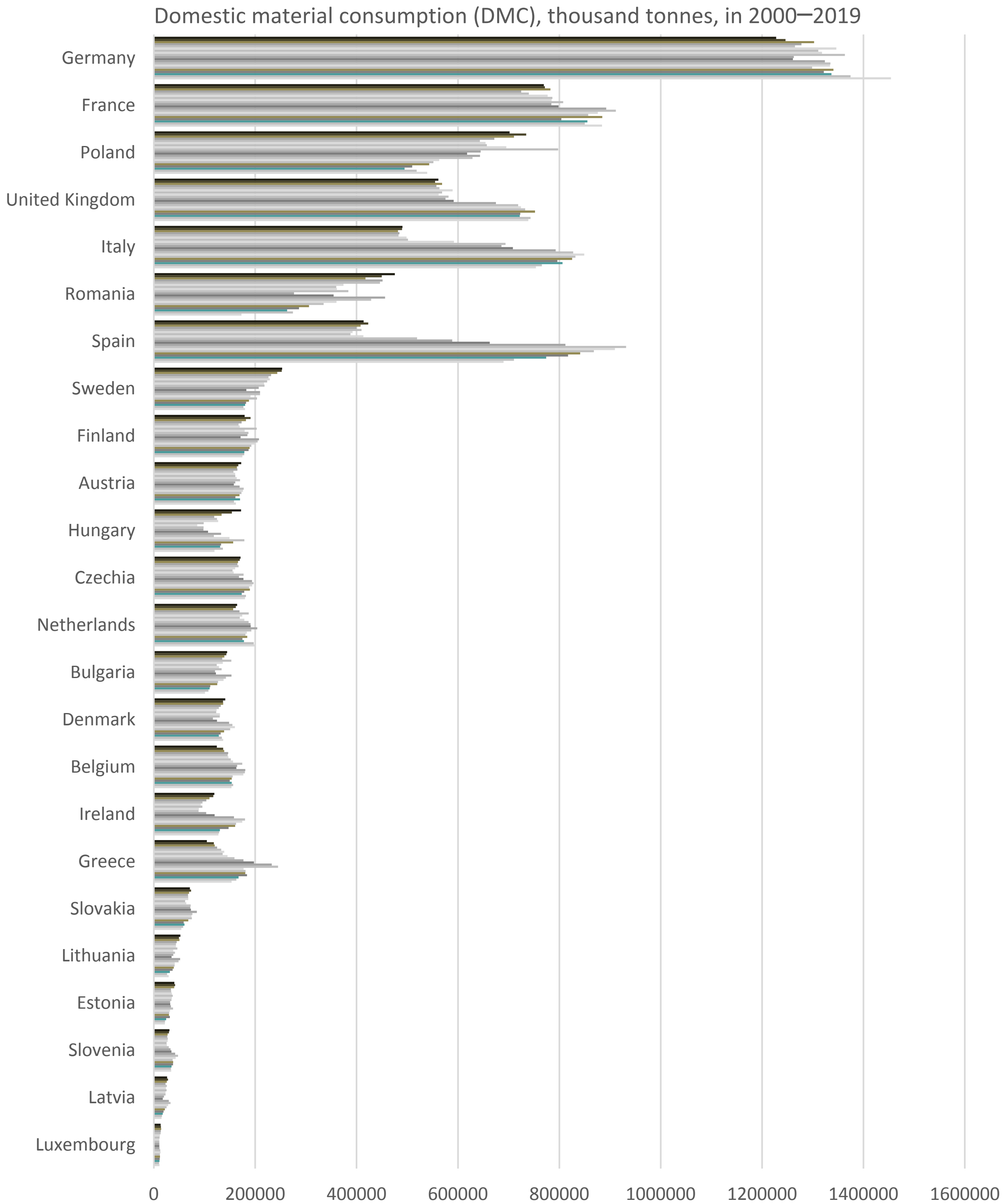


Figure 6. Material footprint / Domestic Material Consumption (DMC) trends in some EU countries in 2000–2019. The most recent year is at the top and the oldest at the bottom of the series of each country. (Eurostat 2020b).

The key targets for the EU policy include decoupling the use of natural resources from economic welfare, reducing the consumption footprint and doubling the circular material use rate by 2030 (European Commission 2020a). Disconnecting waste amounts from GDP has also been the target of waste legislation and the Finnish NWP. The amount of waste per GDP has been monitored as one of the NWP indicators (Ministry of the Environment 2020).

All the dimensions of sustainability are being targeted with circular economy policy. The Circular Economy plan is mentioned as being instrumental in achieving the Sustainable Development Goals (SDGs) by 2030, particularly Goal 12 of ensuring sustainable consumption and production patterns (European Commission 2015). These connections of decoupling waste production and welfare as well as sustainable development create similar logical connections to those UNEP (2011) described in a simple figure with four variables (Figure 7): human well-being, economic activity (as GDP), resource use and environmental impacts. Sustainable development is aspired to through decoupling human well-being and GDP from resource use and environmental impacts. It is achieved when well-being is improved simultaneously with nonmaterial economic growth. Additionally, in scientific analysis (for example Korhonen et al. 2018) for the definition of circular economy, the original WCED definition of sustainable development was employed as the basic reference point.

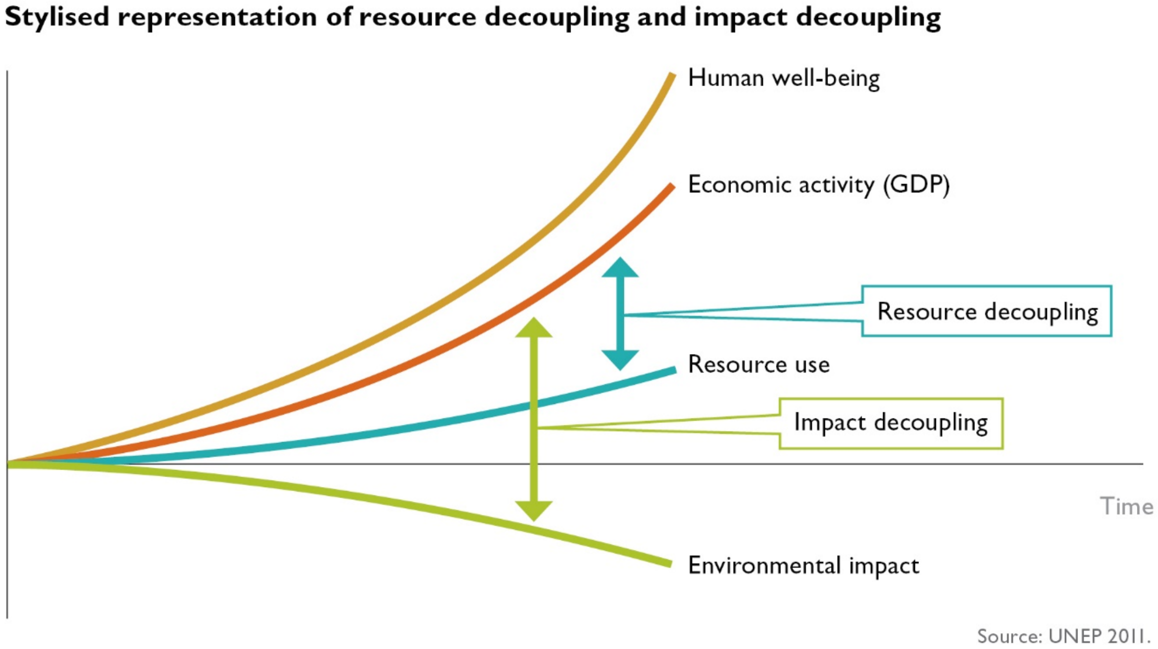


Figure 7. Stylised representation of resource decoupling and impact decoupling (Redrawn from UNEP 2011). Sustainable development is aspired to through decoupling human well-being and GDP from resource use and environmental impacts. Sustainable development is achieved when well-being is improved simultaneously with nonmaterial economic growth.

The Finnish national values of total material requirement (TMR), DMC, GDP and MSW give an estimate of circular economy development and decoupling in Finland. Trends show some correlation between waste amounts, economic growth and the use of natural resources in TMR and DMC (Figure 8). There was an unexpected and unwanted leap in the amounts of MSW in 2018, which seems to correlate more strongly with the TMR than GDP. The national indexed trends of DMC (Statistics Finland 2019b), TMR (Statistics Finland 2019a), GDP (Statistics Finland 2020c), MSW (Statistics Finland 2020a) and GHG emissions (Statistics Finland 2020b) in Finland in 2000–2018 show quite clear coupling of economic growth to the use of natural resources. Additionally, the amount of MSW correlates both with economic growth and TMR. This demonstrates the need for further acceleration of efforts to achieve circular economy.

The GHG emissions are to be monitored in parallel with resource use indicators to ensure a low carbon (European Commission 2016) and carbon neutral (SITRA 2016a, 2019) circular economy. The work done to combat climate change and de-carbonise energy systems can be seen in the decreasing trends of national GHG emissions (Figure 8). Even though the declining trend is a success story, it is still the case that even this level is not enough. This also proves that in order to achieve concrete results, concrete limiting targets are also needed for use of natural resources.

Materials management activities are responsible for two thirds of GHG emissions (OECD 2019). Hence, tackling the overuse of natural resources can also help in solving the climate change crisis.

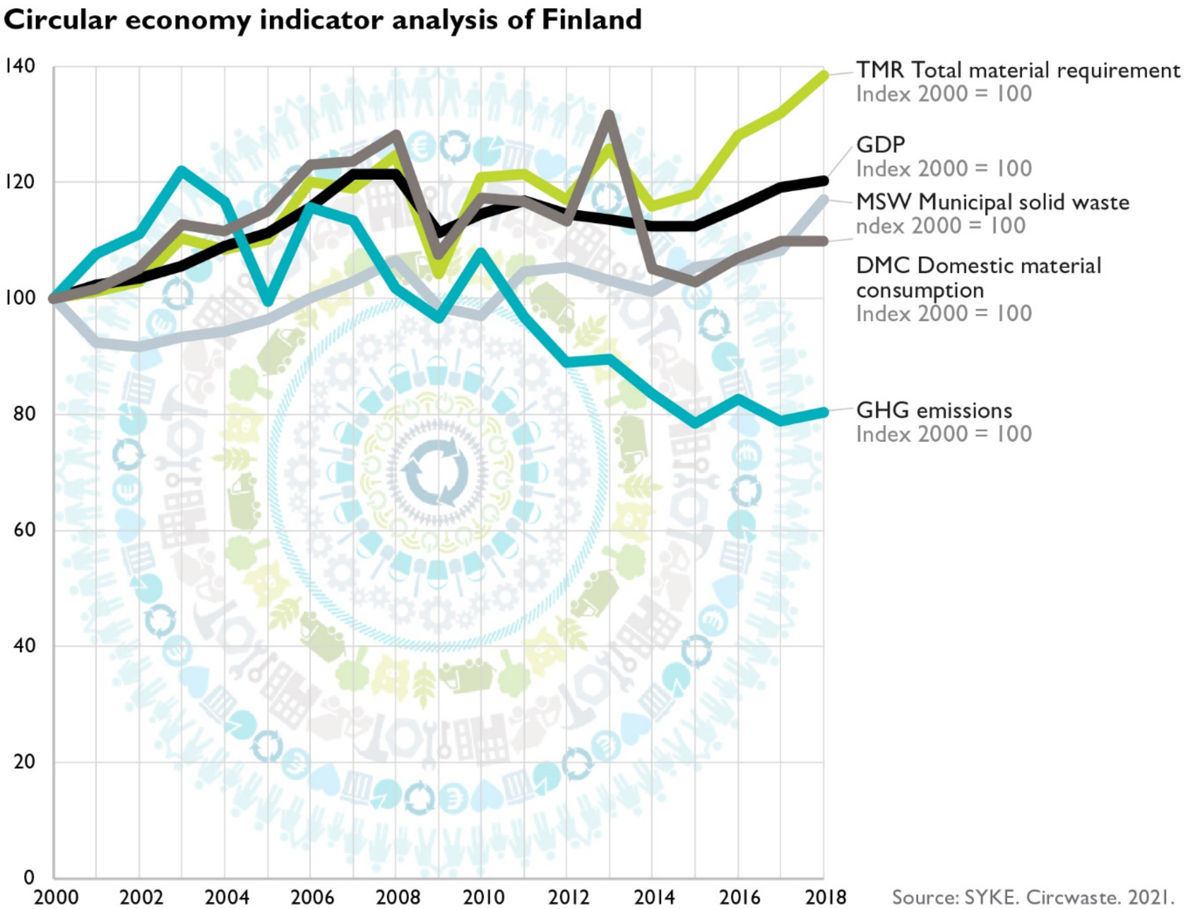


Figure 8. Circular economy indicator analysis of Finland. National indexed trends of DMC (Statistic Finland 2019b), TMR (Statistics Finland 2019a), GDP (Statistics Finland 2020c), municipal solid waste (MSW) (Statistics Finland 2020a) and GHG emissions (Statistics Finland 2020b) in Finland in 2000–2018 show some coupling of economic growth to use of natural resources. The amount of MSW also correlates with both economic growth and TMR. However, GHG emissions have been decoupling from GDP since 2010.

There are significant uncertainties connected to the interpretation of the data and the success of implementing the circular economy from 2020. The situation of 2020 in statistics will be affected by the exceptional circumstances caused by the social segregation procedures for controlling the pandemic caused by the SARS-CoV-2 virus. Circumstances have strongly impacted industry, services and citizen behaviour. Basic industry has been suffering from problems in demand as well as availability of components and labour. Restaurants have periodically been operating at a lower or nearly zero operability level. Inhabitants and consumers have been forced to learn to use remote working, as well as teleshopping and new digital applications to take care of their everyday needs. Citizens have produced increased amounts of cardboard and plastic packaging waste, due to buying separately packed food and increasingly using home delivery. This has caused littering not only in cities but also in national parks (Färding 2020, Ikola 2020).

4.2 Defining sub-national circular economy indicators

Despite the increasing attention on developing indicators and measuring progress, many aspects in the transition to the circular economy, such as multifunctionality of products or the use of sharing platforms, are not yet being monitored (Moraga et al. 2019). Even less is known about the social preconditions for and impacts of the transition to the circular economy (Pitkänen et al. 2020). The suggested social indicators in EcoAPI (European Commission 2020c) only measure societal behaviour, not the experienced impacts. Moreover, most of the current monitoring frameworks and indicators focus on the national level and relatively little is known of sub-national differences within countries (Avdiushchenko & Zajac 2019).

As stated, the quality and usability of circular economy indicators need to be developed. In essence, the need for further developing circular economy indicators arises from critical and practical needs for sub-national data. All European indicator work is carried out to produce national level indicators. Meanwhile, a huge amount of decisions affecting circular economy are made at local level: in municipalities, waste management companies and regional councils. Thus, it would be of great importance to provide local data to support local decision-making.

Public procurers can be considered key players when it comes to circular economy due to their key role as purchasers. They can offer companies options to test circular economy solutions (European Commission 2020, Berg et al. 2019). Public procurers are one of the concrete links in providing real-time information to citizens, thus empowering them to make sustainable consumer choices, as demanded by the European Commission (European Commission 2020c).

In Circwaste, the target has been to deepen knowledge of the progression of the circular economy in Finland by developing a wider set of circular economy indicators. The aim was to gain a comprehensive understanding of the transition to the circular economy in Finland. Indicators were developed for measuring development in the waste sector, businesses and innovations, as well as socio-economic impacts. The primary criteria for circular economy indicators were that they measure the development of the circular economy or the NWP, they can be monitored sub-nationally, and they should be based on regularly updated data, so that the development of the indicators can be followed up on in the future. In addition to this, the indicators developed in the project ought to also be suitable for monitoring other regions and municipalities.

The sub-national indicators have been developed in close cooperation with numerous local stakeholders in the key project regions and forerunner municipalities. For sub-national indicators, data is often not readily available. Thus, the sub-national circular economy indicators differ from the nationally monitored indicators. Usually, local data must still be gathered directly from the actors, such as municipalities, waste management companies, or businesses, through questionnaires and interviews. A key aim of the development of sub-national circular economy indicators was also to point out the current challenges in gathering adequate local data on the circular economy. It is also important to discuss in both local and national administration how the availability of local data for monitoring the circular economy could be made more readily available in the future. The need for sub-national data on the circular economy will most likely only increase.

A summary of these sub-national indicators is presented in Table 10. The individual indicators, their purpose, challenges, possible reservations and the first results are further described in the following chapters.

Table 10. Sub-national circular economy indicators created in the Circwaste project.

Topic	Content	Data Sources
Sub-national Indicators on Waste (chapter 4.3)		
Household waste	The amount of household waste produced in a region per capita The Recycling rate of household waste in a region	Questionnaire, producer responsibility statistics (Centre for Economic Development, Transport and the Environment of Pirkanmaa 2019), national waste statistics (Statistics Finland 2018a), consistency of mixed MSW (Suomen kiertovoima ry KIVO 2020), home composting estimates (Teittinen 2017), statistics on housing (Statistics Finland 2020e)
Household biowaste	The amount of household biowaste in a region per capita Recycling rate of household biowaste in a region	Questionnaire, producer responsibility statistics (Centre for Economic Development, Transport and the Environment of Pirkanmaa 2019), national waste statistics (Statistics Finland 2018a), consistency of mixed MSW (Suomen kiertovoima ry KIVO 2020), home composting estimates (Teittinen 2017), statistics on housing (Statistics Finland 2020e)
Construction and demolition waste (C&DW)	The amount of C&DW in a region The recycling rate of C&DW in a region, excluding soils	National waste statistics (Statistics Finland 2018a), regional statistics on the construction sector (Statistics Finland 2018b), estimates of utilisation of C&DW (Salmenperä et al. 2016)
Waste electric and electronic equipment (WEEE)	The amount of WEEE in the key regions, utilisation rate	Producer responsibility statistics (Centre for Economic Development, Transport and the Environment of Pirkanmaa 2019), consistency of mixed MSW (Suomen kiertovoima ry KIVO 2020)
Waste-specific Indicators of the pilot projects	Various	Various, directly from pilot projects
Total waste amount	Total amount of waste in a region per capita and GDP	Database data on production and use of waste (Merilehto 2018), GDP (Statistics Finland
Business and Innovation Indicators (chapter 4.4)		
Circular economy business	Circular economy business turnover in the key companies in the region, experiences of the companies	Interviews, regional statistics on business structure (Statistics Finland 2018b)
Research and development (R&D)	Financing of CE-related R&D projects	Open online sources, regional coordinators and other stakeholders, interviews
Socio-Economic Indicators (4.5)		
Circular economy employ-ment: quantity and quality – different income categories	To be developed	Statistics Finland, to be developed
Circular economy employ-ment, vulnerable groups	Number of people working in circular economy jobs through subsidised work (work-try-outs or with pay subsidy): proportion circular economy jobs account for of all subsidised work in regions)	Employment Service Statistics (Ministry of Economic Affairs and Employment 2020; https://tem.fi/en/employment-bulletin-and-employ-ment-service-statistics)
Shared resources / joint use community facilities	Number or area (m^2) of public facilities in joint use (public gyms, city bikes, resources shared through public libraries)	Surveys in the Circwaste project and open online data from municipalities

Topic	Content	Data Sources
Higher education on the circular economy	Number of circular economy courses and course credits offered by universities of applied sciences	Survey in the Circwaste project sent to universities of applied sciences in Finland
Accessibility of recycled resources: biogas fuelling stations and e-car charging stations	Travel distance to the nearest biogas fuelling station / e-car charging station	Personal vehicle methane fuel stations (Gasum Ltd 2020), electric vehicle charging points (Sähköautoilijat ry 2020), Finnish Environment Institute SYKE models and databases
Accessibility of recycling services: plastics packaging waste, WEEE and re-usea-ble textiles drop-off sites	Travel distance to the nearest plastic packaging waste, WEEE and re-usable textile drop-off sites	The kierratys.info service (Suomen kiertovoima ry KIVO 2020), UFF, Fida, Red Cross (SPR), Finnish Environment Institute SYKE

Finland has a long history of the statistical use of administrative data sources and development of register data. For example, population data for censuses is collected exclusively from registers without any direct data collection from the population. The register data facilitates regular production of statistical information, often on a sub-national basis, without costly and time-consuming surveys. Therefore, the starting point in this indicator work was to take advantage of existing data sources. However, monitoring of the circular economy on a regional basis turned out to be challenging based on the existing statistical information and data. The circular economy is a new and continuously developing concept that exceeds or falls in between current statistical concepts and categories. Even if the circular economy data is collected, it is often scattered between the registers and databases of different administrative organisations with different principles for data collection. It is not defined exclusively in standard industrial classifications, and instead the circular economy can take place in all industries. Therefore, the circular economy indicators formulated in this project partially take a case-based-approach or have been purposefully targeted at a relatively narrow and exemplary phenomena, which also provides valuable information and can be extrapolated to other regions in Finland or abroad. However, not all the indicators are comparable between the regions due to the unreliability of the background data.

Despite the difficulties in measuring circularity quantitatively, this is the first time a systematic monitoring scheme has been developed for monitoring of the circular economy sub-nationally in Finland. The indicators presented here will be used to monitor the transition to a circular economy and its impacts in Finland regionally throughout the project timeframe (2016–2023). The lessons learned in the formulation of these circular economy indicators can also provide important information on how to further develop registers and data sources in the future. More in-depth research is required to formulate more comparable and comprehensive information for monitoring of the circular economy, both nationally and sub-nationally.

4.3 Sub-national indicators on waste

Monitoring waste streams and recycling rates at sub-national level is important for providing informative data for local decision-making as well as finding ways to achieve the ambitious EU waste recycling targets nationally. In Circwaste, sub-national monitoring of the waste streams highlighted in the NWP as the key strategic topics was developed. These NWP topics include four waste fractions: municipal solid waste (MSW), biodegradable waste, construction and demolition waste (C&DW), and waste electronic and electric equipment (WEEE) (Laaksonen et al. 2018).

This is the first time sub-national monitoring of these waste streams has been carried out in multiple Finnish regions with similar methods. The monitoring methods were developed based on data that is available or can be collected within a reasonable workload and to reasonable accuracy in different regions. For MSW from households and biowaste from households, the monitoring could be carried out for some of the pilot regions targeted based on mostly local data. For C&DW as well as WEEE, the monitoring is based on national statistics weighted by construction industry activity and population, respectively. In addition to this, the formulation of the sub-national waste indicators as well as the data collection and communication with stakeholders has provided a better understanding of the status of local waste monitoring, current practices in the field, and national development ideas concerning local waste monitoring.

In the chapters below, the sub-national waste indicators are presented along with the formulation of the indicators, calculation methods and the first results. All the regional waste indicators will be monitored throughout the project from 2016 to 2023.

4.3.1 Household waste in regions

For municipalities, monitoring municipal solid waste (MSW), and in particular separating the MSW produced by households (household waste) from the total MSW amounts, is a key point of circularity monitoring. Municipalities can influence the production and recycling of household waste by providing information through campaigns and education, for example. Municipalities can also bring the collection of source-separated waste fractions closer to the people by making sorting more convenient.

In the Circwaste project, a robust method for monitoring the amount and recycling of household waste in different sub-national regions in Finland has been developed. Currently, there is a lack of data on MSW on a sub-national basis, even though it is monitored nationally. Waste management for household waste is organised in municipalities. However, the waste management for MSW from companies and other activities is mostly commercial. Some waste fractions are taken care by the producers through producer responsibility. Hence, the sub-national data on waste is scattered amongst numerous sources, and the origin of each waste stream is not monitored collectively and accurately. For households, waste management is mostly centralised to public waste management companies and producer associations, allowing monitoring from a limited number of data sources.

Changes to waste legislation as well as the imprecise interpretation of the definition of MSW hinders accurate sub-national waste monitoring. In this indicator, the definition of waste included in the calculation used the national definition of MSW in waste legislation (The Finnish Parliament 2011).

Sub-national data on MSW from households is collected in Circwaste via questionnaires targeted at public waste management companies. This data is complemented with partly local and partly national data from producer associations, national statistics and estimates (Figure 9).

The questionnaires collect data from the public waste management companies on mixed waste, energy waste, biowaste in MSW and the complementary collection for MSW under producer responsibility (excluding WEEE, batteries and paper, for which national data is used) (see Table 7). Local data on regional collection of packaging waste as well as refund bottles and cans is received directly from the producer associations. These data sources are complemented with national statistics on WEEE, batteries and paper, weighted for each region based on population.

Small-scale on-site composting of kitchen and gardening waste is common in Finland in rural areas as well as in areas with detached housing. Estimates on the on-site composting of kitchen waste are based on a method developed by the Finnish Ministry for the Environment (Teittinen 2017). Only the small-scale on-site composting of kitchen waste, not gardening waste, was considered, based on the national approach to European Waste Directive (European Parliament 2018) reporting. Questionnaire results on composting (Teittinen 2017) as well as local statistics on the structure of housing in each region (Statistics Finland 2020e) are used in the estimation method.

In the questionnaire, the public waste management companies are asked to estimate the proportion of waste produced by households. Being forced to request estimates because of the lack of measured data is one of the biggest challenges and sources of uncertainty in producing the monitoring data on MSW. Estimating the proportion of MSW originating from households in their waste streams is easier for companies that manage the collection logistics themselves. Cooperation between companies, public authorities and the public waste management companies is required for the collection of data in the regions, where individual property owners manage their waste collection. Household waste is often not separated from the rest of the MSW even in the national statistics, and when it is, the separation is based on calculated estimates. For paper, WEEE and batteries, expert estimates are made regarding the proportion of waste from households.

The amounts of household waste were calculated in proportion to the population in the area based on data from Statistics Finland (Statistics Finland 2020e). The recycling rates were calculated based on data from the public waste management companies (questionnaire) and national MSW statistics (Statistics Finland 2020a).

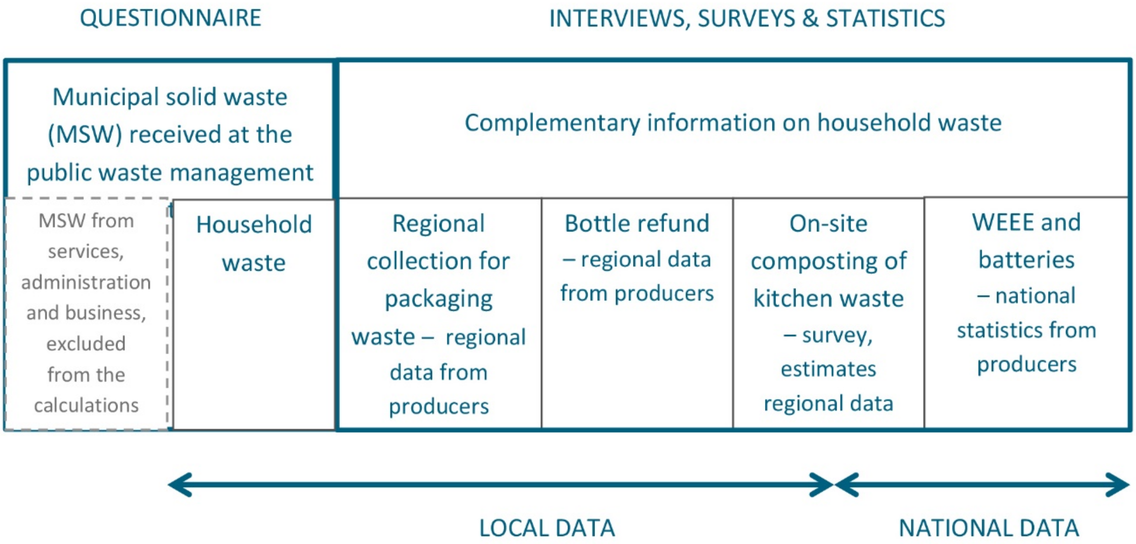


Figure 9. Sub-national monitoring of household waste combines both local and national data from multiple sources.

The pilot round for the monitoring of MSW from households was carried out in 2018 for data from 2016 and 2017. The second round of calculations was carried out in 2020 for the data from 2018–2019, with some modifications to the method as well as corrections to the data from previous years. The data was collected from the five key regions in the Circwaste project (Central Finland, North and South Karelia, Satakunta and Southwest Finland), 10 Circwaste forerunner municipalities, and 11 municipalities in the Finnish Sustainable Communities (Fisu) Network (Figure 10). Some of the Circwaste forerunner municipalities are also involved in the Finnish Sustainable Municipalities network. The questionnaire was sent to all the 20 public waste management companies in these regions and municipalities.

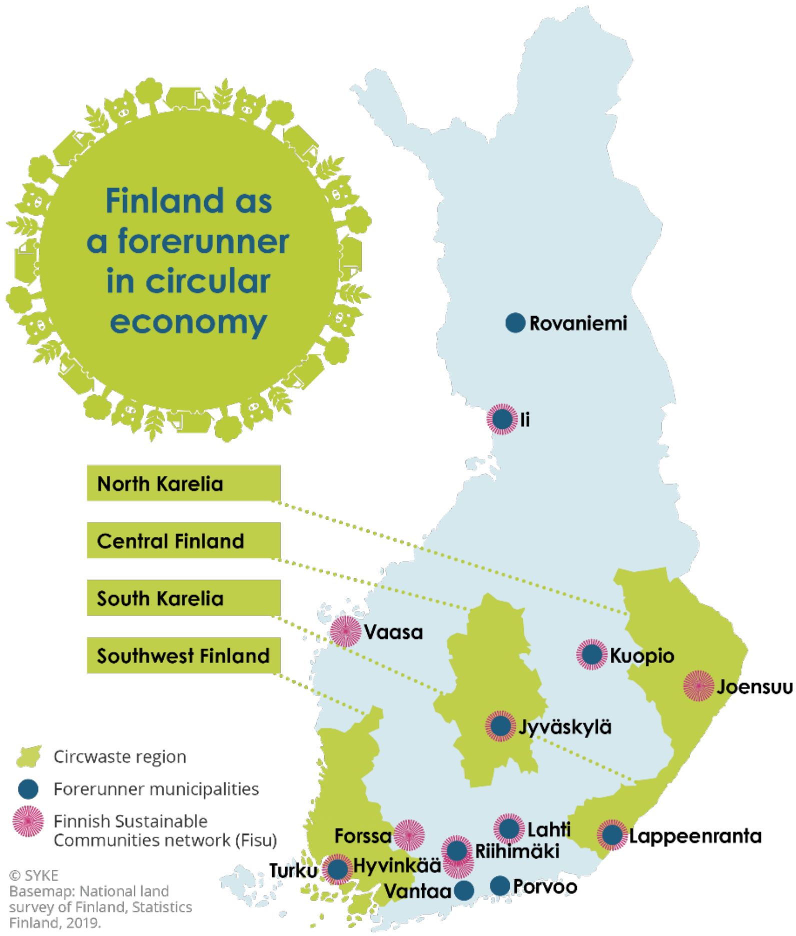


Figure 10. Key regions and forerunner municipalities in the pilot monitoring municipal solid waste (MSW) from households covered by the Circwaste.project.

All the waste management companies replied to the questionnaire, providing valuable information on the current state of local data from households in their regions. However, adequate data to make estimates on the amounts and recycling of household waste could only be gathered for seven regions for 2016–2019 and nine regions for 2018–2019. The estimates of recycling rates and amounts of household waste have been calculated for the operating regions of the public waste management companies for each of the forerunner municipalities where adequate data was available.

The results showed a moderate decrease in household waste amounts in some of the regions over the monitoring period of 2016–2019. The amount of household waste was falling in Hyvinkää, Riihimäki, Joensuu, Jyväskylä, Lahti and Turku. There was significant fluctuation between the years. The decrease in the amounts varied between 1 and 12%, adding up to 40 kg/person per year. Changes in the stock as well as operations of individual waste treatment facilities could explain the high fluctuation. However, no adequate increase in the recycling rates was observed (Figure 11).

There was no significant increase seen in the recycling rate for household waste over the monitoring period. In the regions of Joensuu, Kuopio, Lahti, Porvoo and Turku, there was an increase of 1–2% in the recycling rate. A significantly faster increase in recycling rates ought to be seen in all the regions, in order for Finland to achieve the EU targets of 50% by 2020 and 55% by 2025 in recycling of MSW. The recycling rate of MSW has not been increasing nationally, either. The recycling rate for MSW in Finland was 42% in 2018 (Statistics Finland 2020a).

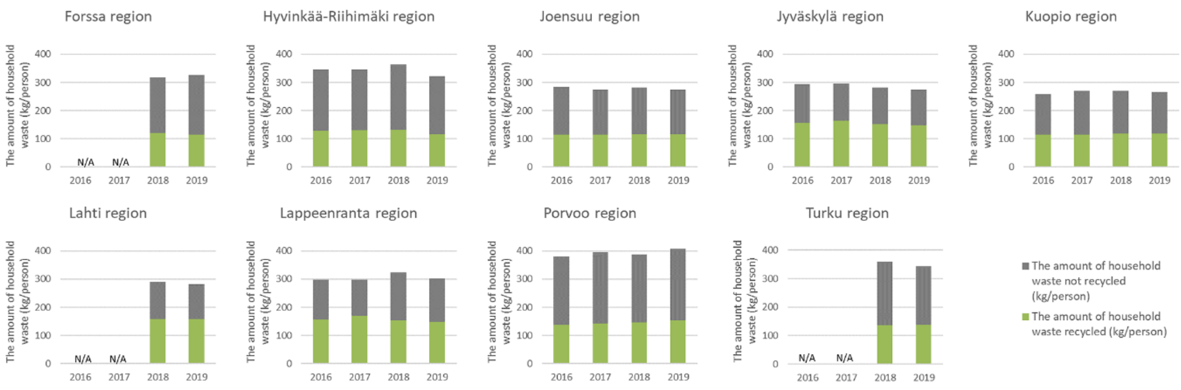


Figure 11. Estimated regional recycling rates are not increasing fast enough, however, the total amounts of municipal solid waste (MSW) from households for the regions around seven forerunner municipalities from 2016 to 2019 in Finland showed a moderate decrease in some of the regions. There is high uncertainty in the estimates due to the lack of reliable and comparable local data on waste. The values cannot be compared between the regions, however, the results can be used in establishing the trends in regional development.

The data on sub-national monitoring of household waste can only be considered estimates, as there are high levels of uncertainty in the data. The results cannot be reliably compared between different regions, since the organisation of waste management differs between regions and this affects the production quality of the local data. For some of the regions inspected, the monitoring cannot be carried out due to a lack of adequate data sources. There have also been significant changes in waste management operations in Finland from 2016 to 2019: The network of regional waste collection sites for packaging waste has been extended and disposing of MSW in landfills has been widely replaced with waste incineration. This also hinders the monitoring of the trend in the results. The collection of data and calculating sub-national estimates on household waste is time-consuming, since it is carried out manually by combining multiple sources of information, including questionnaires. However, the monitoring of household waste also illustrates the practical needs for improving the data systems used for monitoring the waste sector.

4.3.2 Household biowaste in regions

Unsorted biowaste contributes to a large proportion, about 30–35%, of mixed MSW (Suomen kiertovoima ry KIVO 2020). Measures that increase the separate collection of biowaste can thus efficiently increase the recycling rate of MSW. Hence, monitoring the development of separate collection of biowaste is very topical.

The monitoring of biowaste in MSW from households is carried out with a similar method and using the same data sources as the monitoring of household waste. Both biowaste that is sorted in households, collected separately and treated at a centralised waste treatment plant, and kitchen waste that is composted on-site in small-scale home composting containers, are accounted in the monitoring. Data from the centrally treated biowaste is collected via a questionnaire from the public waste management companies (see the previous chapter). The amount of kitchen waste composted on-site is also estimated in the same way as described above. The on-site composting of gardening waste is excluded from the monitoring.

The amount of biowaste left in the mixed fraction of MSW in each region was calculated based on the amounts of mixed MSW (from the survey) and the biowaste content in mixed MSW (Suomen kiertovoima ry KIVO 2020). The biowaste content in mixed MSW is determined from composition analyses of mixed MSW. The data on the composition is acquired from the composition analyses for mixed MSW carried out in different public waste management companies in recent years (Suomen kiertovoima ry KIVO 2020). In regions where the latest composition analysis available in the database was less than five years old, the local composition analysis results were used. In regions where there were no analysis results available in the database or the survey was carried out too long ago, a national average composition of mixed MSW (Suomen kiertovoima ry KIVO) was used.

The amounts of household biowaste were calculated for the seven regions in a similar way to the method for the amounts of household waste. In addition to this, the rates of separate collection for household biowaste are calculated as both separately collected biowaste and biowaste composted on-site divided by the total amount of household biowaste, including the biowaste in mixed MSW. The same uncertainties regarding the reliability of the results are also present.

The source-separation rate of household biowaste was increasing in most of the regions over the monitoring period (Figure 12). The connection between the strictest local rules for separate collection and an increase in the source-separation rate cannot be clearly seen in the monitoring results. In the regions of Jyväskylä and Lappeenranta, separate collection of biowaste is mandatory from all properties. Additionally, in Hyvinkää, Joensuu, Kuopio, Porvoo and Riihimäki, the separate collection of biowaste is mandatory from properties with a minimum of five dwellings. The source-separation rate of biowaste from households was increasing over the monitoring period 2016–2019 in the regions of Hyvinkää, Riihimäki, Jyväskylä, Kuopio and Porvoo as well as in 2018–2019 in the regions of Lahti and Turku. Due to differences in background data from different regions, comparison of the absolute amounts of source-separated biowaste is not possible at this point.

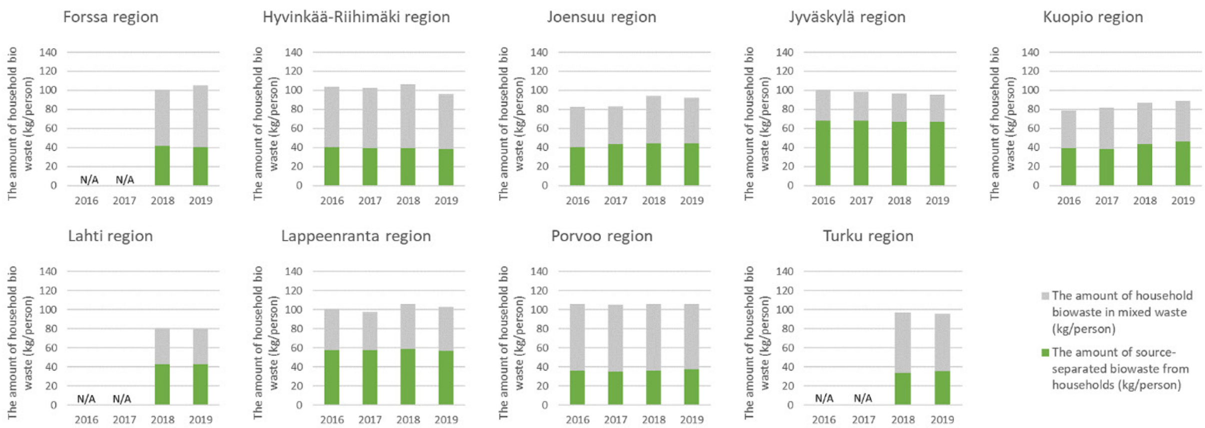


Figure 12. The estimated amounts of source-separated biowaste from households as well as biowaste left in the mixed fraction for the regions around nine forerunner municipalities from 2016 to 2019 in Finland. There was an increase in the source-separation rate in some of the regions, however, there was a decrease in others. Source-separation of biowaste is crucial in achieving the recycling targets set for MSW. There is a high degree of uncertainty in the estimates due to the lack of reliable and comparable local data on waste. The values cannot be compared between the regions. However, the results can be used in indicating regional developments.

4.3.3 Construction and demolition waste

Construction and demolition practices is the second largest producer of waste in Finland after the mining industry (Statistics Finland 2018a). Even nationally, monitoring of construction and demolition waste (C&DW) is challenging in Finland, and depends on estimates. In the project, the possibilities for sub-national monitoring of C&DW were studied. The main criteria for the selection of the method were that 1) the indicator ought to describe the amount and recycling rate of C&DW sub-nationally with reasonable accuracy and 2) the data ought to be collected with relatively simple means, so that it is resource-efficient to repeat the monitoring in years to come.

The first attempt was to collect the data using a questionnaire. Approximately five of the most significant actors in C&DW management were determined in each of the project's key regions using the national environmental compliance database, YLVA (Ministry of the Environment 2020b), and interviewing authorities who monitor the waste management sector. Authority interviews provided us with information on the most significant actors in the field in a certain area as well as local knowledge on the status of the construction sector in the area.

A questionnaire was sent to these companies, requesting data on the amount and treatment of the C&DW received from the same region. Discussions with the companies and responses to the questionnaire showed that the regional amounts of C&DW cannot currently be reliably ascertained with a questionnaire. C&DW is collected from wide regions and determining the origin of a waste stream to a single region, let alone a municipality, is not possible. C&DW often goes through a series of treatment steps before final utilisation. The waste can be stored after collection, pretreated (e.g. for removal of metals or large items), crushed and sorted. After that, the different fractions are usually sent to different locations for recycling, incineration or deposition. The companies interviewed represented all of these steps of waste management. Hence, the waste they receive and treat will overlap with the waste received and treated by the other companies. The individual waste stream is virtually impossible to follow. These same difficulties are the reasons why the data on waste streams from the environmental compliance database YLVA (Ministry of the Environment 2020b) cannot be reliably used for the sub-national monitoring of C&DW either. These approaches had to be abandoned.

As a second attempt, the possibilities for monitoring the C&DW from public construction activities were studied. In the initial data collection efforts and interviews with a few municipalities, it turned out that only few municipalities collect such data, and the data is not comparable between municipalities.

Finally, it was decided that the regional monitoring of amounts of C&DW would be carried out based on national statistics on waste (Statistics Finland 2018a) and statistics on construction business activities (Statistics Finland 2018b) in each of the key regions in the project. The recycling rate, 58%, is only described for C&DW from construction of housing based on modelling in a study by Salmenperä et al. (2016).

The more business activities there are in the construction sector, the more C&DW is produced. The variation in the amounts of C&DW between the project key regions, based on this indicator, is directly dependent on the construction activities (Figure 13). The amount of C&DW per person in 2017 was 2.4 tonnes/person in Southwest Finland and 2.3 tonnes/person in Central Finland. The amounts were 1.9 tonnes/person for both North and South Karelia.

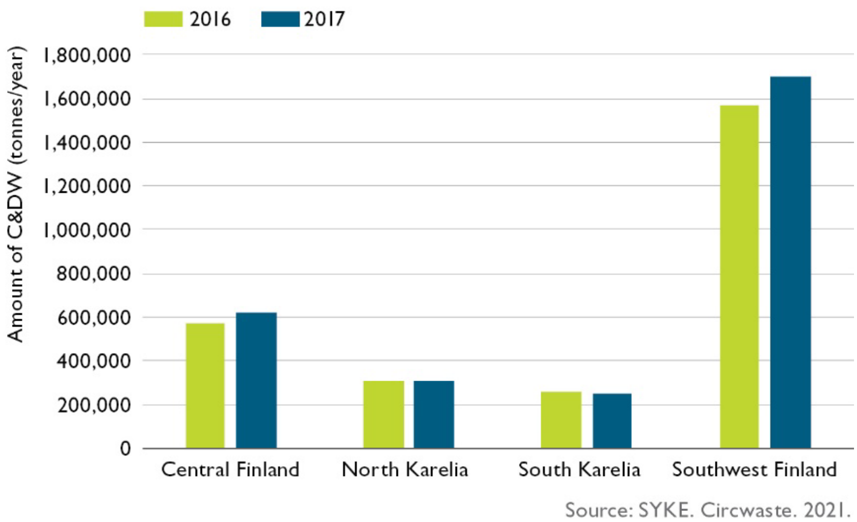


Figure 13. The estimates of amounts of construction and demolition waste (C&DW) vary between the key regions due to differences in construction and demolition activities.

4.3.4 Waste Electrical and Electronic Equipment (WEEE)

The amounts of WEEE in the project key regions are calculated based on the national producer statistics on WEEE collected from households (Centre for Economic Development, Transport and the Environment 2018). The national statistics are weighted according to the population of each of the regions (Statistics Finland 2020f). The utilisation rate of WEEE is calculated by dividing the WEEE collected from the households by all WEEE, including both separate collection of WEEE (Centre for Economic Development, Transport and the Environment, 2018) and WEEE found in mixed waste (Suomen kiertovoima ry KIVO 2020). The content of WEEE in the mixed MSW is estimated based on the composition analysis carried out by the local public waste management company, if such a survey has been carried within the last five years. If not, a national average consistency of mixed MSW is retrieved from the database of the association for public waste management in Finland (Suomen kiertovoima ry KIVO 2020).

Due to the lack of local data on the actual amounts collected, the differences in the amounts and utilisation of WEEE between the key regions are due mostly to the population of the region (Figure 14).

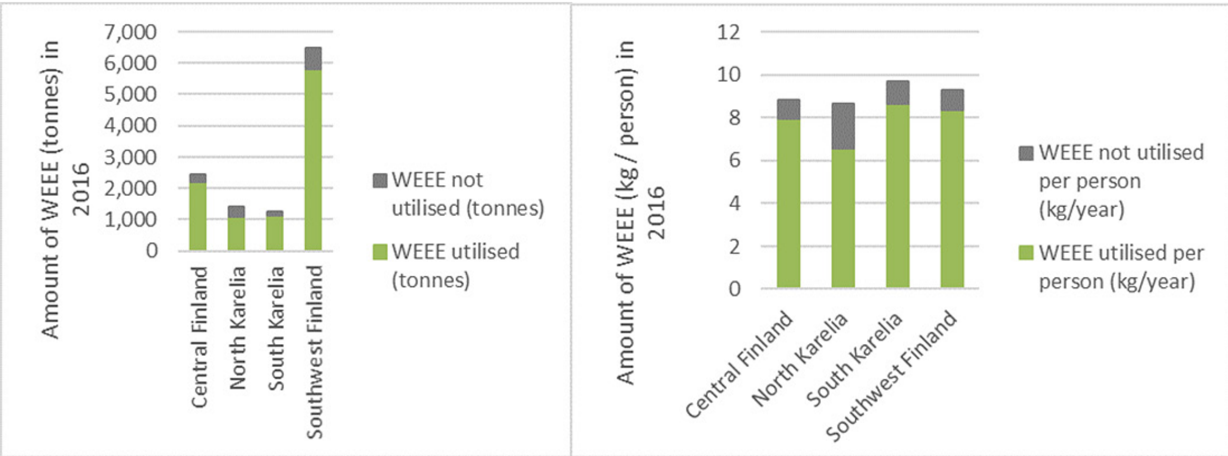


Figure 14. The estimate of the total amount of WEEE is the highest in Southwest Finland, which has the largest population. The amounts and utilisation of WEEE per person are similar in all the regions, according to the approximate estimate based on national monitoring. (Centre for Economic Development, Transport and the Environment, 2018, Statistics Finland 2020f, Suomen kiertovoima ry KIVO 2020).

4.3.5 Waste-specific indicators of the pilot projects

The Circwaste project consists of approximately 20 sub-projects closely linked to waste management and the circular economy. Many of the sub-projects are practical pilots testing new treatment processes, utilisation of secondary materials, or collection and sorting of waste. The pilot projects have determined individual indicators in order to monitor the impacts of the pilots on waste management and the circular economy locally (Figure 15).

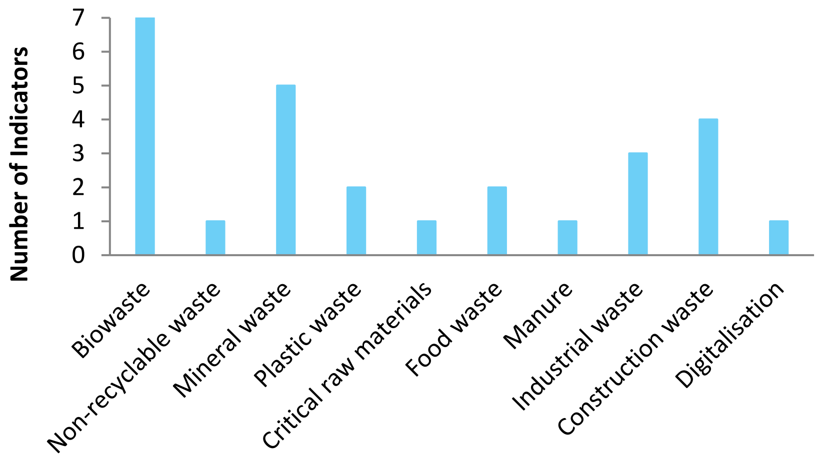


Figure 15. Number of indicators for the waste fractions. Each of the pilots carried out in the project determined project-specific indicators for measuring the effects of the pilot on waste management and circular economy. Most of the pilots are related to biowaste, mineral waste or construction waste.

The project partners carrying out the pilots collect the data, which is then combined by SYKE for collective analysis. The monitoring of individual pilots can give insight into factors such as possible savings in virgin materials from using secondary raw materials or the benefits of a new processing technology for manure for savings in logistics.

4.3.6 Regional waste amounts

One of the key targets of the European waste policy is to decouple the generation of waste from economic growth (European Commission 2020a). As circular economy practices are widely adopted in the economy, the extraction of virgin raw materials ought to decrease, i.e. through decoupling of economic growth and well-being from material use. Since the waste amounts correlate with use of natural resources (Figure 8), circular economy development should also be leading to a decrease in total amounts of waste. Regional waste amounts are thus general indicators of the change to the circular economy.

Total national waste amounts are reported annually by Statistics Finland (2018a). However, sub-national statistics on waste are not available in Finland. Rough estimates of regional waste amounts for Finnish regions can be calculated from the data in the national monitoring database for environmental compliance, YLVA (Ministry of the Environment 2020b). As the database has been designed for monitoring individual plants, the data is poorly suited for collective, sub-national monitoring purposes. Hence, the reliability of the regional estimates is low.

However, in the project, sub-national estimates for total waste amounts are being calculated (Figure Figure 16). The estimates of the total amounts will be proportioned to the population and gross domestic product (GDP) of each of the project's key regions. The business structure of the region will be used to explicate the results, since industrial and mining waste account for the majority of the total waste amounts.

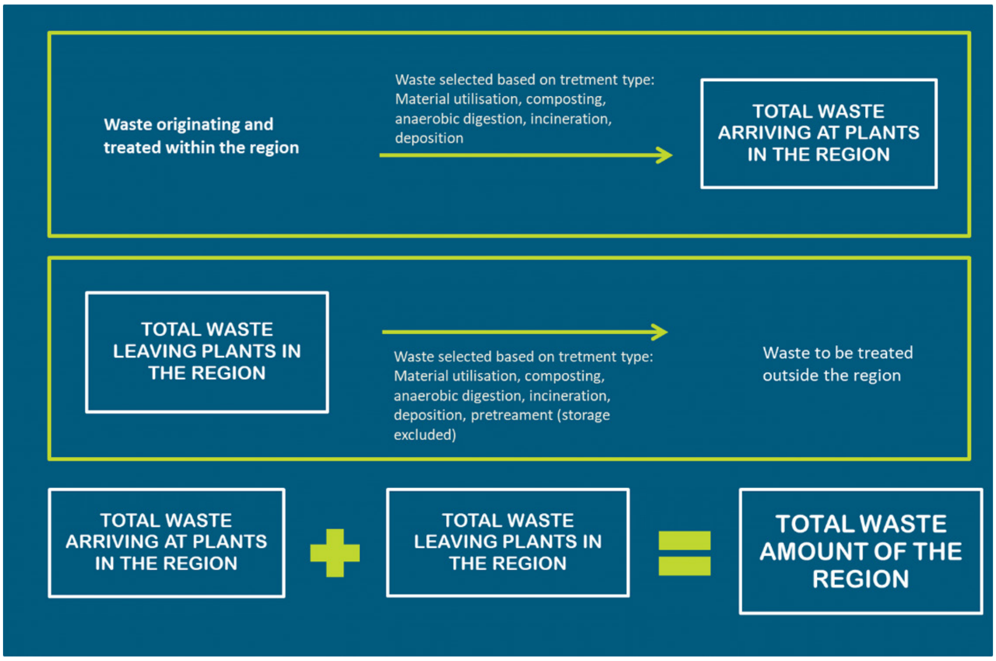


Figure 16. Total waste amounts are estimated as a sum of waste streams coming for final treatment in each region or leaving for any kind of treatment outside the region. The data is collected from the national environmental compliance database (YLVA) (Merilehto 2018).

The reliability of the sub-national waste data from the YLVA database is weak. Currently, the YLVA database is in many cases the only source of waste-related data in Finland. The major threats to reliability in the use of YLVA data for regional analysis are inaccurate origin and final locations of the waste streams, double-counting of waste streams due to pre-treatment chains, missing waste streams due to lack of coverage in the use of the database and errors in issuing the data. In addition to this, from 2016 to 2017 the database was renewed, and new facilities were involved in the use of the database. This change may decrease the reliability of the data and it most likely increased the waste amounts. The errors in the results come from many sources and the magnitude of the errors is difficult to assess.

4.4 Business and innovation indicators

4.4.1 Circular economy business

The circular economy is expected to fundamentally change how business is done. Thus, the monitoring of the circular economy in terms of business, economy and innovations is crucial. At sub-national level, the monitoring of circular economy business in this indicator set consists of qualitative and descriptive monitoring of local forerunner businesses, based on the local economic structure. In addition to these, more comprehensive, quantitative and statistics-based monitoring of circularity in business is being developed by Statistics Finland.

Monitoring the circular economy sub-nationally on a monetary basis is challenging. Multiple approaches in the monitoring of the circular economy business have led to a two-way approach. Firstly, regional circular economy business interviews offer a local, yet mostly qualitative, insight into the development of the circular economy in the business sector. Secondly, an analysis by Statistics Finland on combining existing statistics into a set of circular economy business indicators will monetarise the development of the circular economy business nationally.

The qualitative sub-national research is carried out by monitoring the development of the circular economy turnover of 3–5 locally significant businesses that had an interest in the circular economy in each of the key regions in the project. The companies were selected for the monitoring based on their field of business (Figure 17).

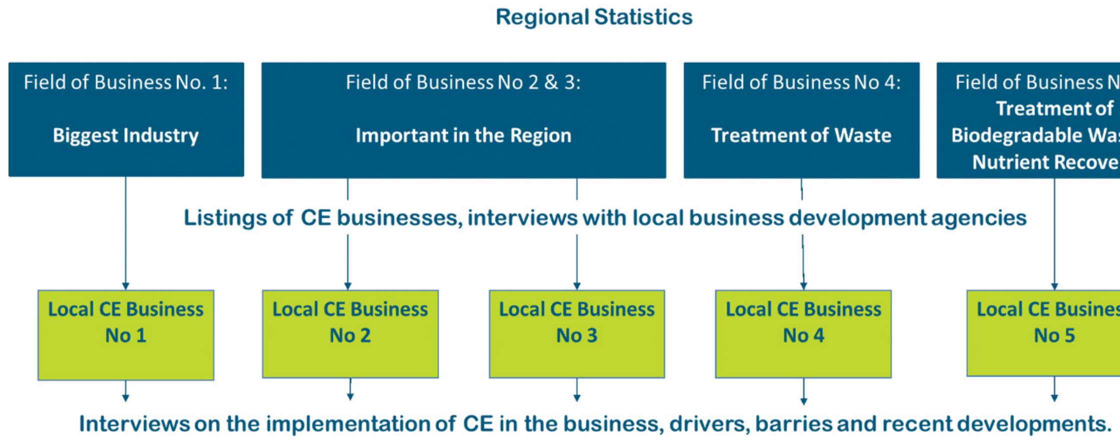


Figure 17. Selection of companies for the circular economy business interviews was based on the key fields of business in each of the project's key regions. After the selection of the key fields, the individual companies in each field were selected based on interviews with local business development agencies, as well as online listings of local circular economy businesses.

The key fields of business for each region were selected based on the structure of the region's economy. The single biggest industrial field was selected based on its economic importance and impact on regional waste production. Two key fields were selected to represent the qualities of the region's economy compared to the other regions. Fields of businesses that were larger in some regions compared to the others were selected, to represent the specific characters of different regions, affecting their ability to implement the circular economy. The last two fields of businesses were selected based on the scope of the Circwaste project for implementing NWP targets. Since the aim of the project is to promote the NWP, the last two fields of business were determined based on the scope areas of the NWP: the waste treatment sector and treatment of biodegradable waste and nutrient recovery.

Within the fields of business selected, individual companies were selected based on their local importance, activity in the circular economy, and interest in participating in the monitoring. The aim here was to increase the probability of acquiring as reliable data as possible on the development of circular economy turnover. The company's interest in the circular economy was determined based on the prevalence of the company in clean tech or circular economy business listings, e.g. from the Finnish Innovation Fund Sitra (SITRA 2017), interviews with local business promotion organisations, and company websites.

An online questionnaire on the implementation of circular economy in individual businesses was carried out and sent for a pilot round to the selected businesses in one of the regions. Due to low response rates and further discussions with statistics authorities on the reliability of the results, the questionnaire was terminated. A new, more detailed approach was taken.

The companies were classified based on their fields of business. For each field, a different approach was taken to define the circular economy turnover. For an example, for an environmental service business, circular economy turnover would include the entire turnover of the company. For the metal industry, circular economy turnover would be evaluated based on the use of recycled feedstock. For the machinery industry, the circular economy turnover would be the sum of the turnover from services, modular design, and re-manufacturing. Due to the complex nature of the topic and possibly biased responses, telephone interviews were chosen instead of an online form.

In the first round of interviews, annual data from 2016–2018 was collected. In addition to business turnover data, background information on the status of the circular economy in the company was also investigated. Most of the companies contacted wished to participate in the monitoring (Table 11).

Table 11. The companies interviewed presented the key fields of business in their regions.

Region	No of Companies Contacted	No of Companies Interviewed	Fields of Business
Central Finland	5	3	Forest Industry Machinery Industry Research and Development
North Karelia	5	4	Waste Treatment Biorefining Information and Communications Services and Machinery
South Karelia	5	3	Waste Treatment Services Biorefining
Southwest Finland	9	5	Waste Treatment Construction Industry Biorefining Metal Industry

Measuring the proportion circular economy business accounted for of companies' turnover turned out to be challenging. For many companies, providing such detailed data on only some operations, parts of the business or individual offices was not practically feasible. In addition to this, open publishing of the turnover data for the circular economy related business operations was not favoured in all the companies. Eventually, the decision was taken to primarily monitor the qualitative status of circular economy in the selected businesses. However, the interviews provide very valuable data on the drivers of and barriers to circular economy in local businesses (Figure 18).

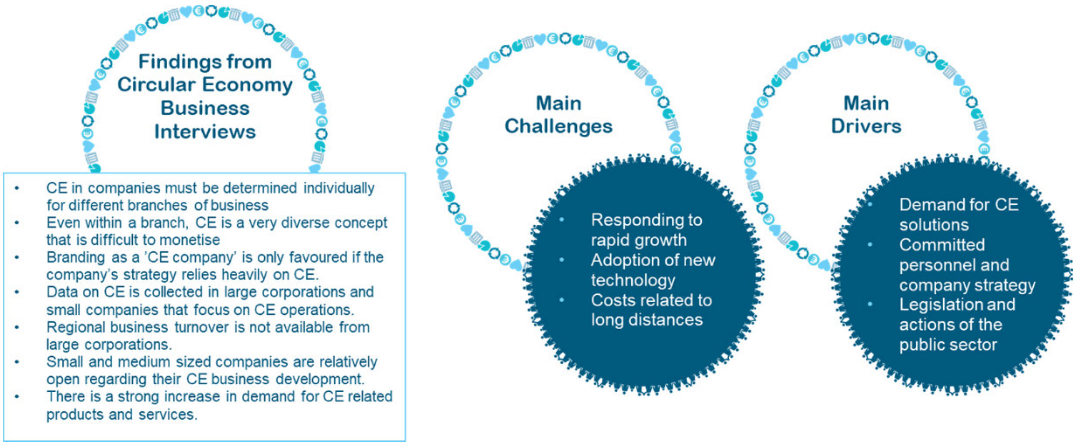


Figure 18. Interviews with local circular economy businesses provided insights on the drivers and challenges of implementing the circular economy in business.

The quantitative monitoring of circular economy business was developed based on experiences from the interviews. Based on previous experiences of Statistics Finland on monitoring the development of the environmental business sector, it is very challenging to measure the development of a multi-sectoral theme such as circular economy. Regional assessment is problematic, mainly due to restrictions in publishing data that is too detailed, where a single company could be identified. Currently, there is no regional monitoring of circular economy business.

Import and export data are only available on a national basis and the allocation of the data to regions, let alone municipalities, has little in the way of grounds in a country with a small population and relatively small number of businesses, such as Finland. Privacy concerns limit the use of regional statistics on businesses. At regional and municipal level, the statistics have large gaps due to protection of privacy of individual businesses.

Statistics Finland has recently started investigating all national data sources in order to find existing data that could be combined into a set of indicators monitoring the development of circular business in Finland.

As already mentioned (in section 4.1), resource decoupling and impact decoupling (UNEP 2011) are aspired to through nonmaterial economic growth. Shifting the demand from traditional business to business in the services sector could meet the requirements of nonmaterial economic growth. This shift also requires changes in customer behaviour and is therefore probably a long-term process. To assess trends in customer behaviour and to predict the role of the service sector, data was produced on the **demand for value added in the services industry**. Instead of the traditional statistical definition of services, only selected services were included in the study. Services selling products and therefore producing ownership of products were left out. The aim was to measure development in Finnish society that is creating value added without increasing material consumption and creating new ownership. The chosen industries were related to maintenance, repair, education, etc. that provide non-material services.

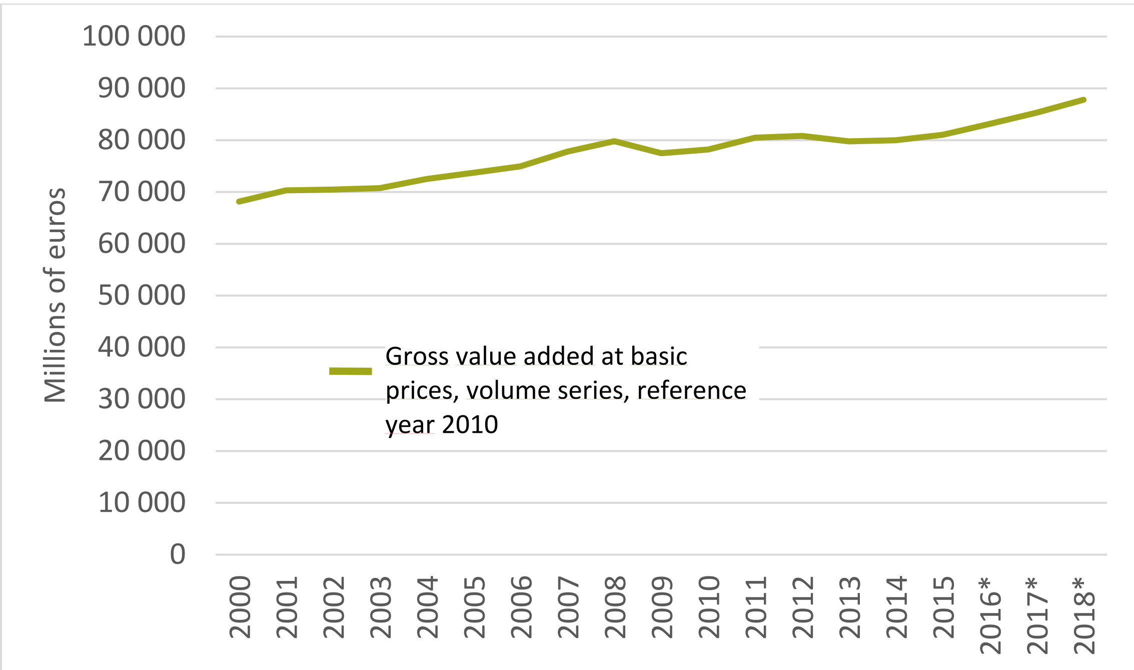


*Figure 19. Development of gross value added of selected services. Selected services covers only selected non-material services, excluding the sale of material products that create ownership. *Preliminary data for 2016–2018.*

From the Standard Industrial Classification TOL 2008 the chosen industries were: maintenance, repair and spare parts of motor vehicles (452, 453, 454), accommodation in hotels etc., restaurants (I, 55-56), information and communication (publishing, radio, television and other telecommunication) (J, 58–63), financial services (K, 64–66), leasing, properties and real estate (682, 683), consulting services, marketing (M, 69–75), renting and leasing, employment services, travel agencies, landscaping, translation services (N, 77–82), education (P, 85), health services (Q, 86–88), culture, entertainment, libraries, sport and other recreational activities (R, 90–93), other services such as organisations (S, 94–96) and households as employers (97).

The results in Figure 19 show that the gross value added of the services sector in Finland in 2000–2018 has increased quite steadily – in total by about 15%. However, there is no clear evidence in recent years that would show increased use of services as aspired to by circular economy.

4.4.2 Research and development (R&D) projects

One of the suggested indicators listed in the eco-innovation action plan is circular economy financing (European Commission 2020c). Growing new business requires research and development (R&D) work to grow, and therefore the indicator R&D financing was chosen.

Data on circular economy R&D projects in the project key regions and in Finland in general has been gathered since the beginning of the project in 2016. By 2019, over one hundred circular economy related projects had been identified in Finland, with a total budget exceeding EUR 81 million (Figure 20). This does not represent all the R&D activities in the circular economy in Finland, however. There is no comprehensive database on such projects. The manual data collection is based on monitoring the work of fellow researchers and research institutes, monitoring publications and funding decision, and participating in events related to the circular economy.

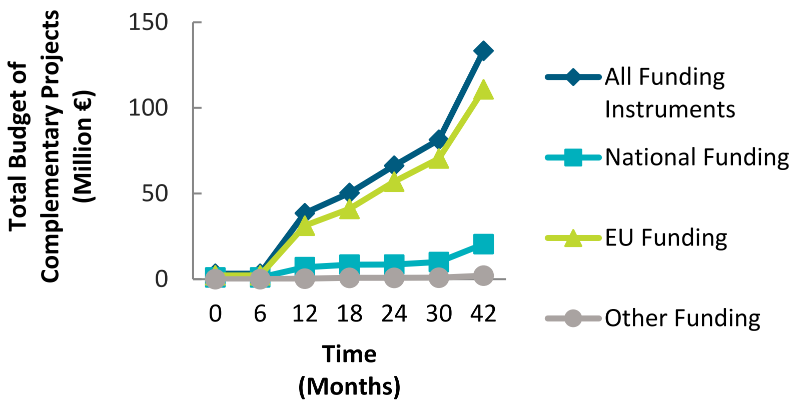


Figure 20. The total budget of circular economy related projects launched in Finland from 2016 until spring 2020. Funding from the European Union dominates as the main source of funding.

The increase in the number and total budget of circular economy projects is due to a large extent to increased knowledge on ongoing projects, not necessarily an increase in funding. Hence, these results may only be interpreted as suggestive. However, the number of projects as well as their budget imply that funding for the circular economy is currently readily available in Finland. The public budget in Finland for research and development is about EUR 2 billion (Statistics Finland 2020d). A total of about EUR 140 million focused on the circular economy can be considered quite significant, however, compared to overall Finnish public financing.

The monitoring is focused on the four key regions in the project (Figure 21). The project partners within the regions provide valuable information on the newly launched circular economy projects in the regions, as well as apply funding for kick-off projects for Circwaste.

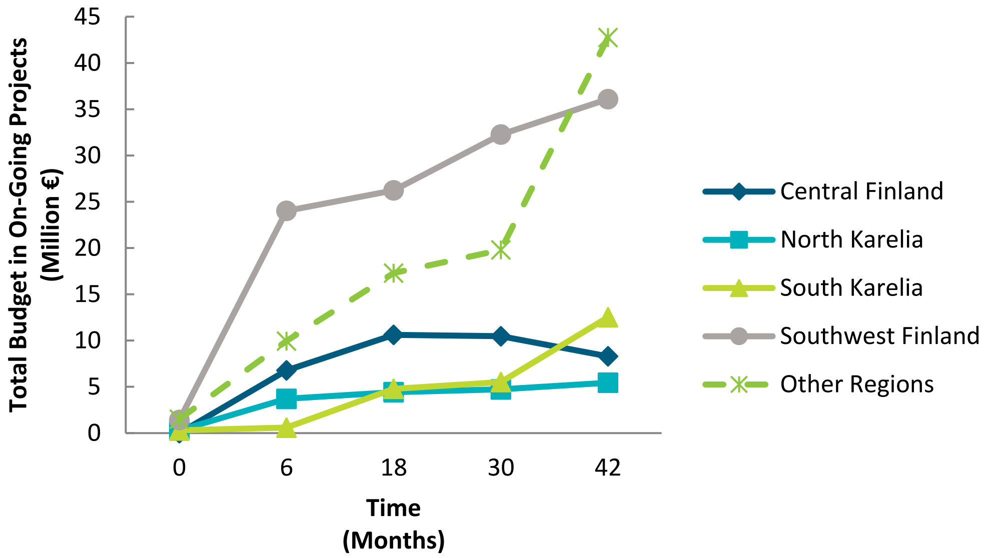


Figure 21. The number of the CE-related projects running has been highest in the Circwaste key region with the largest population – Southwest Finland. Other regions dominate in terms of the number of projects running, as regions such as the capital region, the Helsinki metropolitan area, are not among the key project regions.

A project as extensive as Circwaste is a major player in the national circular economy R&D world. The project actively connects actors in different projects working with similar or synergetic topics. For further information, see chapter 2.5 Complementary projects and municipalities.

4.5 **Socio-economic indicators**

The monitoring of socio-economic impacts of the circular economy most commonly focuses on the economic impacts (Pitkänen et al. 2020). It is expected (European Commission 2015 and 2020) that the transition to the circular economy will lead to an increase in employment and job creation through emergence or transformation of existing businesses and technologies. Similarly, the enhanced resource productivity and recycling of resources is expected to boost sustainable economic growth.

While the focus in circular economy indicator development has mainly been on environmental and economic impacts, only preliminary attempts have thus far been made to assess the social impacts of the transition to a circular economy (e.g. EcoAP, see Table 9 and European Commission 2020c). The transition to a circular economy, however, is also a profoundly social transformation. Sustainable circular economy production and consumption necessitates the participation of citizens. Citizens take part in circular economy, among other things, as consumers, users and maintainers of circular economy goods and services, as well as through reselling and returning discarded items and sorting and delivering waste for recycling (e.g. Wastling et al. 2018). On the other hand, the transition to a circular economy can have major social implications, such as unequal distribution of the benefits and disadvantages of the circular economy between different groups of people and geographical regions. Moreover, the much-aspired-to transition from owning to a sharing economy may not be equally welcomed or an easy step for all. (Pitkänen et al. 2020).

The Circwaste project aims to meet these needs to develop social indicators that can be used to monitor the impacts and prerequisites of the circular economy in the key project regions on a regular basis. Since no previous examples existed, a set of expert workshops was organised to elicit ideas and possibilities for monitoring the social aspects of the circular economy. In the first workshop, ideas for possible circular economy social indicators were identified and brainstormed. Some established examples and frameworks for assessing social impacts were used, including the UN sustainable development goals (SDGs), social impact assessment framework (Vanclay 2003) and community capitals framework (Emery & Flora 2006). The aim of the workshop was to collect ideas for indicators that would cover all the different spheres of social impacts, ranging from impacts on human health and well-being to culture, social justice, rights, accessibility of services, fears, hopes and future prospects (see Vanclay 2003). After collecting as many ideas as possible, in the following workshop the ideas were ranked and those that had the highest potential were selected for indicator development. Six criteria proposed by van Haaster et al. (2016) were used in ranking the ideas:

- clarity (to measure a clear and measurable entity)
- logic and simplicity (an unambiguous measurement rule and needs to be logically linked to the criterion it is supposed to measure)
- applicability (applicable to different regional settings across Finland)
- relevance (representing key aspects of social sustainability)
- coverage (indicators must cover the main aspects of the circular economy)
- feasibility/data availability (indicators must draw on information that can be obtained and updated regularly).

Based on the ranking, the following indicators that measure different types of social impacts and aspects of the circular economy were chosen for further development and testing: circular economy employment (different income categories, vulnerable groups' employment possibilities), shared resources and public spaces in joint use, circular economy capacity building and education, accessibility of recycling services and sustainable vehicle fuel sources. In addition to equality perspectives on accessing sustainable fuels, biogas fuel was chosen because it uses biowaste originating from municipalities as its raw material. Electric car charging points were chosen, because use of electricity to power cars facilitates creation of the conditions for replacing fossil natural resources with more sustainable energy sources, such as wind, solar and water.

4.5.1 Vulnerable groups' circular economy employment

The indicators on employment are important in monitoring the regional capacity of circular economy for creating jobs and growth but also for people's wellbeing. One aim of the circular economy is to increase wellbeing and equality ('to not leave anyone behind') (European Commission 2020a), so these factors must also be measured. The overall numbers in terms of employment, however, do not say much about the quality of the employment: Does the circular economy entail equal opportunities for people despite their social standing? What are the consequences of the circular economy for employment opportunities and jobs within more traditional fields of industry and business? To measure how circular economy employment opportunities are socially distributed, the project aims to develop indicators that measure the quality of circular economy employment, such as the division of jobs between different income or background education categories. These indicators are being developed together with Statistics Finland and will be published later in 2020.

This indicator measures the quality of circular economy employment in terms of the employment opportunities of vulnerable groups in circular economy jobs. The employment of vulnerable groups means people that may have difficulties in finding employment themselves and are therefore supported by different labour market policy services, which aim to advance the employment of the jobseekers. In Finland, the Ministry of Economic Affairs and Employment compiles statistics on the clients of the Employment and Economic Development offices (TE offices) in Employment Service Statistics. Services included in the statistics are, for example, labour market training, wage subsidies, training, work/training trials and job alternation leave. After consulting experts in labour market policy services, two different types of services were chosen as the basis of the indicator. These are targeted in particular at vulnerable groups such as young people with a low level of education, immigrants, people with disabilities and the long-term unemployed:

- Work trials in circular economy related work. A work trial (*työkokeilu*) is a tool to support entering or returning to the job market in situations where career options are not clear. During the work trial the participant receives unemployment benefit and the trial can last up to 12 months.
- Wage subsidies for circular economy related work. Wage subsidies (*palkkatuki*) often follow work trials and are intended for employers to encourage them to hire an unemployed jobseeker. The length of the wage subsidy is case-specific, and the employer can have up to 50% of the salary subsidised.

Employment Service Statistics record the number of people in work trials and with a wage subsidy annually in different regions by different categories, such as gender and age. Moreover, the statistics record the job titles of certain professions using the International Standard Classification of Occupations (ISCO) developed by the International Labor Organisation (ILO). In order to distinguish circular economy occupations, the classification, translated to the Finnish context by the TE-offices (TE-palvelut 2016), was searched for all occupation descriptions that referred to recycling or waste. To keep the indicator simple, the search was limited to recycling and waste. Other circular economy functions, such as repair, remanufacturing and rental or leasing services were excluded, because of the lack of comparable data. The search resulted in a list of 11 occupations ranging from manufacturing managers to town and traffic planners, incinerator operators, cleaners and refuse workers. Only three out of these 11 occupations returned hits for work trials and wage subsidies from the Employment Service Statistics: office cleaners (code 91121), cleaners at construction sites (91126) and refuse sorters (96121). The cleaners were further excluded from the analysis, so it was ultimately decided that the study would focus only on refuse sorters.

According to the ISCO classification, *refuse sorters identify, collect and sort discarded items suitable for recycling at dump sites and recycling enterprises or in buildings, streets and other public places* (International Labour Office 2012, 352). According to the classification, refuse workers are elementary workers situated at the lowest skill level – 1. At this level, typically only primary level or first stage basic education is required, and the occupations involve the performance of simple and routine physical or manual tasks. In the Finnish context it has been further specified that *refuse workers work in tasks related to the take-back, collection, sorting and handling of paper, cardboard, metal, glass and plastic. The work can also be related to the receiving or selling of used things, furniture, clothes and equipment* (TE-palvelut 2016). Typically, refuse workers in Finland are employed at recycling centres, secondhand shops and flea markets maintained by municipalities, private companies or third sector organisations. The designation of work trials and wage subsidised work under the occupation refuse sorter may not always be clear. For example, those working in the sale of recycled items may just as well be designated as sales assistants.

According to the statistics, out of the over 1,100 different occupations, refuse sorter is one of the most common occupations for work trials and wage subsidised work, trumped only by secretaries and shop sales assistants. In 2019, 3.6% of all work trials and 3.9% of wage subsidised work periods were carried out as refuse sorters nationally (see Figure 22 & Figure 23). In some of the project key regions the percentages were even higher. When comparing the figures between 2016 and 2019, a slight increase can be detected nationally and in almost all the key regions. This suggests that the importance of circular economy related work is increasing for providing employment opportunities for vulnerable groups with limited professional skills.

However, there are some reservations that need to be taken into account when interpreting the indicator. Firstly, the indicator is heavily based on labour service policy practices, which may differ between years and different TE-centres and regions. For example, the overall number of people employed through wage subsidies has increased, which suggests that more funds have been directed to this labour service instrument. Moreover, work trials and wage subsidies do not necessarily lead to subsequent, longer-term, employment. For example, it has been found that wage subsidies in the municipality sector in particular are not very effective in increasing the long-term employment of people (Asplund et al. 2018). Hence, although work trials and wage subsidies as refuse workers are important in activating people, they may not lead to long-term employment in the circular economy sector.

Secondly, there are also some reservation in relation to how this indicator captures or measures the transition to the circular economy. The indicator assumes that as new circular economy business opportunities and activities emerge, the significance of the field also increases in the vulnerable groups' labour service. However, the opposite development is also possible. As the profitability of the traditional circular economy functions, such as sorting, recycling, collecting, repairing etc. increase, this may increase private businesses' interest in the field, shifting the focus from the public and third sector organisations' non-profit and charity work to business development. This may also have consequences for the employment of vulnerable groups.

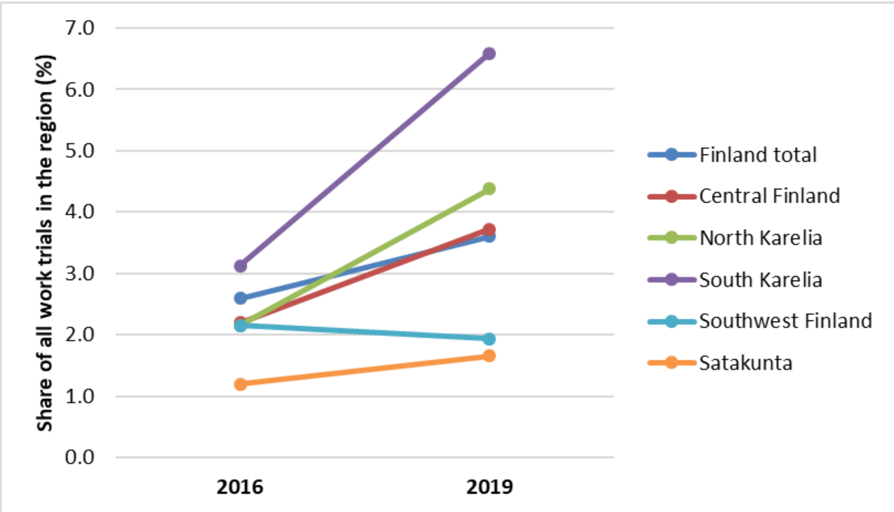


Figure 22. Circular economy employment quality. The proportion of workers in work trials in refuse sorter roles in 2016 and 2019 by region. Source: Ministry of Economic Affairs and Employment 2020: Employment Service Statistics.

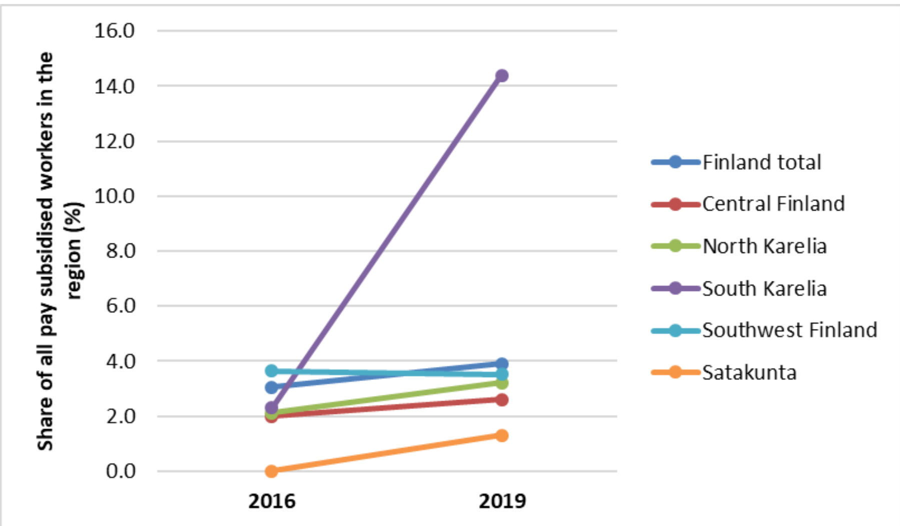


Figure 23. Circular economy employment quality. The proportion of pay subsidised workers who work in refuse sorter tasks in 2016 and 2019 by region. Source: Ministry of Economic Affairs and Employment 2020: Employment Service Statistics.

4.5.2 Shared resources

This indicator focuses on the availability of public shared resources. The term public shared resources is used here to mean the different types of public facilities and goods that are available to citizens for free or for a small fee. The availability of shared resources is relevant in terms of the circular economy as they allow people to avoid consumption and use existing resources more efficiently. More specifically, it was decided that the monitoring would focus on joint use public school facilities, bike-sharing and library items excluding books. These three examples were chosen as they cover different types of shared resources that can be available in municipalities of different sizes and with different needs.

There is no national data available on public shared resources, so the data had to be collected individually from the different municipalities. Collecting data from the whole country comprehensively would not have been possible. Therefore, the availability of resources was investigated at in the capitals of the five project key regions and in one smaller municipality in each of the regions (see Table 12). To make the number of shared resources comparable between different sized municipalities, the indicator results will be presented as values per 1,000 or 10,000 citizens.

Table 12. Key project regions, municipalities included in the study of shared resources, and the populations of the municipalities at the end of 2019 (Statistics Finland 2020f). Capitals of the key regions are indicated in bold.

Key region	Capital or smaller municipality included in the study	Population
North Karelia	**Joensuu**	76,850
	Nurmes	9,552
South Karelia	**Lappeenranta**	72,634
	Imatra	26,508
Central Finland	**Jyväskylä**	142,400
	Muurame	10,164
Satakunta	**Pori**	83,934
	Kankaanpää	11,286
Southwest Finland	**Turku**	192,962
	Kaarina	33,937

Joint use community facilities and online booking systems

Community facilities in joint use are public spaces and facilities, such as schools, libraries or sports facilities, that can also serve the wider community beyond their main purpose. Such public shared spaces are an important form of sharing economy, as they benefit the community's social, recreational or civic needs. They can be used to save significant amounts of resources, such as energy and materials, as well as ensuring existing idle public spaces are used more efficiently.

Originally, the aim of this project was to gather data on different types of spaces in joint use offered by municipalities in the project key regions by contacting the municipalities or collecting data from online booking systems. The initial plan was to collect data both on the number and the area of the different types of spaces. However, there were various challenges in the process.

First, spaces in joint use can be difficult to separate from municipalities' general infrastructure. Spaces that have specifically been built for municipal citizens' use, such as library facilities, rug washing sites, sports fields or community gardens, could all be considered spaces in joint use. Although society also benefits from public infrastructure resources, in this study the facilities in joint use were limited to spaces that are intended for other uses but that have the potential to be used outside of their original purpose and, hence, promote the goals of circular economy. Such spaces include, for example, sports halls in schools, classrooms and other spaces such as canteens, but exclude all the previous examples as they were originally constructed to be freely shared and used by all municipal citizens.

Furthermore, to be able to collect comparable data from different municipalities, it was decided that the indicator would focus only on the use and availability of school spaces. School spaces are mainly used for education purposes only during the daytime on weekdays, but must be heated and maintained with public funds every day. Using these existing spaces for other community purposes, too, is more resource and energy efficient than building and maintaining separate community facilities.

Second, the different ways of measuring and indicating the sizes of spaces make them very difficult to compare. For example, the sizes of sports halls in schools were indicated by floor area. However, the sizes of classrooms and other facilities were indicated by the number of people they are suitable and safe for. In addition to this, it was noted that floor area does not necessarily indicate the functionality of a shared space. For example, classrooms are often significantly smaller than sports halls, but as they are used for different purposes, they might be suitable for the same number of people. Therefore, only the number of spaces was finally included in the comparison.

The results of the indicator are represented in Figure 24. The number of joint-use school spaces varied between 49 in the biggest cities of Turku and Jyväskylä to three in Nurmes, the smallest municipality included in the comparison. On average, there were approximately three school spaces per 10,000 citizens, with Lappeenranta ranking the highest and Joensuu the lowest.

Besides problems related to the availability of reliable and comparable data, there are also some reservations that should be taken into consideration when interpreting the results. It must be considered that the number of shared public spaces does not fully describe the savings in resources in each of the cities, as the size of the spaces varies significantly. In some municipalities, the classrooms are smaller, but there are more of them in joint use. In other municipalities large spaces may benefit many more users.

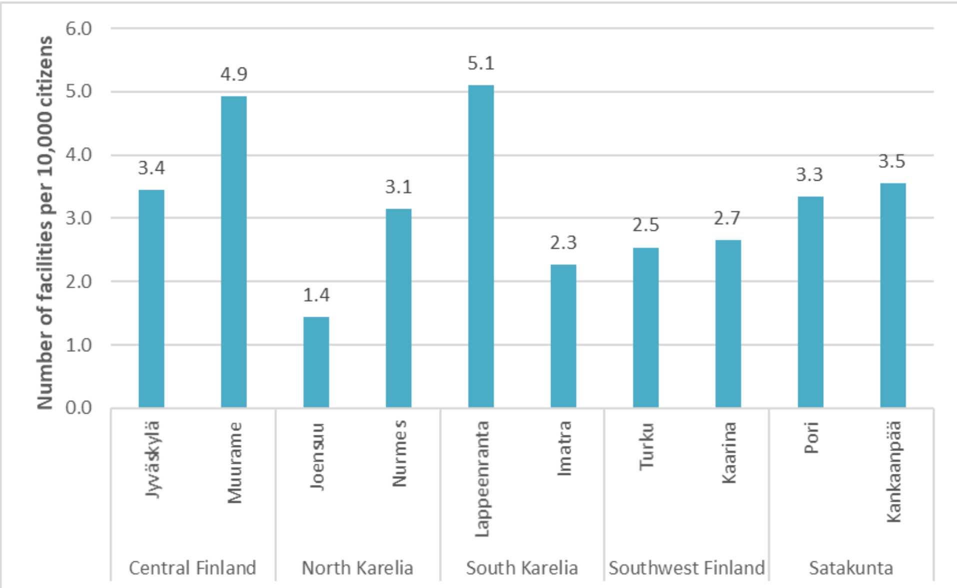


Figure 24. The number of school spaces in joint use per 10,000 citizens.

The data used in the comparison was collected primarily through the municipalities' websites and online booking systems. It was found that in the bigger municipalities in particular, there often was no centralised information available on all the public facilities in joint use. Although most municipalities had some type of a public facility booking system, this did not mean that all the available school spaces were listed there. Apart from sports halls, there was usually no information available online on the school spaces available for the use of citizens. The school classrooms were only covered in the booking system of one of the municipalities (the municipality of Lappeenranta). In addition to this, the school classrooms and gym halls were often managed by different people or booking systems. The schools themselves were usually responsible for letting out their spaces. In many municipalities the only way to book a school facility was to contact the school principal or secretary directly.

Establishing an online booking system is an effective way to intensify the joint use of public spaces (KEINO 2020). Based on the findings of this study, there is a lot of potential in the development of such systems in Finnish municipalities. To complement the indicator of joint-use community facilities, a comparison of the online booking systems available was conducted.

The different booking systems were rated using a four-level scale indicating the availability and functionality of the system. The openness of the system to different user groups as well as limits on its use were also investigated. This indicator focuses mainly on the level of digitalisation in the sharing of public facilities. However, it does not measure the number of facilities in joint use. Therefore, even a high rating for the booking system does not necessarily mean that the availability of shared facilities is extensive. It is essential to measure both the availability of shared facilities and the usability of the booking system to get a comprehensive view of the joint use of facilities in municipalities.

It was found that six of the ten municipalities included in this study had a well-developed system with an open online booking for all users and different types of bookings in the summer 2020 (Table 13). All the regional capitals had an online booking system available. In some municipalities, there were different parallel booking systems available. For example, the municipality of Turku had a system for library spaces and another one for sports halls. The municipality of Nurmes was the only municipality that did not have an existing online booking system. However, in a municipality with a small population the need for an online system could be lower than in a regional centre. The municipality of Joensuu, on the other hand, had an online catalogue of the availability of the facilities, instead of a booking system. There, the bookings were made either via email or telephone

Table 13. The degree of digitalisation of the booking of public facilities in joint use in the different municipalities in Finland. Booking systems in each municipality were rated according to the extent of functions and the level of openness to different users in the summer of 2020. Regional capitals are shown in bold.

Region	Municipality	Booking system rating	Description of the booking system
North Karelia	**Joensuu**	1	System with no option to book (catalogue style)
	Nurmes	0	No online booking system
South Karelia	**Lappeenranta**	3	System with the option to book for everyone, with different types of bookings
	Imatra	2	System with the option to book but limited in use (e.g. only for clubs or associations; only regular booking)
Central Finland	**Jyväskylä**	3	System with the option to book for everyone, with different types of bookings
	Muurame	3	System with the option to book for everyone, with different types of bookings
Satakunta	**Pori**	2	System with the option to book but limited in use (e.g. only for clubs or associations; only regular booking)
	Kankaanpää	2	System with the option to book but limited in use (e.g. only for clubs or associations; only regular booking)
Southwest Finland	**Turku**	3	System with the option to book for everyone, with different types of bookings
	Kaarina	3	System with the option to book for everyone, with different types of bookings

Bicycle-sharing

This indicator monitors the number of city bicycles in the municipalities. Public bicycle programmes and bicycle sharing have received increasing attention over recent years. Many Finnish municipalities have introduced their own bicycle-sharing schemes through which citizens and tourists can rent a bicycle for a small fee. Bicycle sharing schemes encourage shared use and allow citizens to avoid buying a bicycle. In addition to this, they encourage citizens to avoid using other, more resource intensive modes of transport, such as private cars or even public transport. Bicycle sharing can, thus, have many environmental and social effects by creating a larger cycling population, increasing transit use, decreasing GHG emissions and improving public health (DeMaio 2009).

Data on the number of city bicycles was collected from the municipalities or from the operator managing the bicycle sharing scheme. Out of the ten case municipalities, the municipalities of Joensuu, Lappeenranta, Imatra, Turku and Pori each had a city bicycle sharing scheme in the summer of 2020. In all these cities, the bicycle sharing scheme was relatively new, adopted in either 2018 or 2019.

In absolute numbers, the city of Turku had 300 bikes, Joensuu 90, Lappeenranta 85, Pori 57 and Imatra 50. In these municipalities, the number of city bicycles per 1,000 citizens varied between 0.7 and 1.9(Figure 25). In Pori, the number was somewhat lower than in the other municipalities. However, the number of bicycles in the town of Pori (57) included 50 conventional city bicycles and seven bicycles that could be borrowed from the town service point for a certain amount of time for a deposit. The latter have been in use since 2000, significantly longer than city bicycles in all the other towns.

The towns of Jyväskylä, Kaarina, Kankaanpää, Nurmes and Muurame had no city bicycles in the summer of 2020. The main reasons for municipalities not taking up city bicycle sharing schemes include the maintenance and operational costs. For example, Vaarala & Översti (2017) estimated that introducing a comprehensive bicycle-sharing scheme with 300 bicycles, bicycle stations and docks in the town of Jyväskylä would cost approximately EUR 400,000/year. The high cost and lack of offers from companies led the municipality of Jyväskylä to withdraw its plans for introducing a bicycle-sharing scheme (YLE 2019). In the town of Kaarina, city bicycles were also considered when the regional capital, Turku, purchased its bicycle scheme in 2018. However, it was estimated that the bicycles would not be used enough to warrant their costs, and the funds were eventually spent on improving public transport instead (Kaarina-lehti 2018).

The remaining municipalities that had no city bicycles each have fewer than 15,000 citizens. In these small towns the costs of introducing a bike sharing scheme might be considered too high relative to the potential use of the bikes by locals and tourists. Even for a less comprehensive scheme without stations and docks, the annual costs of city bicycles can be tens of thousands of euros (Vaarala & Översti 2017).

On the other hand, the small size of a municipality does not always indicate that there would not be interest in a bicycle sharing scheme. The municipality of Imatra, a smaller town than Kaarina by population, has the highest number of bicycles per 1,000 citizens compared to all other municipalities investigated. The lack of city bicycle sharing scheme does not necessarily mean that citizens do not have access to shared bicycles. The libraries of some of the smaller municipalities investigated offered bicycles to borrow. The shared bicycles from libraries are dealt with in greater detail in the next chapter, focusing on library items.

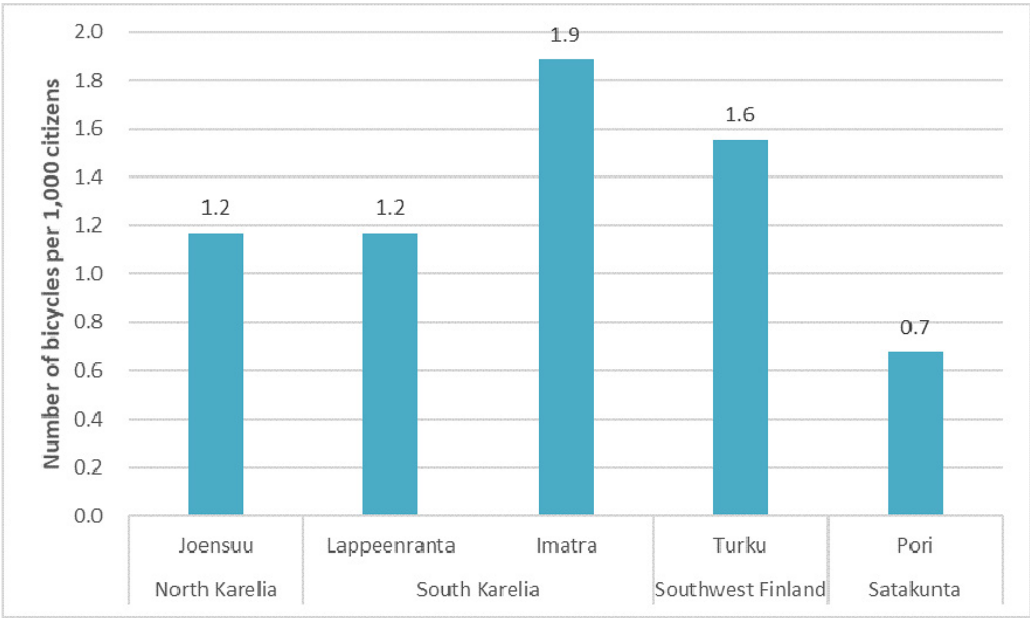


Figure 25. The number of city bicycles per 1,000 citizens in the selected municipalities in the Circwaste project in June 2020. Towns with no bicycle sharing schemes were excluded from the figure.

Library items

Besides the community spaces and city bicycles in joint use, the availability of shared library items at the public libraries in the selected municipalities is also monitored in the project. As can be seen from the indicators of shared resources, different municipalities have different strengths. For example, smaller municipalities rarely have comprehensive city bicycle sharing schemes. However, smaller-scale lending from libraries may provide the citizen with the same service. Thus, it is essential to look at different types of shared resources.

Public libraries can basically be regarded as sharing economy pioneers. According to the law, all Finnish municipalities should have a library service. Libraries have expanded their selection beyond books, magazines, CDs and DVDs. Nowadays, they often also loan out other types of items, such tools and devices, equipment for hobbies or musical instruments. The sharing of such items can help to reduce consumption and give people access to resources that they could not otherwise afford to purchase.

The number of items was recorded from the online systems that all the public libraries investigated had. All the case libraries used a similar online management system that allowed users to search for all books and items stored in the libraries. Available items other than books, magazines, CDs or DVDs were listed under a sub-category called *item* (in Finnish: esine). Thus, everything that was identified as items by libraries themselves could be included in the indicator. However, information on how often the library items were loaned out was not recorded or shown in the online systems. Hence, even though this indicator shows the number of items on offer, it does not describe the popularity of use of the shared items.

All the case public libraries offered library items, which shows that libraries around the country have expanded their services and are beginning to test different types of new activity. There was variation in the number of items available per 1,000 citizens, varying from 0.8 items per 1,000 citizens in the municipality of Kaarina to 6.1 items per 1,000 citizens in the municipality of Nurmes (Figure 26). The absolute number of items was higher in the bigger cities (the municipalities of Jyväskylä, Pori, Joensuu and Turku), where there were also more public library services available. However, the municipalities with the lowest number of citizens (Nurmes and Muurame) had proportionally the highest numbers of items per 1,000 citizens. The municipalities of Kaarina and Turku (both located in Southwest Finland) had the lowest numbers of items per 1,000 citizens.

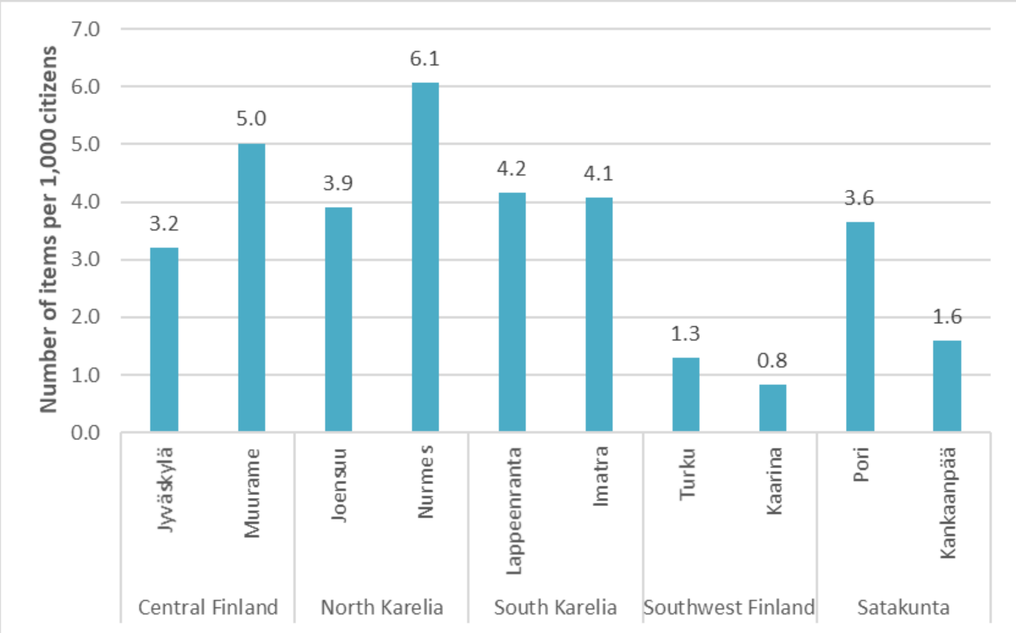


Figure 26. The number of library items per 1,000 citizens in June 2020 in the selected municipalities in Finland. Available items other than books, magazines, CDs or DVDs were listed under the category Library Item.

In addition to the number of items available in libraries, the types of item were also investigated. The libraries offered a large variety of items, and the selection differed between the municipalities. The items were divided into rough categories to see which were the most prominent categories. In all the municipalities, the most commonly found items were equipment for hobbies, including board and yard games, sports equipment and musical instruments.

Clothes and accessories were also commonly found in the libraries. Even though reusable canvas bags (which are most likely borrowed by customers to carry the books home) were the most common accessories found, umbrellas and reading glasses of different strengths were also listed. Household appliances and tools were found in most of the municipalities, but there were generally only a few of them available. In addition to this, there were several household energy meters available. Some libraries loaned out vehicles, such as kick scooters or bicycles. Interestingly, in the municipality of Nurmes, which ranked the highest in terms of available items per 1,000 citizens, many of the items on offer were handicrafts equipment, such as knitting needles or crochet hooks. Such equipment for hobbies was not present in any other municipality.

4.5.3 Higher education in a circular economy

This indicator monitors the development of circular economy capacity in Finland. Moreover, the indicator focuses on circular economy learning offerings at higher education institutions. Education plays a pivotal role in developing the awareness, knowledge and skills required in the transition to the circular economy. Finland has been recognised as a global front-runner in higher education on circular economy (Ellen MacArthur Foundation 2018). In a study by the Ellen MacArthur Foundation (2018), a total of 25 Finnish higher education institutions were found to offer circular economy related courses with the emphasis on environmental, business and design aspects of the circular economy in particular.

The indicator on circular economy education was limited to the circular economy education offerings of universities of applied sciences (UAS). UASs were chosen as the focus as there are 22 UASs in Finland that extensively cover all the different regions (Table 10). Data on circular economy courses was collected from the UAS's online course catalogues. Any courses that mentioned the term 'circular economy' in the course name or description were included in the indicator. The term was checked in Finnish, Swedish and English, as these are the languages of instruction in Finnish higher education. The analysis and figures will use abbreviations of the names of the institutions. These abbreviations and information on the UASs included in this study can be found in Table 14.

Table 14. Finnish universities of applied sciences with abbreviations and campus locations.

Institution	Abbreviation	Campus locations	Region*
Arcada University of Applied Sciences	Arcada	Helsinki	Uusimaa
Centria University of Applied Sciences	Centria	Kokkola, Ylivieska	Central Ostrobothnia
Diaconia University of Applied Sciences	Diak	Helsinki, Oulu, Pori, Pieksämäki, Turku	Several regions
Haaga-Helia University of Applied Sciences	Haaga-Helia	Helsinki	Uusimaa
Häme University of Applied Sciences	HAMK	Evo, Forssa, Hämeenlinna, Lepaa, Mustiala, Riihimäki, Valkeakoski	Kanta-Häme
Humak University of Applied Sciences	Humak	Nurmijärvi, Kauniainen, Helsinki, Kuopio, Turku, Tampere, Korpilahti, Jyväskylä, Imatra, Joensuu, Kemi, Oulu	Several regions
JAMK University of Applied Sciences	JAMK	Jyväskylä, Saarijärvi	Central Finland
Kajaani University of Applied Sciences	KAMK	Kajaani	Kainuu
Karelia University of Applied Sciences	Karelia	Joensuu	North Karelia
LAB University of Applied Sciences	LAB AMK	Lappeenranta, Lahti	Päijät-Häme, South Karelia,
Lapland University of Applied Sciences	Lapin AMK	Kemi, Tornio, Rovaniemi	Lapland
Laurea University of Applied Sciences	Laurea AMK	Hyvinkää, Leppävaara, Lohja, Otaniemi, Porvoo, Tikkurila	Uusimaa
Metropolia University of Applied Sciences	Metropolia	Helsinki, Espoo, Vantaa	Uusimaa
Novia University of Applied Sciences	Novia	Jakobstad, Raseborg, Turku, Vaasa	Several regions
Oulu University of Applied Sciences	OAMK	Oulu, Oulainen	North Ostrobothnia
Satakunta University of Applied Sciences	SAMK	Pori, Rauma, Huittinen, Kankaanpää	Satakunta
Savonia University of Applied Sciences	Savonia	Kuopio, Varkaus, Iisalmi	North Savo
Seinäjoki University of Applied Sciences	SeAMK	Seinäjoki	South Ostrobothnia
Tampere University of Applied Sciences	TAMK	Tampere, Ikaalinen, Mänttä-Vilppula, Virrat	Pirkanmaa
Turku University of Applied Sciences	Turku AMK	Turku, Salo	Southwest Finland
VAMK University of Applied Sciences	VAMK	Vaasa	Ostrobothnia
South-Eastern Finland University of Applied Sciences	XAMK	Mikkeli, Kouvola, Savonlinna, Kotka	Several regions

* A map of Finnish regions is presented in Attachment 2.

Data was collected from the course catalogues for the academic year 2019–2020. Originally, the aim was to monitor the uptake of circular economy education by the number of participants completing the courses. However, it turned out to be difficult to produce comparable data from the different UASs. Ultimately, only the number of courses and their ECTS credits were monitored. The indicator compares the ECTS credits offered by different UASs, as the number of course credits better illustrates the extensiveness of the education compared to only monitoring the number of courses. After the compilation of data from the online catalogues, the results were sent for review and checking to all the Finnish UASs. Some of the UASs supplemented their course list and some courses that were not related to the circular economy were removed from the list.

Circular economy education at Finnish UASs based on the amount of course ECTS credits is presented in Figure 27. As the results show, 20 out of the 22 UASs have some circular economy education provision. The institutions with no circular economy courses (Diaconia UAS, Humak UAS) are also the only UASs fully focused on teaching arts and humanities, such as health care, social and youth work, cultural management and language interpretation. The highest number of credits are offered by Turku UAS in Southwest Finland and Lapland UAS.

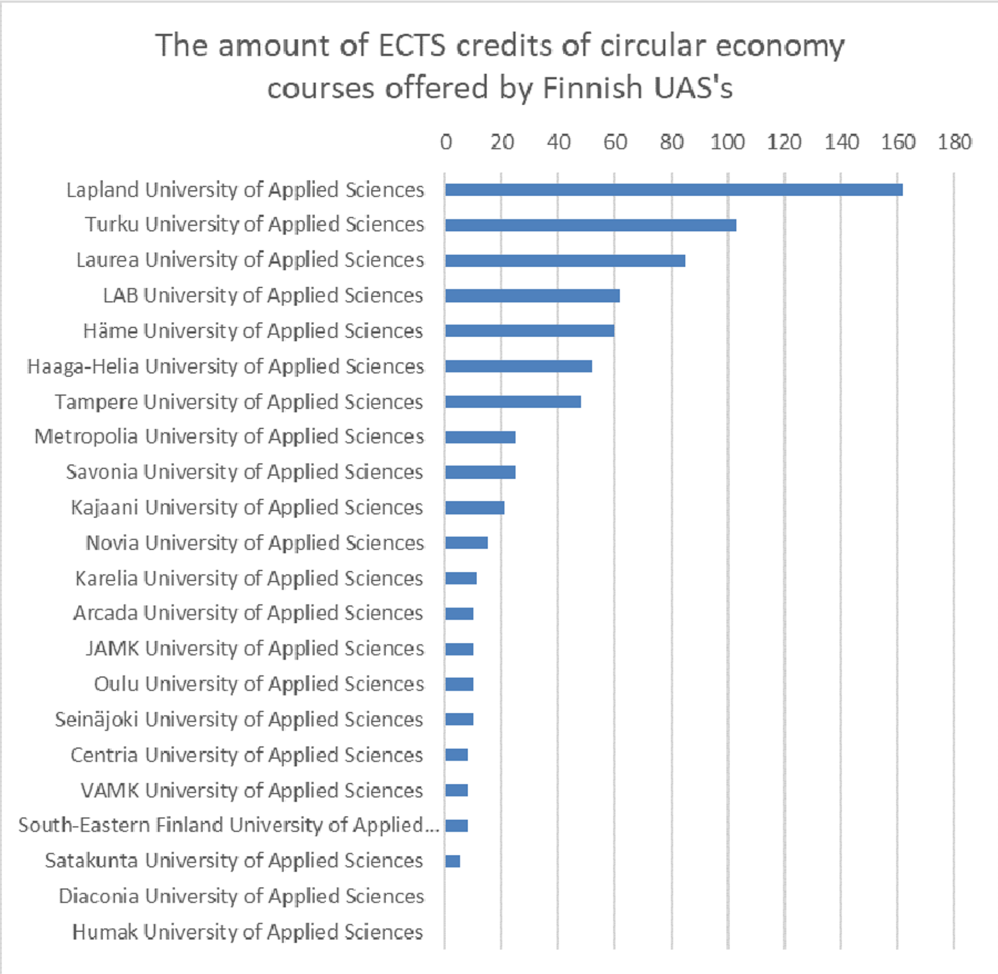


Figure 27. Total credits from the circular economy courses at Finnish universities of applied sciences in the academic year 2019–2020.

In addition to the number of courses and credits, the results were divided into six categories based on the disciplines of the courses: engineering; business; agriculture, forestry and bioeconomy; interdisciplinary; design; and health and welfare. The majority, 46.2%, of the total credits were offered in engineering (Figure 28). However, it must be noted that engineering covers a variety of subdisciplines, which were all included in this category. Circular economy education was also often offered in the disciplines of business, agriculture, forestry and bioeconomy. Credits in these fields made up 42% of the total credits. Interdisciplinary courses made up only about 7.9% of the total credits. However, interdisciplinary courses were often available to a much greater number of students from different backgrounds and even students outside of the university. The design courses (3.1% of the total) were only available at two of the UASs: Savonia UAS and Häme UAS. Similarly, the health and welfare courses (0.9% of all available credits) were only available at Laurea UAS. However, the existence of both design and health and welfare courses shows that circular economy education in Finnish UASs spans a large variety of disciplines.

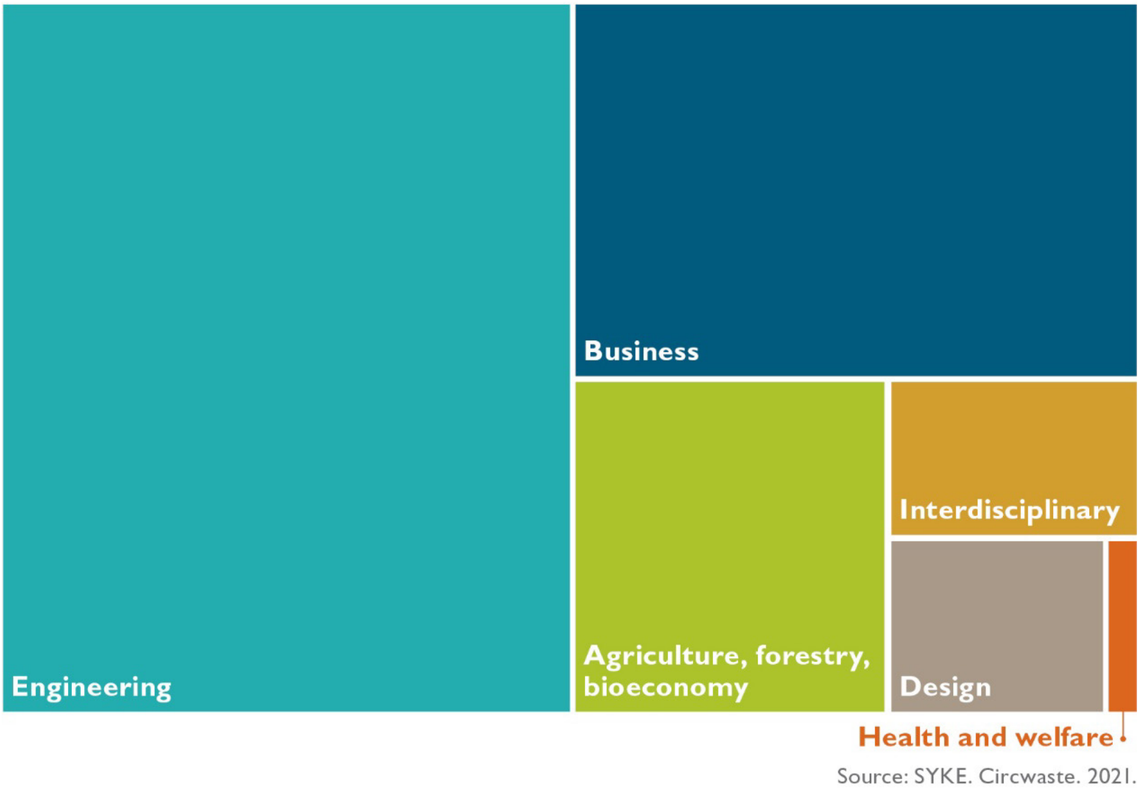


Figure 28. Distribution of the circular economy course credits in the Finnish UASs by discipline in the academic year 2019–2020.

Additionally, five UASs (Kajaani UAS, Lapland UAS, Laurea UAS, Savonia UAS and Tampere UAS) had one or several degrees offered in professional specialisation studies related to the circular economy. These are studies intended for those already in working life, who have already completed a degree or otherwise acquired equivalent competence. Studies are often conducted in close contact with working life excluded from the indicator and they only reach a very limited number of students. Four of the degrees (at Kajaani UAS, Lapland UAS, Savonia UAS and Tampere UAS) were focused on engineering or bioeconomy, which supports the general distribution of courses. On the other hand, Laurea UAS offered a 'Degree Programme in Social Services', which focused on the perspective of social circular economy.

Another limitation of this indicator is that it does not necessarily describe the actual amount of circular economy higher education entirely or accurately. Several of the UASs contacted responded that in many courses, the circular economy is discussed, even if it is not mentioned in the name or description of a course. On the other hand, the listing of courses includes also courses that only briefly mention the circular economy in the course description. For example, a respondent from Seinäjoki UAS mentioned that they would not characterise one of the courses listed in the UAS's section as a circular economy course, even though it does fulfil the conditions required in the chosen method. It met the requirement of the indicator, however, and was included in the list of the circular economy courses. Although the course listings were corrected after the feedback from the UASs, the indicator is only indicative of the real amount of circular economy education at Finnish UASs.

4.5.4 Accessibility of waste bring sites

The transition to a circular economy is also a profoundly social transformation. Sustainable circular economy production and consumption necessitates the participation of citizens. The citizens take part in the circular economy, among other things, as consumers and users of circular economy goods and services. They can also support the circular economy through returning discarded items and sorting and delivering waste for recycling.

Improving waste sorting in households is important for the circular economy transition and meeting ambitious recycling targets. Households are key in reducing and sorting waste for recycling and, in general, taking back discarded items so that valuable resources can be recycled. One of the most important factors influencing households' recycling behaviour is the availability and accessibility of recycling services: how far away from home the nearest bring sites are and how conveniently the bring sites are located in terms of people's everyday mobility practices (e.g. Miafodzyeva & Brandt 2013; Miliute-Plepiene & Plepys 2015). The possibilities for participating in the circular economy, however, are not necessarily equally distributed. Studies on recycling behaviour have determined a variety of socio-demographic, technical-organisational, socio-psychological and context dependent variables that have an impact on households' recycling behaviour. For example, higher income and education levels correlate with greater willingness to recycle and the closeness and condition of collection points directly influences recycling behaviour (Miafodzyeva & Brand 2013).

The accessibility of waste bring sites is especially important in Finland, which is geographically a large country with one of the lowest population densities in Europe. Although a large proportion of the population is concentrated in the Helsinki metropolitan area and other bigger cities, 28% of Finns live in more sparsely populated rural areas (Helminen et al. 2020). In these areas the accessibility of services, such as waste bring sites, can become a critical factor for people's recycling behaviour. To assess the distribution of opportunities to participate in the CE, a set of accessibility indicators was formed. The indicators measure the accessibility of waste management services, such as bring sites for different waste fractions, as well as the accessibility of recycled resources.

The accessibility and standard of waste management services are regulated in Finland. According to the Government Decree on Packaging and Packaging Waste (518/2014), the availably of bring sites and recycling points should be sufficient and they should be equally distributed and accessible in all regions, taking into account population density. Furthermore, the bring sites should be located close to convenience stores or other widely used service facilities or be along commonly used routes. The Decree also sets a limit for the minimum amount of the sites for different waste fractions, stating that there should be at least 1,850 bring sites for separate collection of glass, metal and cardboard waste and all population centres with over 500 residents should have at least one bring site. For plastic packaging there should be at least 500 bring sites and all population centres with over 10,000 residents should have at least one.

This indicator monitors the accessibility of bring sites for plastic packaging waste, reusable textiles and WEEE. These three represent very topical yet different types of waste fractions with different recycling networks and possibilities. The accessibility is estimated as the residents' distance to the nearest bring site via roads and walkways, based on the Digiroad road network dataset (Finnish Transport Infrastructure Agency 2020). The estimation illustrates how easy and time-consuming source separation is and whether the bring site can be accessed by foot or bike or if a car needed to transport recyclables. The indicator uses the kierratys.info service, maintained by the Finnish Solid Waste Association, as its main data source (Suomen kiertovoima ry KIVO 2020b). In addition to this, for textiles the data used on reusable textile collection points is maintained by three organisations: UFF, Fida and the Finnish Red Cross (SPR) (UFF 2020, Fida 2020, SPR 2020). For WEEE, retail, electronics and home appliances stores that take back discarded electrical appliances were included (data purchased from the AC Nielsen (2020) retail register and the Statistics Finland (2020i) business register).

The availability and accessibility of bring sites varies between residential areas, municipalities, and regions in different parts of Finland. Although there are bring sites all over the country, the sites are most easily accessible in the densely populated areas and cities in the south. On average, residents of the Uusimaa region have the shortest distance to the bring sites and residents of Lapland the longest. Hence, the accessibility of the bring sites is connected to the accessibility of all services and to the number of potential users. In some regions, long distances or a lack of local bring sites may reduce willingness to sort and recycle.

Differences in the accessibility of bring sites also have an impact on how socially equal and just the recycling opportunities are experienced as being in different parts of the country. For example, in sparsely populated areas the closest recycling point may only be accessible by car, as with other services. As online distance selling and using transport services and carriers become more popular, this causes pressure on more customer-oriented waste management services. Additionally, the advancing of the circular economy as well as ambitious recycling targets and tightening regulations increase pressure in terms of developing the availability and accessibility of recycling possibilities.

Collecting and **processing plastic packaging waste is** the responsibility of the producers who have set up local bring sites (e.g. Rinki sites) where people can drop off their waste. Furthermore, some municipalities own and maintain separate bring sites for plastic packaging. In addition to this, property-specific plastic waste collection points (kerbside collection) have become more common in recent years, especially in bigger urban settlements. Along with tightening waste legislation. kerbside collection will become obligatory for all residential properties that have five or more apartments. This will increase opportunities for plastic packaging waste recycling, at least in population centres.

Plastic packaging waste bring sites are relatively widely distributed in the different regions, although the bring site network is the densest in the more densely populated areas in southern and southwestern Finland (Figure 29). In Uusimaa, 72% of people live within two kilometres of the nearest bring site. In more sparsely populated areas in eastern and northern Finland the accessibility of the sites is lower. In Lapland, 72% of people live over two kilometres from the nearest bring site. The network of plastic packaging bring sites has increased rapidly in recent years. Since 2018, new bring sites have been set up in particular in western Finland as well as in more sparsely populated areas (Figure 30).

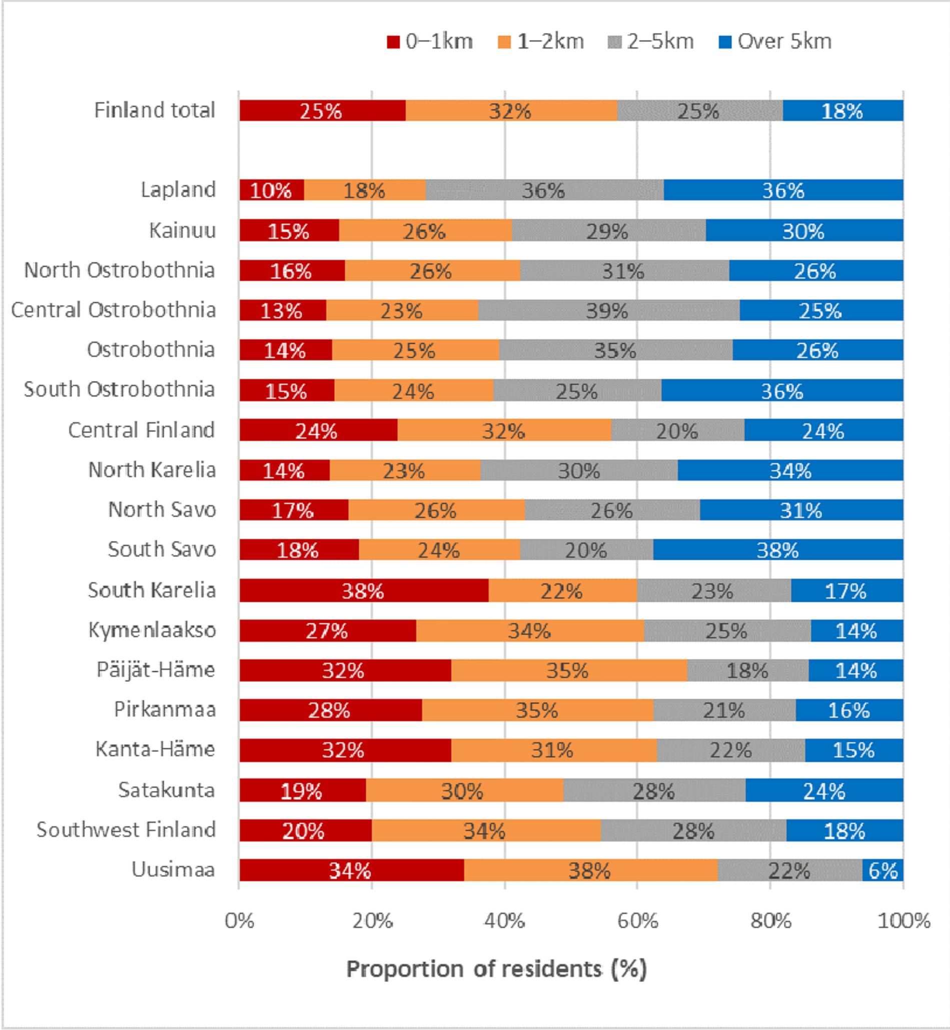


Figure 29. Accessibility of plastic waste bring sites by region in Finland in 2019.

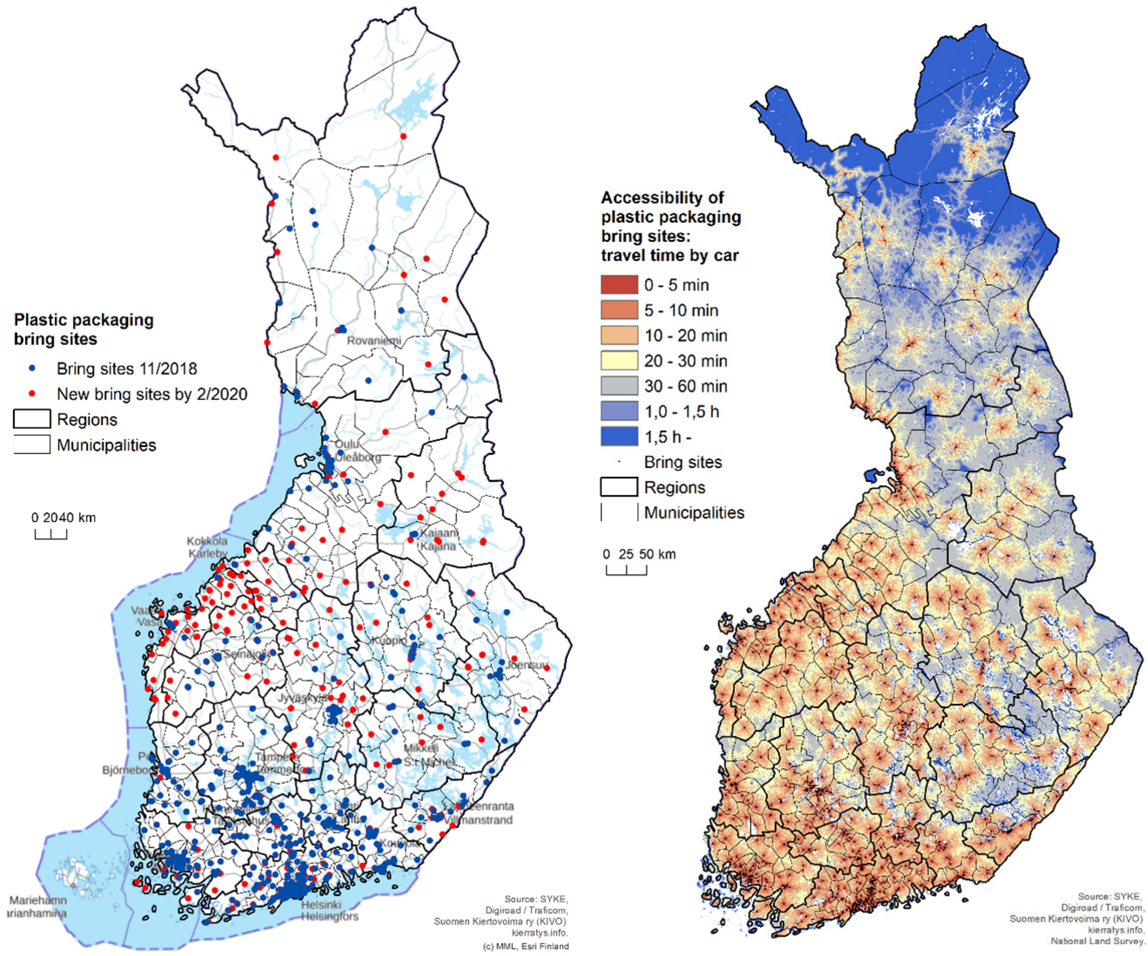


Figure 30. Accessibility of plastic waste bring sites in Finland in 2019.

Reusable textiles are currently recycled in Finland by a range of private charities and clothes shops. These organisations have set up bring sites to collect clothes, shoes and other textiles to be sold second hand or donated in Finland or abroad. The focus is here on the bring sites managed by three organisations UFF, Fida and the Finnish Red Cross, which have an extensive network of bring sites across the country. End-of-use waste textiles not suitable for reuse are not nationally collected yet and instead end up in mixed waste and are incinerated. Regional collection and recycling of waste textiles is planned to start in 2023, two years earlier than the Waste Directive requires. Additionally, a large waste textile refinery is planned to be in operation in Finland by 2023. This will facilitate the recycling of waste textiles into raw material for the textile industry.

Bring sites for reusable textiles are relatively evenly distributed across the country. All the three charities/textile reuse organisations have their own bring sites in many municipalities. As for plastic packaging waste, the bring sites for reusable textiles are mainly located in population centres, easily accessible by foot or on bike (see Figure 32). A total of 51% of Finns live within one kilometre of the closest textile bring site. In Central Ostrobothnia over half of the population live more than 2 km away from the closest bring site (see Figure 31).

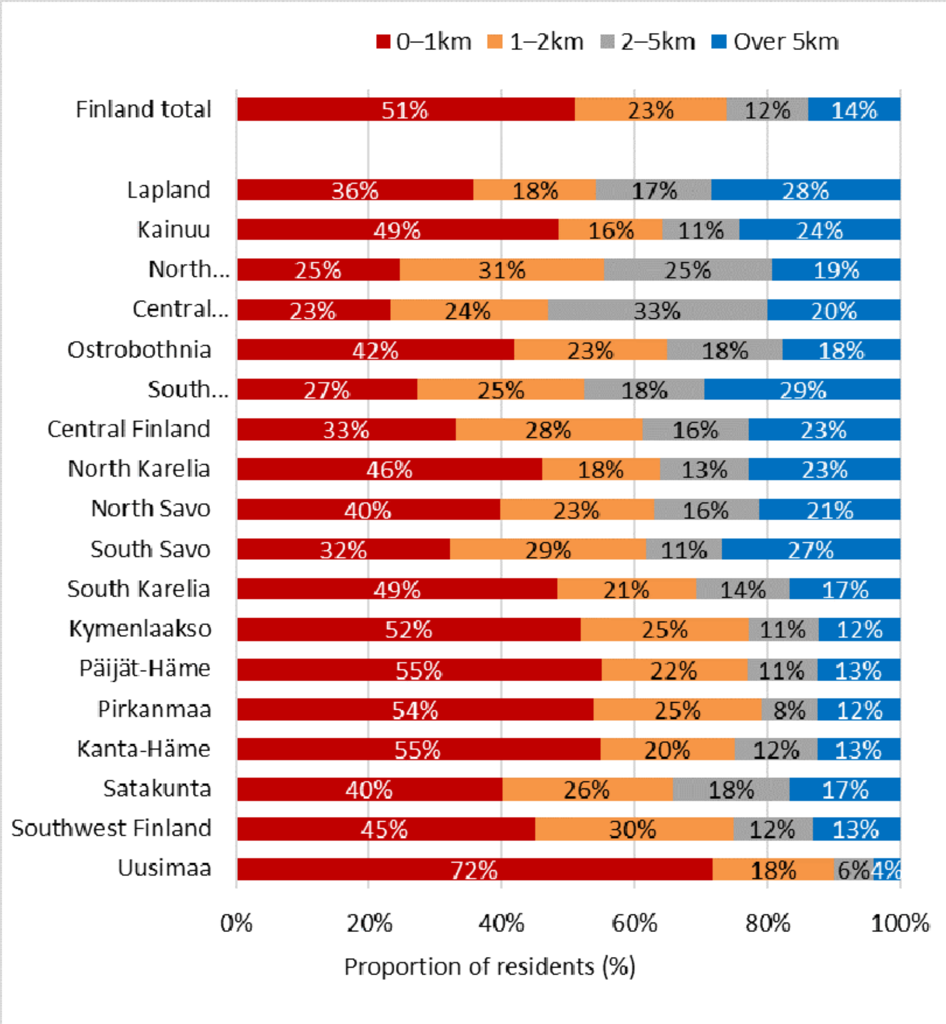


Figure 31. Accessibility of textile bring sites operated by private organisations in Finland in 2019.

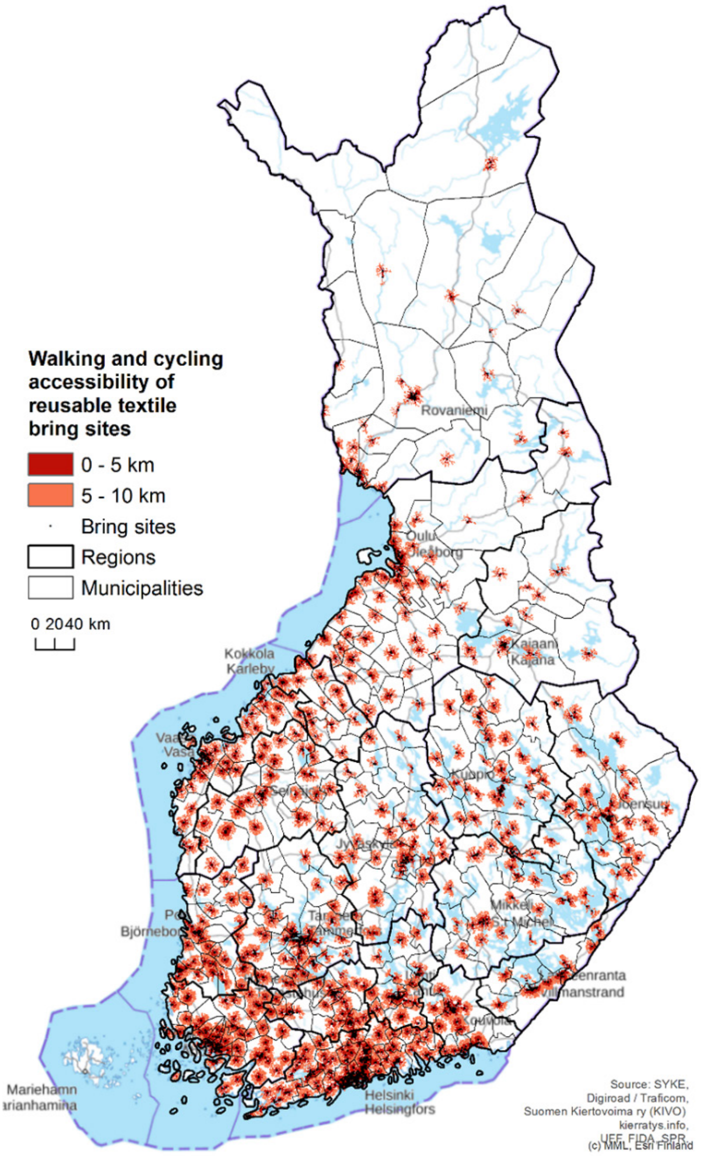


Figure 32. Accessibility of textile waste bring sites in Finland in 2019 by foot or bicycle.

Recycling **WEEE** is important as electronic appliances contain a lot of valuable and critical raw materials. The challenge is that old appliances are not always brought back for recycling. It has been estimated that, for example, 80% of old mobile phones are not recycled, but instead people keep and store them at home (YLE 2020). Old appliances and often also less energy efficient appliances are sometimes also taken to rural second homes (summer cottages). Organising collection and recycling of WEEE is the responsibility of the producers. Besides separate bring sites, all shops selling electric appliances take back discarded items. In WEEE accessibility studies, electronics and home appliances stores that are over 200 m^2 in size or employ at least two people have been included in the analysis. In addition to this, retail stores over 1000 m^2 in size are also included, since bigger retail stores usually sell electric appliances.

WEEE bring sites and shops taking back electric appliances are mostly located in population centres. A total of 40% of people in Finland live within 1 km of the closest WEEE collection point (Figure 33). As for the other waste fractions, WEEE collection points are most accessible to the residents of the most densely populated regions. However, residents of some more sparsely populated regions (Kainuu, North Karelia) also stand out as having relatively high accessibility (Figure 34).

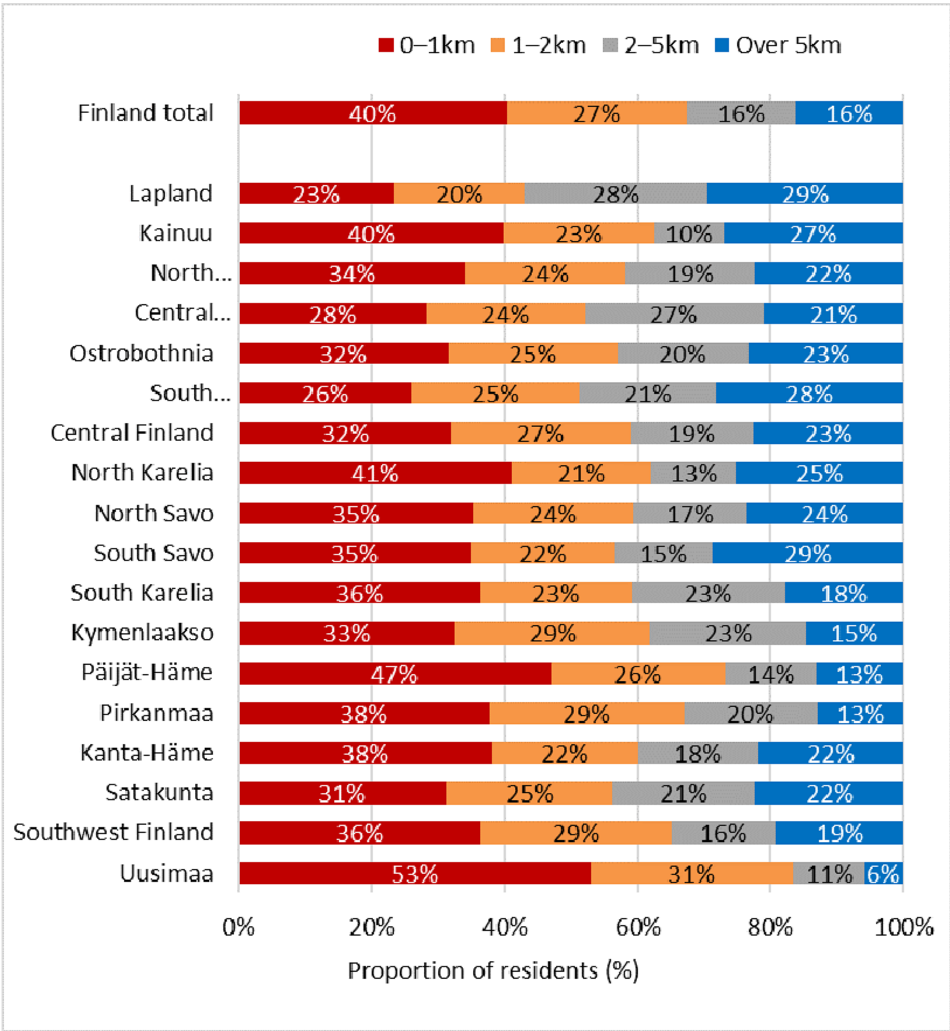


Figure 33. Accessibility of WEEE bring sites regionally in Finland in 2019.

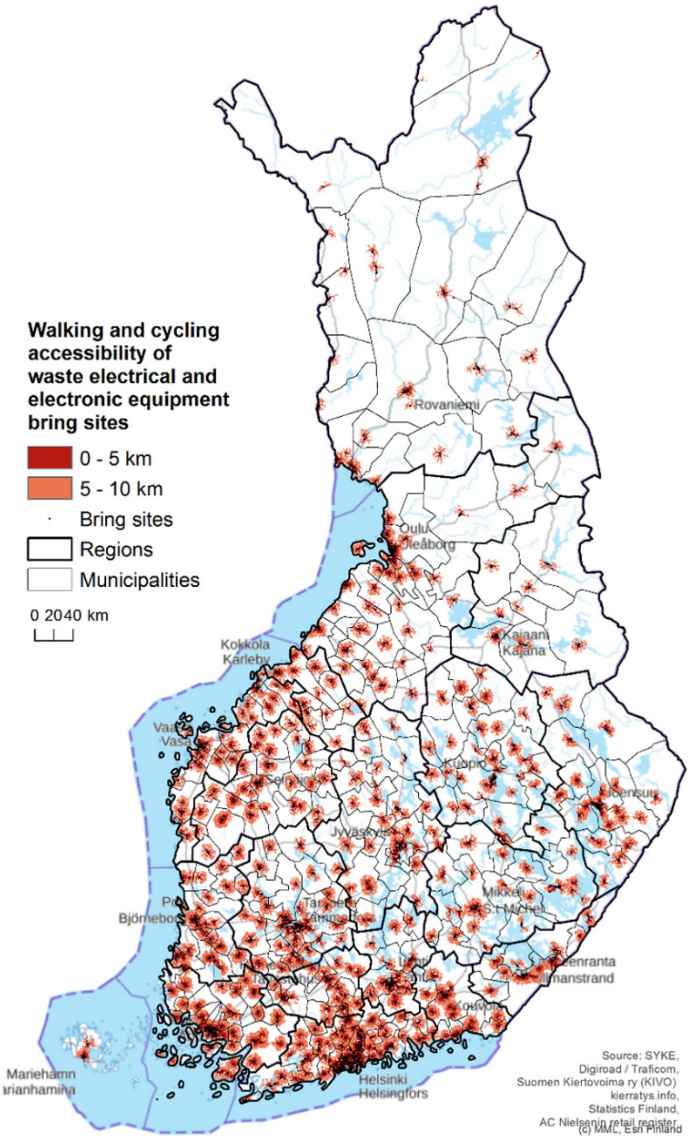


Figure 34. Accessibility of WEEE disposal sites by foot and bicycle in Finland in 2019.

4.5.5 Accessibility of fuel stations for gas and charging points for electric vehicles

A quarter of the greenhouse gas emissions produced in Finnish municipalities come from road transport (Finnish Environment Institute SYKE 2020). In 2017, land transport used 49,704 TJ worth of oil products. In comparison, the use of electric energy and biogas equated to 4,803 TJ and 27 TJ, respectively. (Statistics Finland 2020g) Road transport is also one of the key sources of fine particle emissions (Savolahti et al. 2018).

Using public transport and choosing walking or cycling over driving decreases the use of natural resources, emissions and the number of cars on the roads. Public transport, on the other hand, covers mostly towns, but not rural areas, and the long distances outside town centres hinder the use of bicycle and pedestrian traffic. Another way to reduce emissions, particularly at respiration height, and to save use of natural resources is to drive cars with alternative power sources, such as biogas or electricity from renewable sources. However, access to these services is not equal for all people in Finland. In some regions the services are more accessible than in others.

Development in the accessibility of fuel stations for gas vehicles and charging points for electric vehicles in Finland is monitored as one of the circular economy indicators in Circwaste. In Finland, biogas is produced mainly from waste materials through anaerobic digestion. Biogas can be upgraded into biomethane that can be used as fuel in gas-powered vehicles. In southern Finland, biomethane can be fed into the gas grid. In other regions, there are stand-alone methane fuel stations that primarily provide biomethane produced locally. The residue from biogas production, or digestate, is used as a fertiliser or soil amendment.

Thus, using biomethane fuelled personal vehicles can be considered part of the CE, particularly in remote regions with limited options for using public transport or bicycle and pedestrian traffic. Monitoring the accessibility of electric car charging points serves as a complementary indicator for monitoring sustainable transport possibilities in regions with limited access to public transport or bicycle or pedestrian traffic and biogas stations. Because of their lower acquisition costs, biogas fuelled vehicles can currently be considered a more accessible transport alternative for people than electric cars.

Accessibility indicators include calculating the distances for residents from their home to the nearest fuel stations and charging points via the road network. The Digiroad road network dataset (Finnish Transport Infrastructure Agency 2020), as well as building and population data from the Population Information System (Digital and Population Data Services Agency 2020), were used in the modelling.

The distances indicate the ease of access. In some cases, the distances can also indicate whether it is viable in the first place to purchase a gas or electric vehicle. Distances describe the differences in services available for citizens in different regions. The development in accessibility is monitored annually, starting from the end of 2019. The main sources of information include Gasum Ltd's database for gas fuel stations (Gasum Ltd 2020) and the Sähköautoilijat association's data on charging points in Finland (Sähköautoilijat ry 2020).

Access to both gas fuel stations and public electric car charging points was easiest in southern and southwestern Finland at the end of 2019 (Figure 35). Electric car charging points could be found throughout the country, whereas northern and eastern Finland still largely lacked fuel stations for gas-powered vehicles. The drive time to gas fuel stations was at maximum 10 minutes in the centres of towns with a gas grid or biogas plant. In northern Finland, outside the Oulu region, and in eastern Finland, the drive time to a gas fuel station exceeded 1.5 hours. Electric car charging points were accessible in all regions, but mostly in the town centres in the north and in the east.

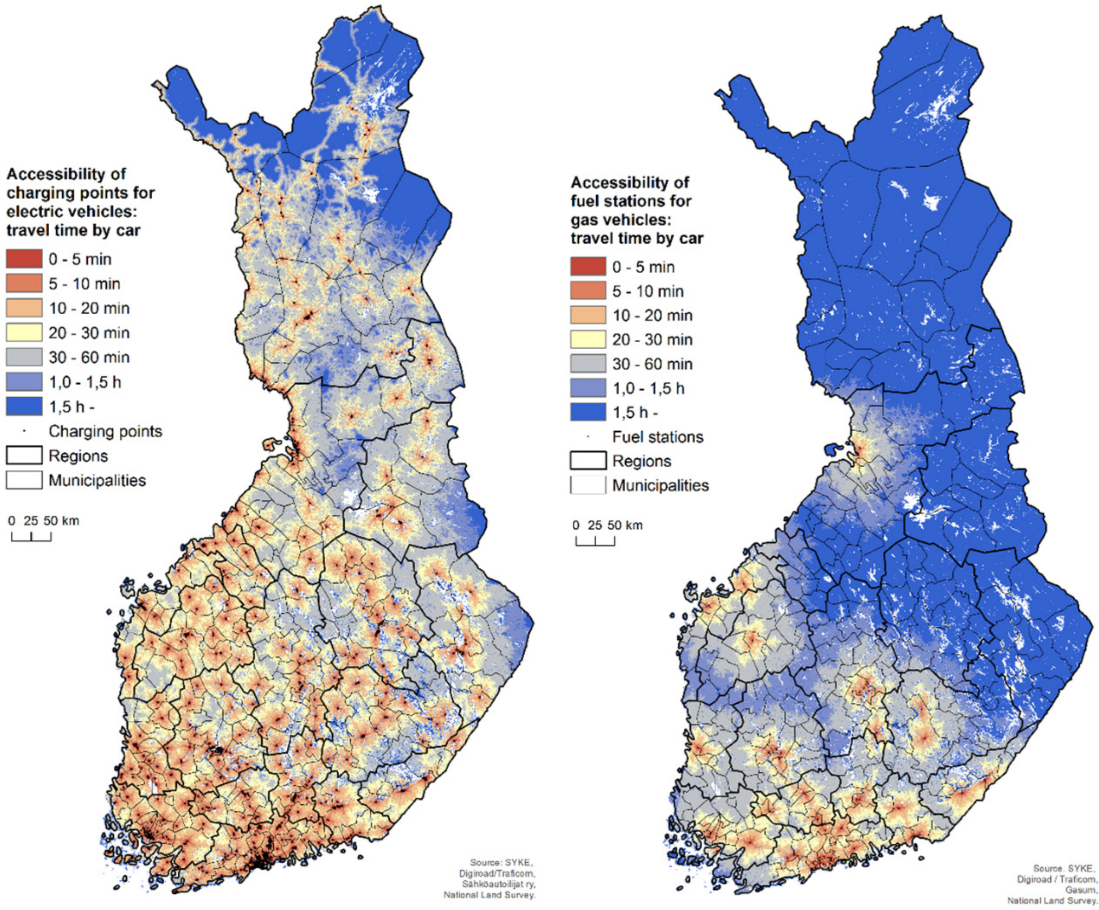


Figure 35. The drive time to gas fuel points and electric car charging points was short in the centres of towns at the end of 2019. Accessibility of gas fuel points was the best in the area around the grid or in towns with a biogas plant. Electric car charging points could be found in the centres of many smaller towns. Calculations include only the public charging points, not the option to charge cars at home.

Over half of the people living in the medium-sized municipalities of Nokia, Imatra, Mäntälä and Joutsa in western, southern and southeastern Finland, had a drive of under five minutes to a gas filling station at the end of 2019. In all the 10 municipalities with the highest population in Finland, over 90% of the inhabitants lived within a reasonable drive of less than 20 minutes from a gas fuelling station. In northern Finland, only in the Oulu region were the gas fuelling stations accessible (Figure 36).

Electric car charging points were readily accessible in the municipalities of Järvenpää, Helsinki, Kauniainen, Hanko, Hyvinkää, Tampere and Kerava in 2019 in southern Finland. In these municipalities, over 90% of the population lived within a five-minute drive of the charging point. Additionally, in the municipality of Jakobstad in Ostrobothnia and in the municipality of Kemi in Lapland, 89% of the population lived near a charging point. The accessibility of the charging points was the weakest in the municipalities with a smaller population in eastern and northern Finland, located far away from regional centres. In addition to this, in remote, small municipalities in Central Finland, Ostrobothnia, Satakunta and Southwest Finland, over 98% of the population lived beyond a 20-minute drive from an electric car charging point.

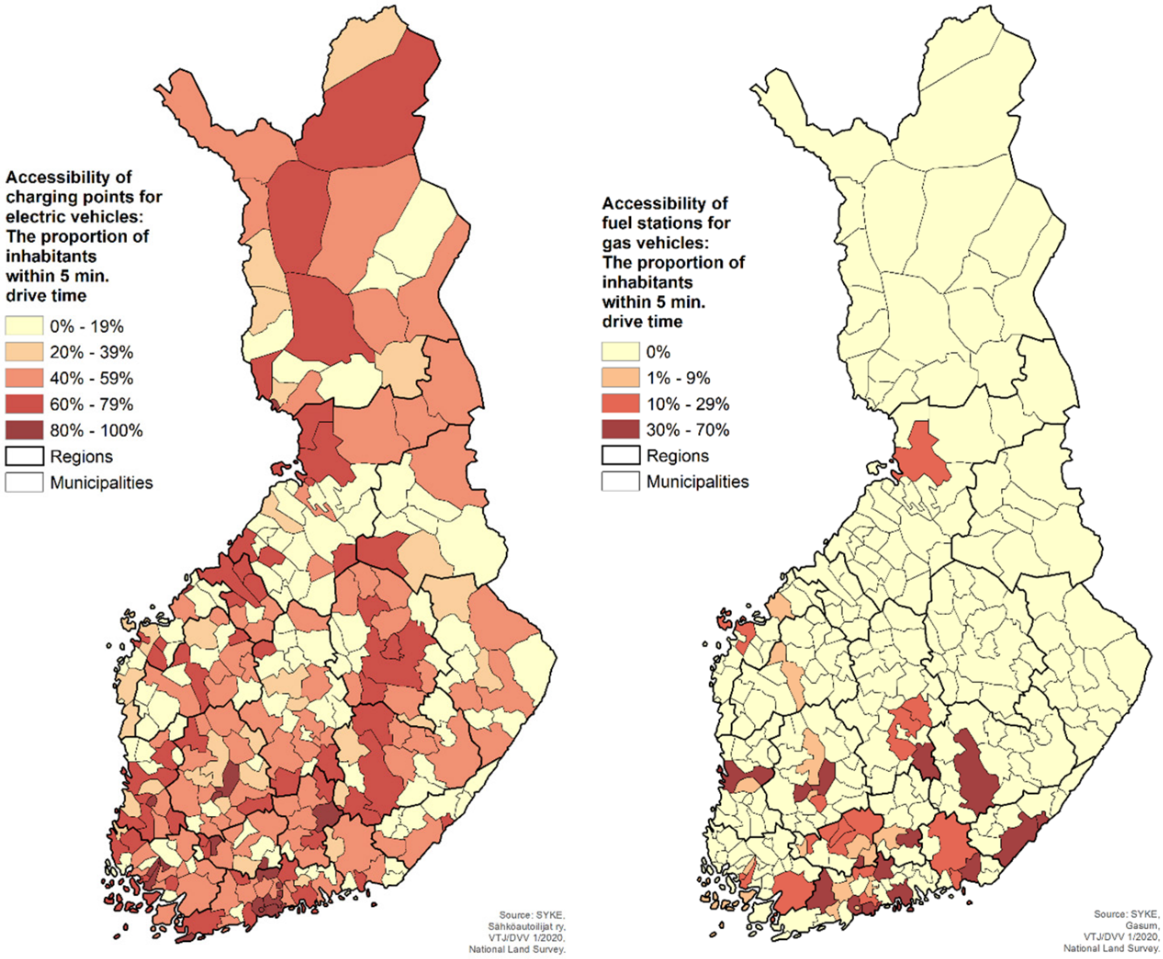


Figure 36. The accessibility of gas fuelling stations and electric car charging points was best in southern Finland at the end of 2019. The electric car charging network covered most of the country, whereas the gas network was centralised in the south along the gas grid.

In the regions of Kainuu, Lapland, North Karelia and North Savo in eastern and northern Finland, as well as in Central Ostrobothnia in the west, the whole population in 2019 lived far away from gas fuelling stations (Figure 37). On the other hand, in the Uusimaa region in the south, 90% of the population, and in the regions of Kymenlaakso, Kanta-Häme and South Karelia 80% of the population, respectively, lived within a 20-minute drive of a gas fuelling station.

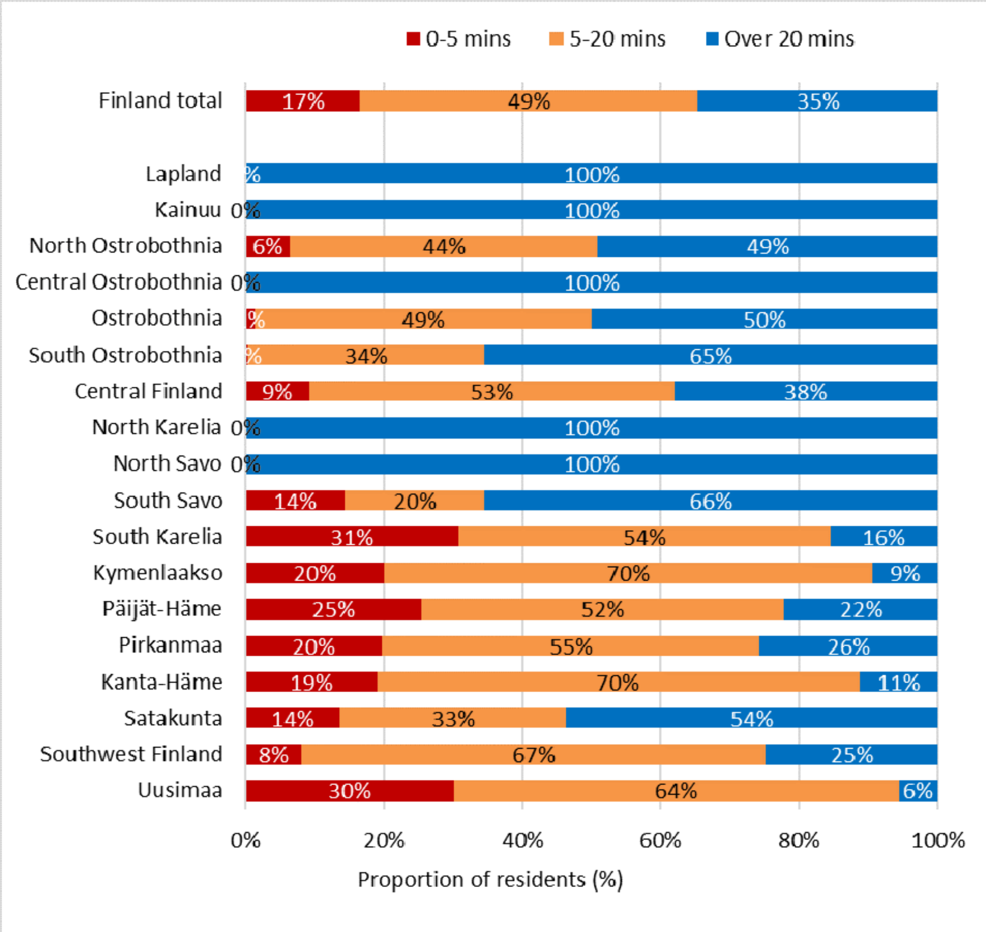


Figure 37. Accessibility of gas stations in regions, measured in drive time. There were significant differences in the accessibility of gas fuelling stations between the regions at the end of 2019 in Finland. In Kainuu, Central Ostrobothnia, Lapland, North Karelia and North Savo regions, the entire population lived far away from the gas fuelling stations.

In the regions of Kainuu, Northern Karelia and North Ostrobothnia, electric car charging points were the least accessible measured in drive time in 2019 (Figure 38). In these regions, 17–25% of the population had a drive of over 20 minutes to the nearest charging point. The charging points were most easily accessible in the regions of Uusimaa, Central Ostrobothnia, Päijät-Häme, Southwest Finland and Kymenlaakso. In these regions, 98–100% lived within a 20-minute drive of the nearest charging point.

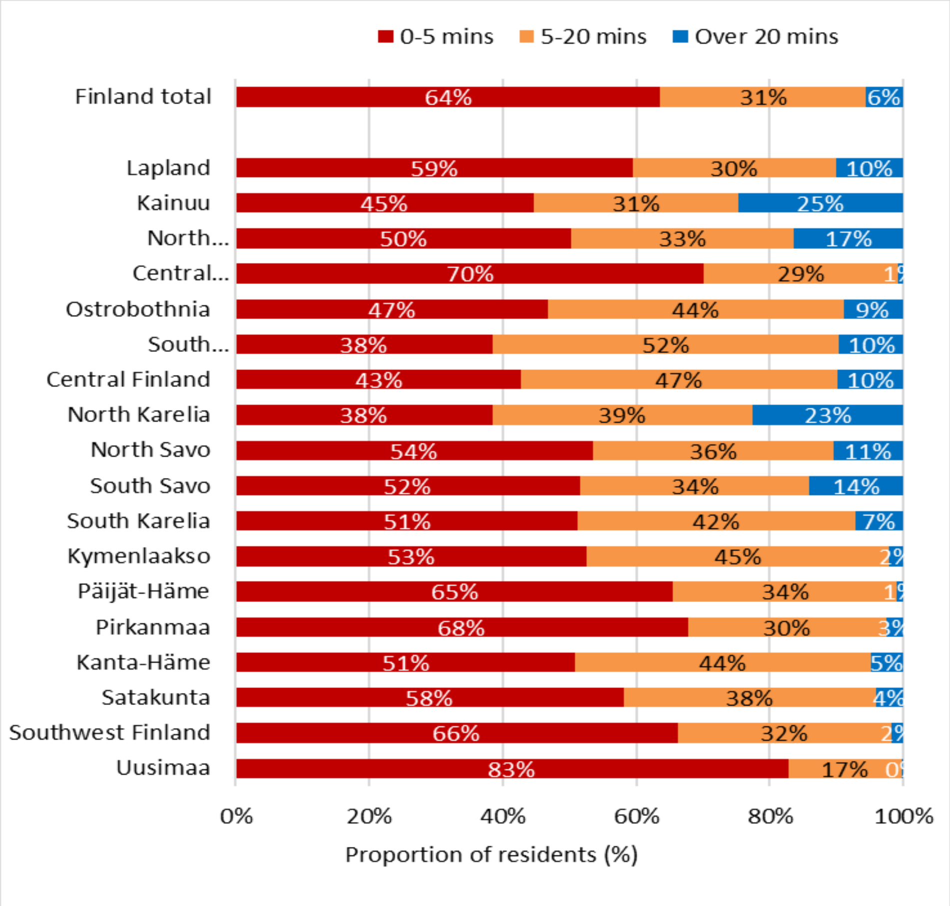


Figure 38. Accessibility of charging points, measured in drive time at the end of 2019. The differences between Finnish regions in the accessibility of electric car charging points were smaller than the differences in accessing gas filling stations. Of the population, 75–100% lived at maximum a 20-minute drive away from the charging points.

4.6 Perspectives on social acceptance of the systemic change circular economy entails

Because of its systemic nature, the implementation of circular economy needs proper monitoring of socio-economic impacts (see section 4.5): not all the desired changes – digitalisation, service economy, transition from owning to a sharing economy – may be easy for all, and they might not be felt to be fair either. Achieving a circular economy requires changes in citizen behaviour in accepting more sustainable consumption behaviour and adopting new services and forms of ownership. In addition to socio-economic factors, human consumption behaviour is motivated by other complex factors, too. In order to be truly adopted, the required circular economy activities cannot be too contradictory to the human motivators.

Namely, shifting to a sharing economy may be quite a dramatic change for people. Hood (2019, according to Seppälä 2020) states that psychologically, ownership and accumulating materials are elemental parts of the identity of humans in developed countries, or more precisely, of who we want to be. For people in developed countries, ownership is part of social value, i.e. status, because our culture values individual status. For comparison, in hunter-gatherer cultures that are collective, ownership is not valued (Hood, according to Seppälä (2020)). People have learned to value and want what others value, too, and have also learned to reward themselves with new products. Brockis has found in her studies (according to Seppälä (2020)) that the more expensive the product, the greater the happiness experienced associated with having it, because of the dopamine hormone released when we get what we want. The marketing sector takes advantage of this feature of human nature and is constructed to bring about new needs and desires. Especially effective are advertisements that claim limited availability, popularity and tell stories of personal experiences or positive health effects (Terhi-Anna Wilska, according to Seppälä (2020)). All this shows that dematerialisation is not an easy task, as long as the products are equated to status symbols. Breuning has discovered (according to Seppälä (2020)), that the key to working ourselves loose from materialism is to understand where the desire for owning is growing from – from wanting what everybody else has and to learn to be happy with what we already have. Studies have shown that feelings of happiness and satisfaction can reduce our materialistic behaviour and increase generosity (Loretta Breuning, according to Seppälä (2020)). All this proves that wellbeing has a great impact on the opportunities to implement a circular economy and that these social aspects must be considered in planning the reform. Value reform from a material-based society to an experience-based society can therefore help in achieving circular economy or even be a necessity. Later in the Circwaste project, the attitudes and values of people and how they are connected to the circular economy or waste management will be measured.

5 Impact assessment of circular economy activities

System-level changes may cause environmental burden or benefits.
The factors potentially slowing down the change are also assessed.

5.1 **Monitoring life cycle (LC) based environmental impacts of promoting the circular economy and national waste plan in regions**

LCAs can be applied in assessing the environmental performance of a product or service. This methodology was also applied in assessing the environmental impacts – benefits and challenges – of implementing the circular economy and the targets of the NWP.

The environmental impacts caused by the measures of the Circwaste project, as well as other activities promoting the implementation of the NWP in the regions and municipalities, are monitored throughout the project. The environmental impacts are assessed from the viewpoint of emissions and use of natural resources, considering potentially avoided emissions and use of resources.

Besides the potential environmental benefits of the implementation of circular economy and the NWP in general, recycling and other waste management systems require natural resources and energy inputs that cause harmful impacts to the environment. These harmful impacts in terms of the selected indicators are roughly assessed to get a system level picture of the impacts caused. The harmful impacts are assessed against potentially avoided impacts. Finally, the overall net impacts are obtained by deducting harmful impacts from the benefits (Figure 39).

The idea of the assessment is to calculate the impacts and benefits for the baseline year 2016 and then for 2017, 2019 and 2021 and to compare them to see possible trends.

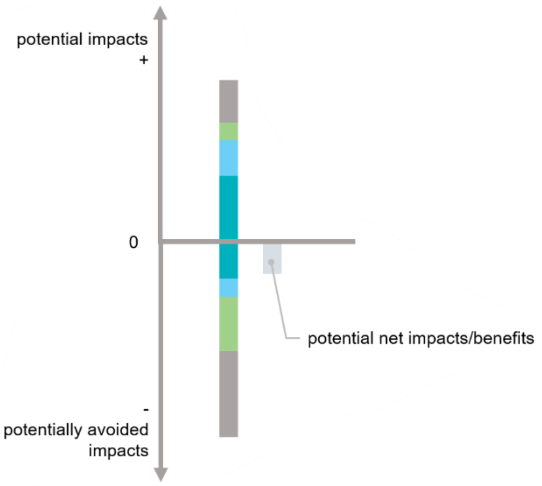


Figure 39. Theoretical illustration of net environmental impacts calculation for waste management processes.

5.1.1 Methodology of the assessment

To assess the impacts of developing waste management operations in the regions, first, the necessary waste management processes were defined based on the waste flows that could be quantified at the level of Circwaste municipalities and regions. The impacts of treating these waste flows were modelled to create the baseline scenario. The waste flows were: mixed municipal solid waste (mixed MSW), municipal biowaste, plastic packaging waste, waste paper and cardboard, waste metals, waste glass and WEEE from households.

The most suitable waste management unit process data was collected from the Ecoinvent database (Wernet et al. 2016). For processes not available in the database, or for processes that were not representative enough, data was collected predominantly from Haupt et al. (2018) and modified to better represent Finnish conditions. The unit process data was used to calculate the environmental impacts and resources consumption caused by the respective waste management activity, be it waste incineration or recycling, for example. This data represents inputs of energies and materials and outputs of energies, materials, emissions and wastes.

Selecting the most appropriate available unit processes for modelling was not straightforward. It is not always easy to understand the processes that are covered and to interpret whether they represent the desired activities. Moreover, most processes represented either Swiss or general European conditions, not Finnish ones. Waste management is a local activity that can be challenging to generalise. The unit processes selected for this task were modified to better represent Finnish conditions, typically by modifying energy inputs. However, following the rough assessment level, they were not otherwise adjusted to reflect waste management technologies used in Finland.

The same Ecoinvent (v3.4) database was used as a source of data for calculation of potential benefits that can be gained by processing each type of waste – either by recovering it for energy or recycling it into a secondary raw material.

The basic LCA model was created in the SimaPro software tool. The life cycle impact assessment and inventory results were exported to Excel, where an easy-to-use calculator was created. The calculator makes it possible to calculate impacts and potential benefits of waste management in the upcoming monitoring years without the need to use SimaPro, or any other LCA software. The Excel calculator also makes it possible to change certain assumptions for a scenario analysis.

5.1.2 Inventory definition

The inventories collected for most of the waste management process, as well as for the avoided materials and energy, were selected based on the requirements specified in the project plan. The selected basic environmental impact indicators for monitoring are presented in Table 15.

Table 15. Definition of the selected environmental impacts indicators.

Environmental impact indicators		Specification
Emissions	Carbon dioxide equivalent emissions; CO2e	Climate impacts, calculated as the sum of air emissions contributing to climate impacts. Corresponds with ReCiPe 2016 Midpoint (H).
	Nitrogen emissions; N-tot	Marine eutrophication, calculated as the sum of waterborne nitrogen emissions. Corresponds with ReCiPe 2016 Midpoint (H).
	Phosphorous emissions; P-tot	Freshwater eutrophication, calculated as the sum of waterborne phosphorous emissions. Corresponds with ReCiPe 2016 Midpoint (H).
Resources non-renewable	Ferrous metals	Inputs of iron as a raw material.
	Non-ferrous metals	Raw material inputs of aluminium, copper, lead, nickel, tin, titanium and zinc. Precious and rare earth metals were excluded.
	Sand	Inputs of sand (unspecified and quartz, in ground) as a raw material.
	Clay	Inputs of clay (bentonite and unspecified) as a raw material.
	Other minerals	Inputs of gravel as a raw material.
Resources renewable	Biomass	Raw materials inputs of standing wood – primary forest; soft; hard; unspecified.

Data on collected household waste flows (Chapter 4.3) represents volumes of waste collected by waste management operators that provide collection services in the respective municipal regions. At the time of the impact assessment, the initial estimates of the waste amounts were available for 2016 and 2017 (Table 16) and later will be completed with data for 2019 and 2021. The changes in the estimation method after the initial estimations were carried out explain some of the difference in the results showed in Table 16 and Chapter 4.3. However, the change is mostly due to amounts of gardening waste included in the initial estimates, which has a minor effect on impact assessment. The waste flows are presented in tonnes per year.

Table 16. Total amounts of MSW from households in the forerunner municipality regions according to the initial estimates in 2016 and 2017. This data with specific amounts by fraction is used in the impact assessment.

	The amount of household waste (kg/person)					
Year	**Hyvinkää and Riihimäki region**	**Joensuu region**	**Jyväskylä region**	**Kuopio region**	**Lappeenranta region**	**Porvoo region**
2016	335	313	345	396	325	344
2017	330	303	348	405	320	343

In order to calculate environmental impacts associated with waste management of waste generated in the respective municipalities, the proportion of the population in the respective municipalities was used (Table 17). This proportion was combined with the total collected waste flows.

Table 17. Population in Circwaste municipalities used in allocating the environmental impacts for the municipalities.

Municipality	Year	Population in collection region	Population in municipality	Proportion of population, %
Hyvinkää	2016	344,563	46,596	13.1
	2017	344,882	46,739	13.6
Riihimäki	2016	344,563	29,160	8.5
	2017	344,882	29,021	8.5
Joensuu	2016	112,706	75,848	67.3
	2017	112,589	76,067	67.6
Jyväskylä	2016	170,193	138,850	81.6
	2017	171,647	140,188	81.7
Kuopio	2016	216,354	117,740	54.4
	2017	215,477	118,209	54.9
Lappeenranta	2016	130,506	72,872	55.8
	2017	129,865	72,909	56.1
Porvoo	2016	186,948	50,144	26.8
	2017	186,389	50,159	26.9

5.1.3 Results of LC based environmental impact analyses of household waste management

The results of the life cycle based environmental impact analyses of municipal waste management in the selected Circwaste municipalities – Hyvinkää, Riihimäki, Joensuu, Jyväskylä, Kuopio, Lappeenranta and Porvoo – are presented in Figure 39–Figure 49. Life cycle inventory data for these calculations is reported in Attachment 3. The bars above the x-axis represent negative impacts and consumed natural resources. The bars below the x-axis represent potentially avoided impacts and potentially avoided use of natural resources due to use of secondary raw materials produced in the recycling process.

It must be noted that both environmental impacts and benefits are results of a rather general model that only partially represents the real situation. In particular, the potentially avoided impacts and consumption of natural resources are highly subjective to the case-specific reality. The results indicate that the waste-specific impacts are sensitive in particular to two assumptions: the assumed avoided primary metals and the assumed avoided energy source of heat production due to mixed MSW incineration. Differences in environmental impacts between municipalities are caused by the differences in population and in the total household waste amounts treated in the municipality. The figures on the population in municipalities can be found in Attachment 5. In the model it is assumed that heat recovered in mixed MSW incineration replaces heat generated by combusting natural gas. While this is a valid assumption, it could just as well replace heat originating in coal power plants (greater potentially avoided impacts) or heat originating in waste biomass boilers (smaller potentially avoided impacts). Regarding metals, generally speaking, primary metals have a much greater environmental footprint than secondary (recycled) metals. However, due to the lower quality of secondary metals, these typically cannot fully substitute for primary metals and need to be blended with them to achieve the desired properties.

Therefore, the results, and in particular the potentially avoided impacts, represent the best possible scenario – which might be hard to achieve in real life. LCAs of waste management environmental impacts is a complex discipline. Not only does it ideally require country, or even region, specific primary data on waste management processes, its results can be challenging to interpret. Depending on the way the system has been modelled, what avoided impacts have been considered and whether the model was designed as an attributional or consequential one, the conclusions may vary. In particular, when focusing on the potentially avoided impact, one can conclude that the more waste is produced, the more environmental benefits are gained through avoidance of primary materials and fossil-based energy production. The potentially avoided impacts presented represent the most optimistic scenario, but in reality, the benefits from recycling and energy recovery will always be smaller due to downcycling, inefficiencies and market saturation.

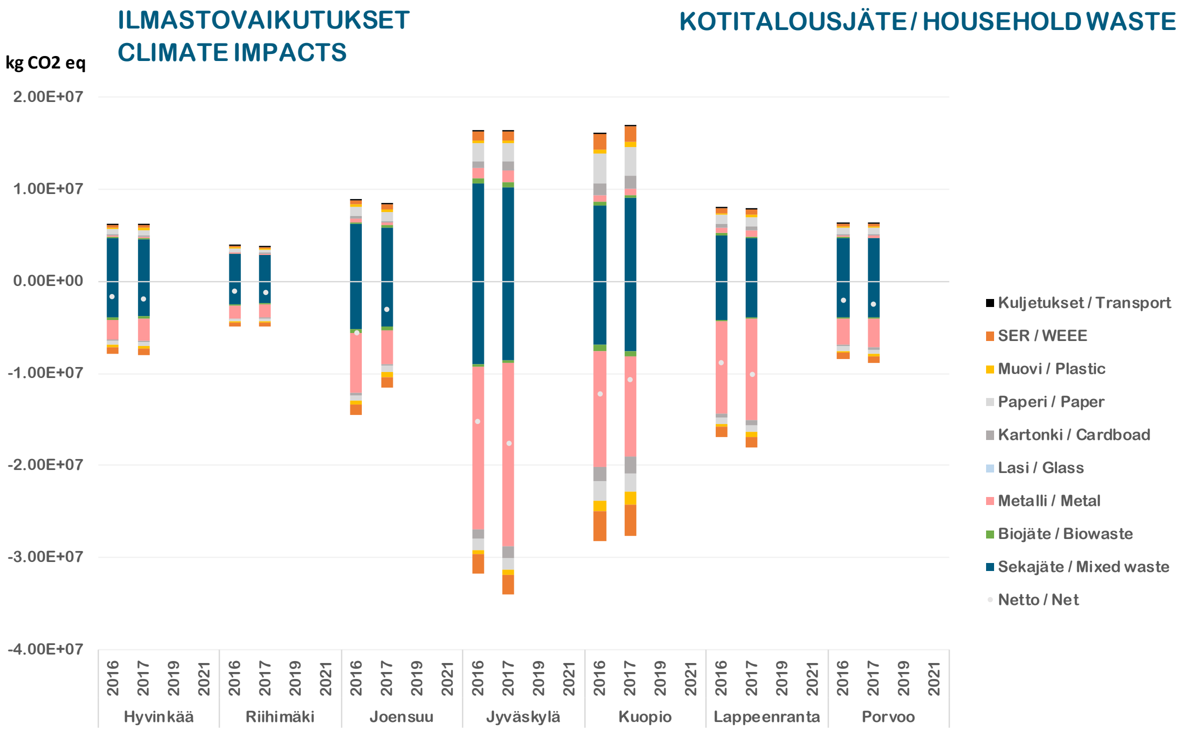


Figure 40. Climate impacts and potential benefits (below the x-axis) of waste management of household waste in seven Circwaste municipalities for the baseline year 2016 and for 2017.

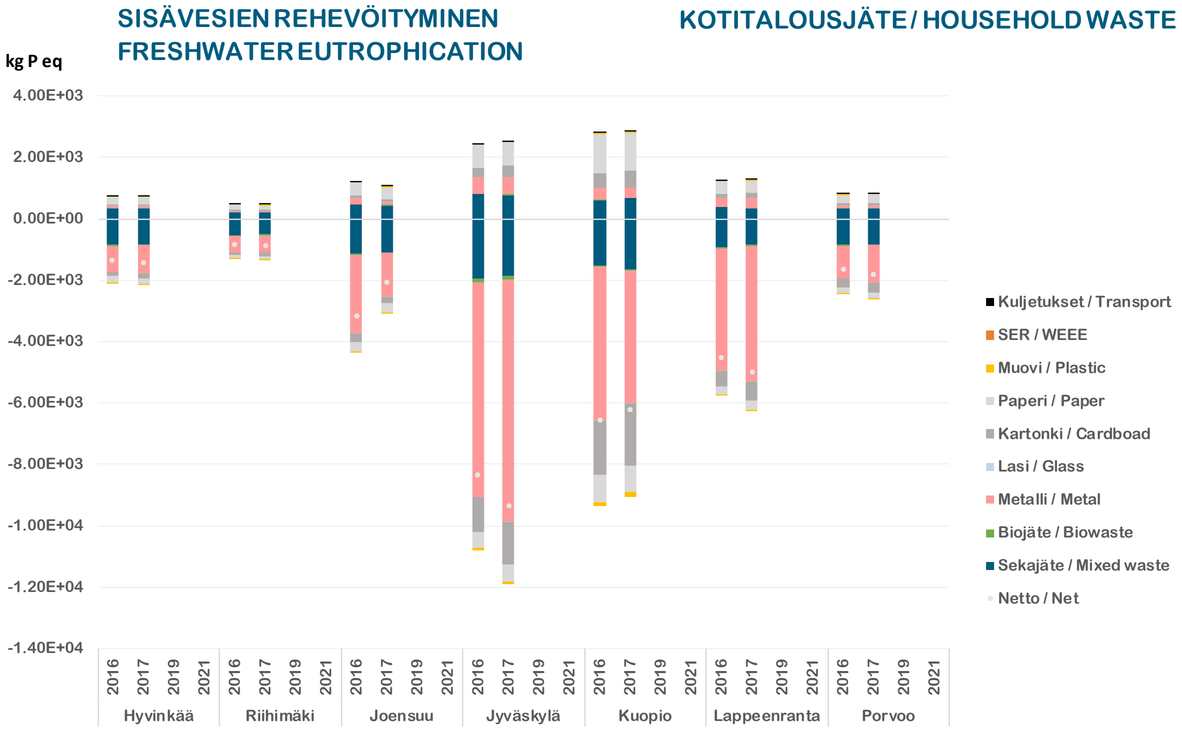


Figure 41. Freshwater eutrophication impacts and potential benefits (below the x-axis) of waste management of household waste in seven Circwaste municipalities for the baseline year 2016 and for 2017.

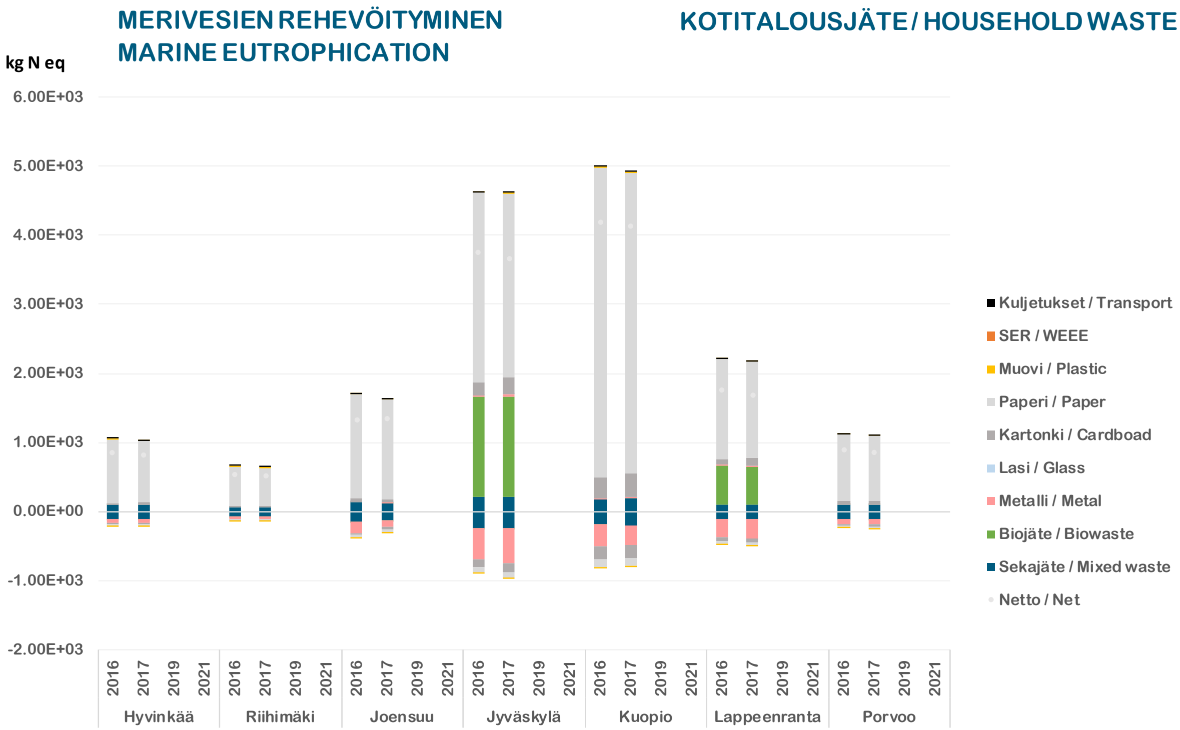


Figure 42. Marine eutrophication impacts and potential benefits (below the x-axis) of waste management of household waste in seven Circwaste municipalities for the baseline year 2016 and for 2017.

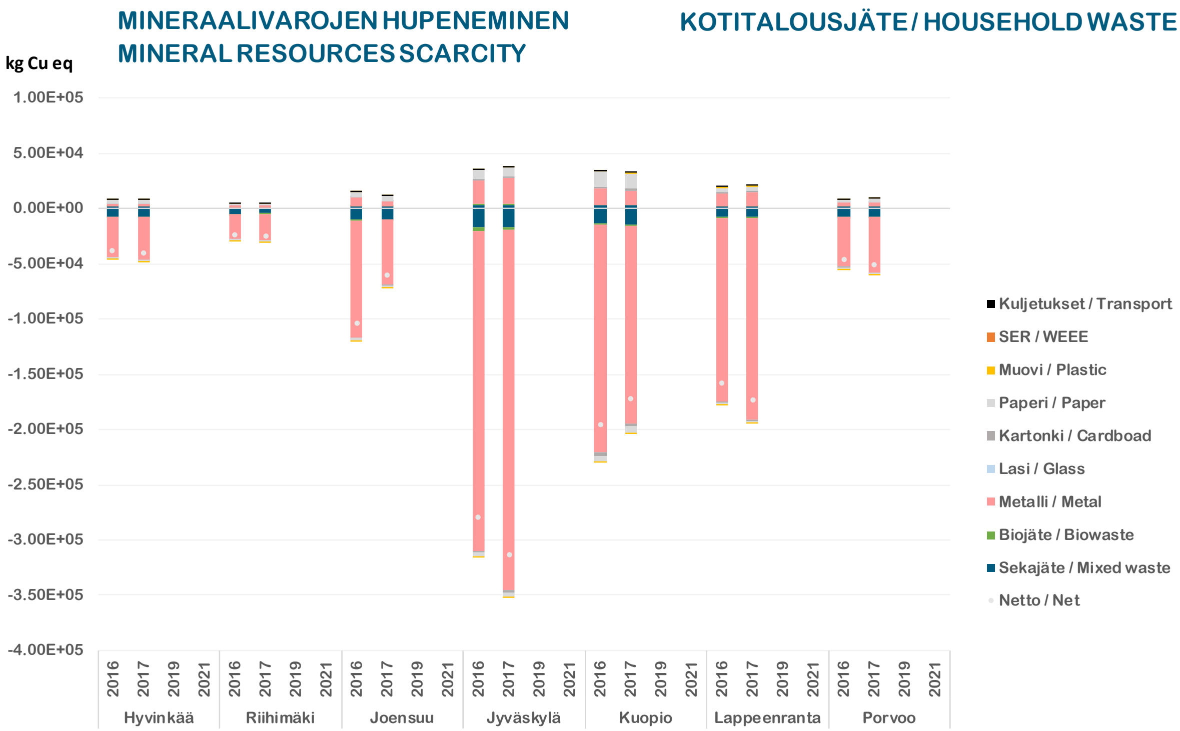


Figure 43. Mineral scarcity impacts and potential benefits (below the x-axis) of waste management of household waste in seven Circwaste municipalities for the baseline year 2016 and for 2017.

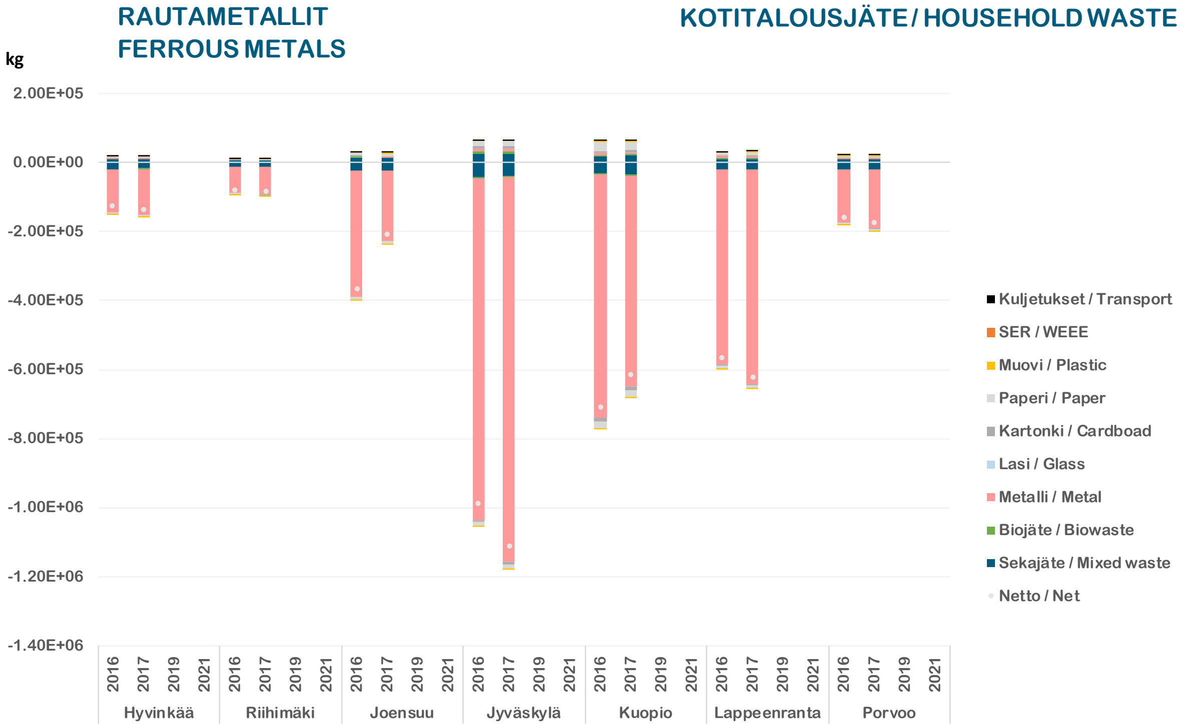


Figure 44. Consumption of (above the x-axis), and potentially avoided consumption of (below the x-axis), ferrous metals caused by waste management of household waste in seven Circwaste municipalities for the baseline year 2016 and for 2017.

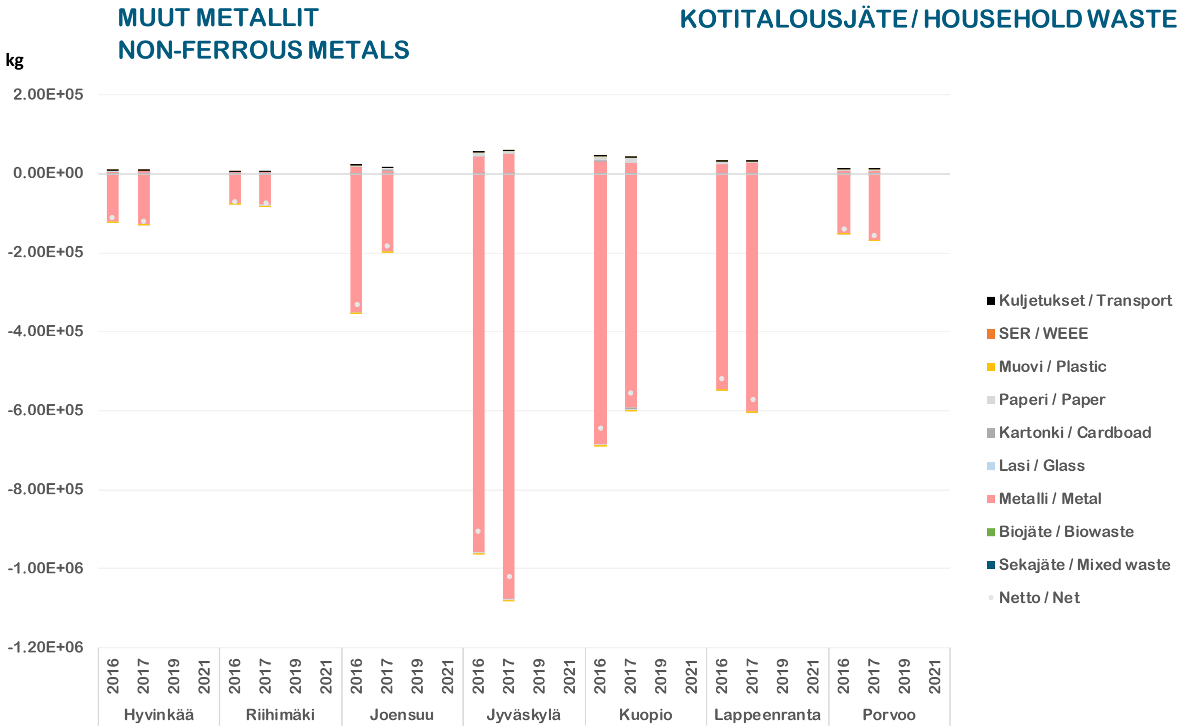


Figure 45. Consumption of (above the x-axis), and potentially avoided consumption of (below the x-axis), non-ferrous metals caused by waste management of household waste in seven Circwaste municipalities for the baseline year 2016 and for 2017.

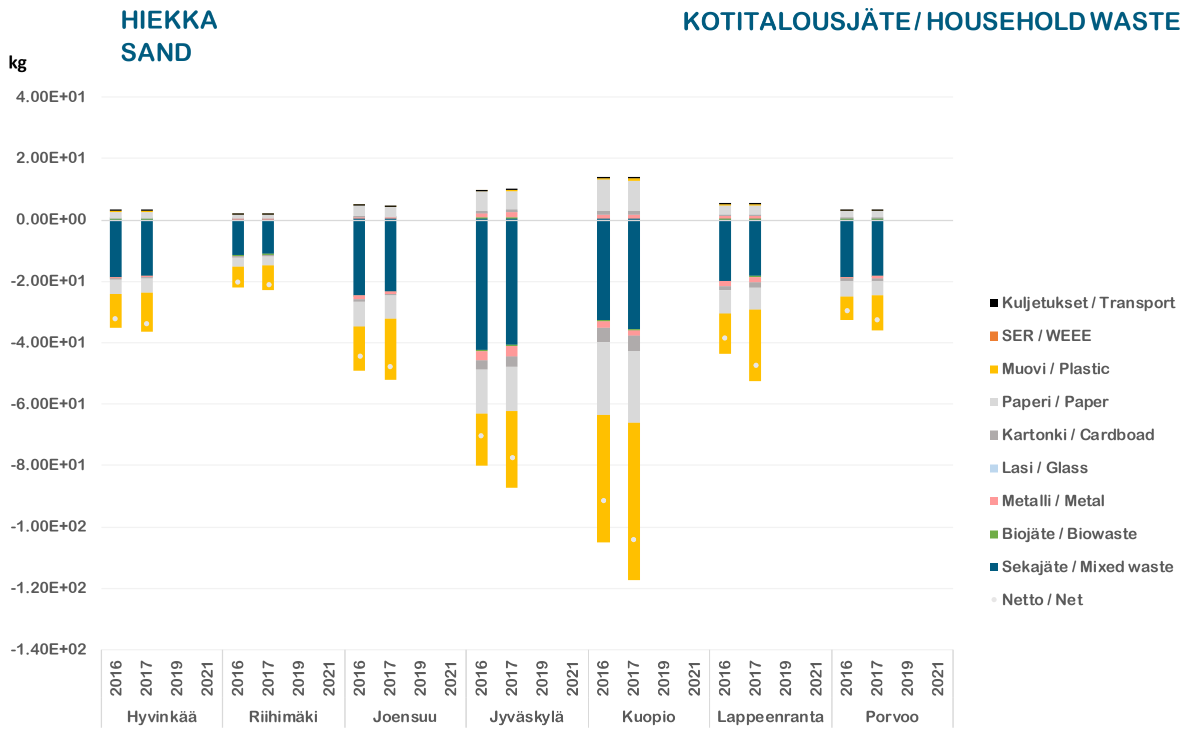


Figure 46. Consumption of (above the x-axis), and potentially avoided consumption of (below the x-axis), sand caused by waste management of household waste in seven Circwaste municipalities for the baseline year 2016 and for 2017.

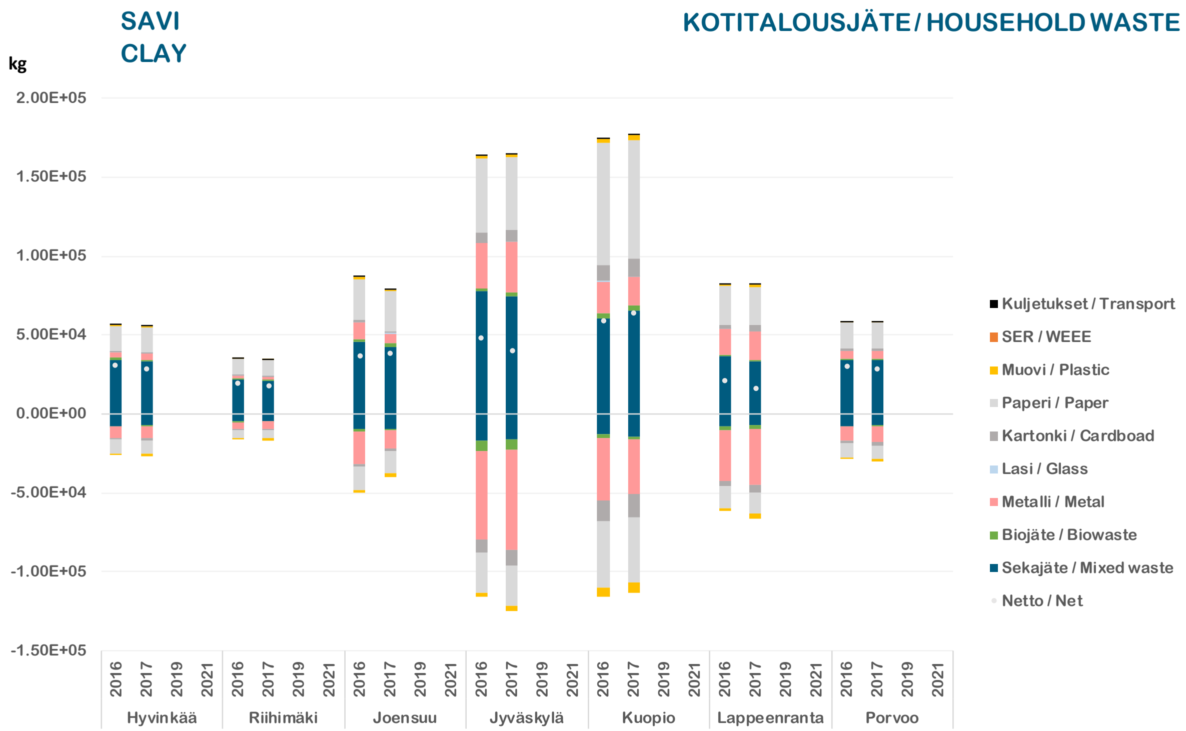


Figure 47. Consumption of (above the x-axis), and potentially avoided consumption of (below the x-axis), clay caused by waste management of household waste in seven Circwaste municipalities for the baseline year 2016 and for 2017.

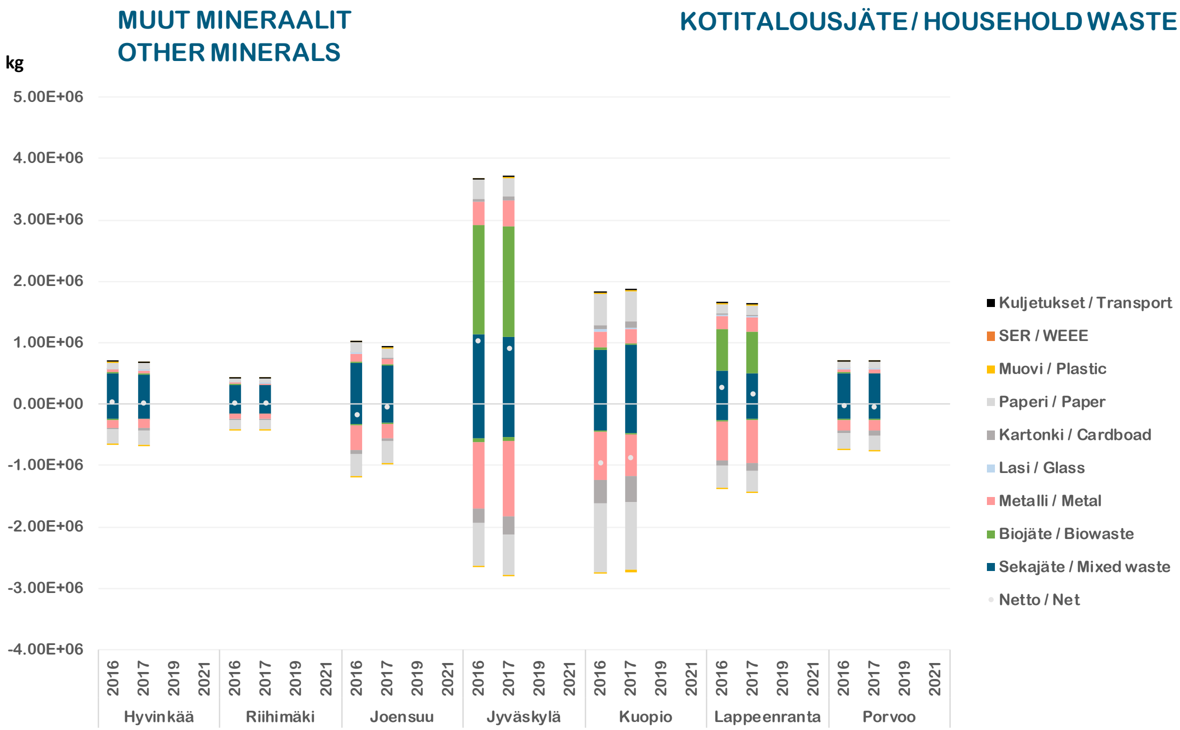


Figure 48. Consumption of (above the x-axis), and potentially avoided consumption of (below the x-axis), other minerals caused by waste management of household waste in seven Circwaste municipalities for the baseline year 2016 and for 2017.

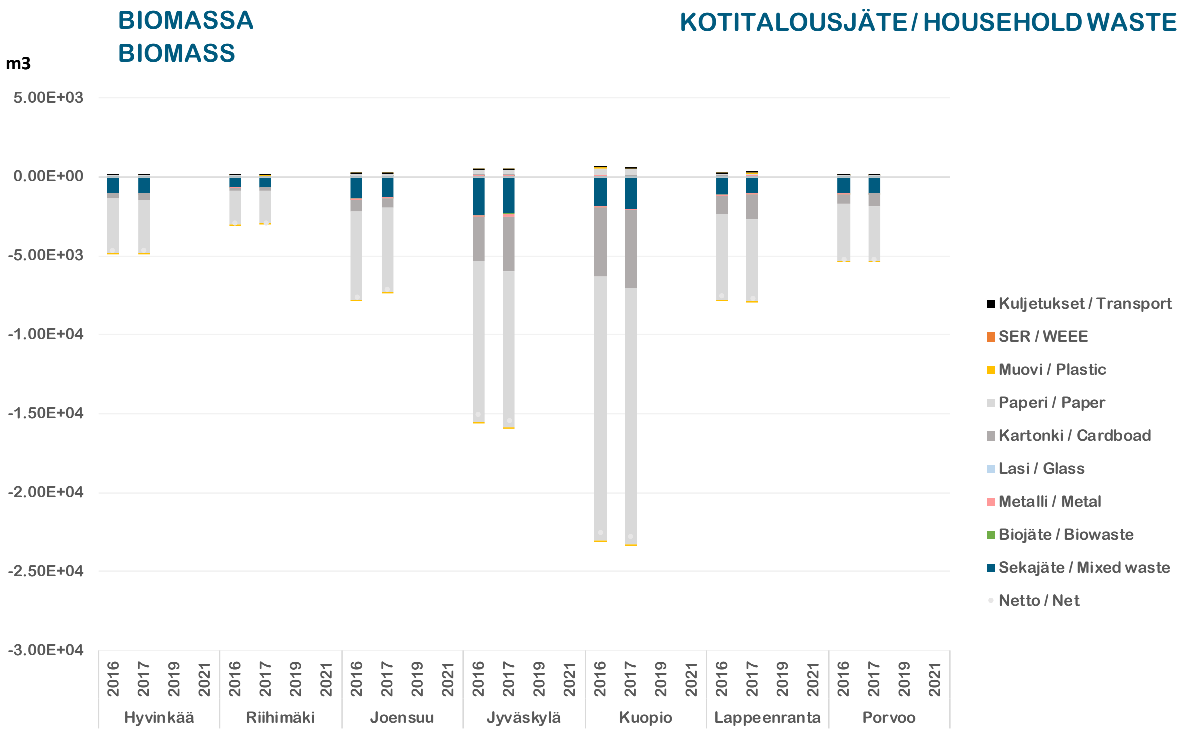


Figure 49. Consumption of (above the x-axis), and potentially avoided consumption of (below the x-axis), biomass caused by waste management of household waste in seven Circwaste municipalities for the baseline year 2016 and for 2017.

In all the impact categories, the most beneficial way of reducing environmental impacts of the waste sector is to avoid producing waste. After only two years of data collection and modelling, there are not yet observable clear trends in environmental impacts (Figure 40–Figure 49). But in the meantime, while searching for means for minimising the impacts of waste management activities, preferences in decision making can be supported with LCA based results. Due to the waste amounts and the type of treatment, mixed MSW energy recovery and waste paper recycling are the main contributors to the climate impacts caused by municipal waste management. The largest potential climate benefits can be achieved by investing in metal recycling and efficient heat recovery from MSW incineration. The climate benefits presented above, however, do not necessarily fully reflect the market reality. The magnitude of the potential climate benefits depends on the actually avoided materials (primary or secondary) and energy (renewable or fossil).

In freshwater eutrophication, waste paper treatment is potentially having the greatest direct impacts, whereas the greatest potentially avoided impacts are related to metal recycling, MSW energy recovery, and efficient cardboard recycling. In the marine eutrophication category, paper treatment dominates the potential direct emissions associated with biowaste treatment. The impacts in mineral resources scarcity can be reduced through metal recycling.

The rest of the results are based on inventories and not on impact assessments. In other words, these are the resources consumed along the value chain of waste management activities. Based on the results, the use of natural resources in waste management is minimal. The only exception is the consumption of other minerals. Even the consumption of those, nevertheless, is relatively low for all waste treatments considered. On the other hand, the consumption of natural resources can be minimised through the avoidance of primary materials consumption by increasing recycling.

5.1.4. Organising training and networking events for stakeholders

Three training and networking events have been organised for the forerunner municipalities on life cycle thinking (LCT) based evaluations. In addition to raising awareness and understanding of LCT, the events aimed at offering the forerunner municipalities help in performing LCT based evaluations on their planned activities for promoting the implementation of the NWP. One practical training session on the use of a free LCA tool, CCaLC2, for assessing environmental impacts and costs was also organised.

The first LCT workshop, attended by 32 representatives of the forerunner municipalities, presented the concept of an LCT clinic based on the model developed in the project 'Framework for developing companies' environmental life-cycle impacts' (Finnish Environment Institute 2015). Discussions with the participants revealed the following themes to be of common interest: multi-purpose and more efficient use of municipalities' premises, shared use of cars, various fuels for vehicles, investments in biogas plants, and construction and demolition (C&D) waste. These themes were considered very challenging to evaluate by means of an LCT clinic due to factors such as difficulties in setting boundaries for evaluations and the complex nature of the systems.

Based on the first workshop, discussions in the second workshop were focused on 1) increased use of shared spaces, and 2) prevention of demolition (waste), repurposing and reusing building elements. The participants, 39 in total, were first walked through a general life cycle of a building (or a physical infrastructure) and some of the environmental issues associated with the different life cycle stages. The following facilitated discussions offered the representatives of the forerunner municipalities an opportunity to learn from each other on how to implement different solutions successfully implemented elsewhere. Simultaneously, the workshop offered the opportunity to jointly formulate concerns and obstacles regarding the two topics.

In addition to LCT workshops, a training event was organised for stakeholders interested in using the CCaLC2 tool, which was assessed by the project to be the most appropriate LC tool for enterprises and administration. The assessment was based on an online questionnaire for Circwaste consortium enterprises and a review of LCA tools available on the internet. Based on the results of the questionnaire, the tool should be easy to use. Additionally, the tool should be free of charge and have good guidance. To identify such a tool, a review of the following LCA tools available on the web was carried out:

- CCaLC2 (Carbon calculations over the life cycle of industrial activities, University of Manchester)
- OpenLCA (Open source LCA software, GreenDelta)
- WARM (Waste reduction model, USEPA).

A webinar for training stakeholders on use of the CCaLC2 tool was organised with help from the tool developers at the University of Manchester. The tool contains data on selected impact categories from the Ecoinvent database, version 2.2. and is available from the University of Manchester website (www.ccalc.org.uk). The user can also apply their own inventory data to calculate various environmental impact categories and costs.

5.2 Input-output impact assessment of regional activities

In order to model the systemic impacts of implementing the circular economy in the regions, a basic version of the regional impact assessment model was developed for each of the five Circwaste key regions. The model includes two main elements: monetary input-output (IO) tables and environmental extension. The monetary tables include 54 industries with data on output, value added and employment. The current version of environmental extension includes greenhouse gas emissions (kg CO_2 equivalent) from 2010. The regional IO models were built on the national IO model of Finland for 2015 (Statistics Finland 2019c) and regional accounts for 2015 (Statistics Finland 2019d). Using the Cross-Industry Location Quotient (CILQ) method and balancing method, the model for each Circwaste key region was regionalised, resulting in industry-by-industry input-output models. This approach allows for a regional assessment of environmental impacts with respect to the regional monetary flows. This kind of model can be replicated for any region in the EU, providing there is regional economic data for industries, national input-output data and national or regional environmental load data available.

On the basis of modelling results, key regions can be compared from different viewpoints, e.g. employment, value added and environmental impacts (Figure 50–Figure 52). It is also possible to analyse the economic and environmental aspects of the regional industries.

Analysis of the industry-wide environmental impacts in the regions is possible on the basis of modelling results. The model provides information on which industries have potential to reduce their environmental impacts. To analyse NWP measures, the applied measures must be translated to monetary changes into the model. This modelling requires detailed data on both regional waste flows and industry resolution. The methodology for translating NWP measures to comply with the basic IO-model has been tested and will be further developed later during the project, and the LCA modelling will be incorporated into the model.

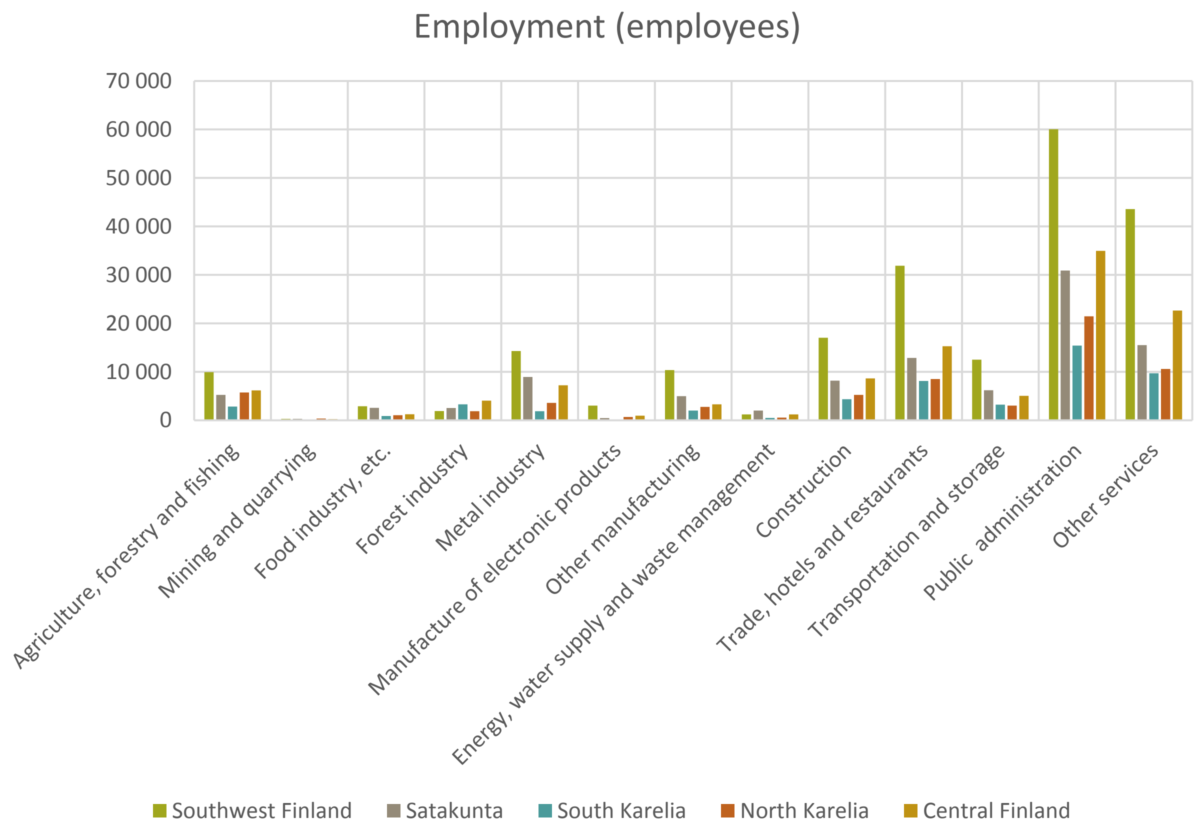


Figure 50. Example of results from the regional impact assessment model: employment in five key regions (aggregation to 13 industries) in 2015.

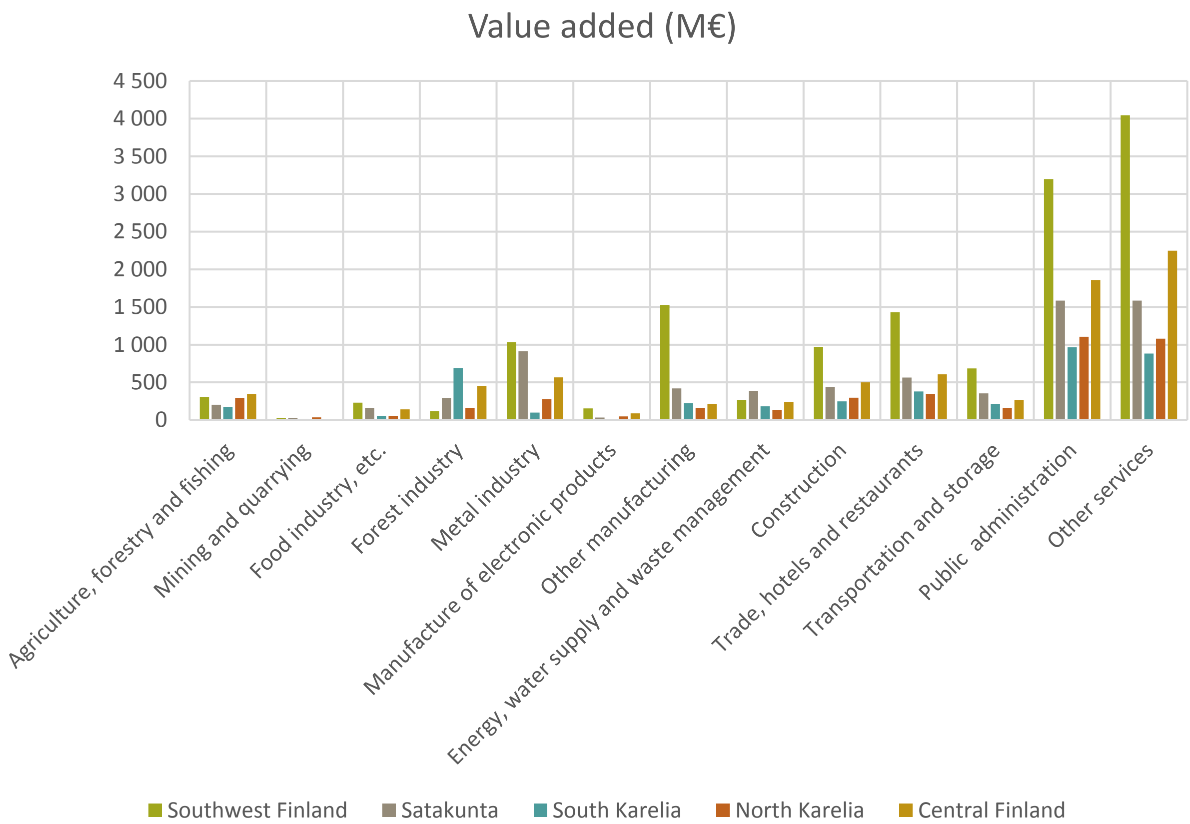


Figure 51. Example of results from the regional impact assessment model: value added in five key regions (aggregation to 13 industries) in 2015.

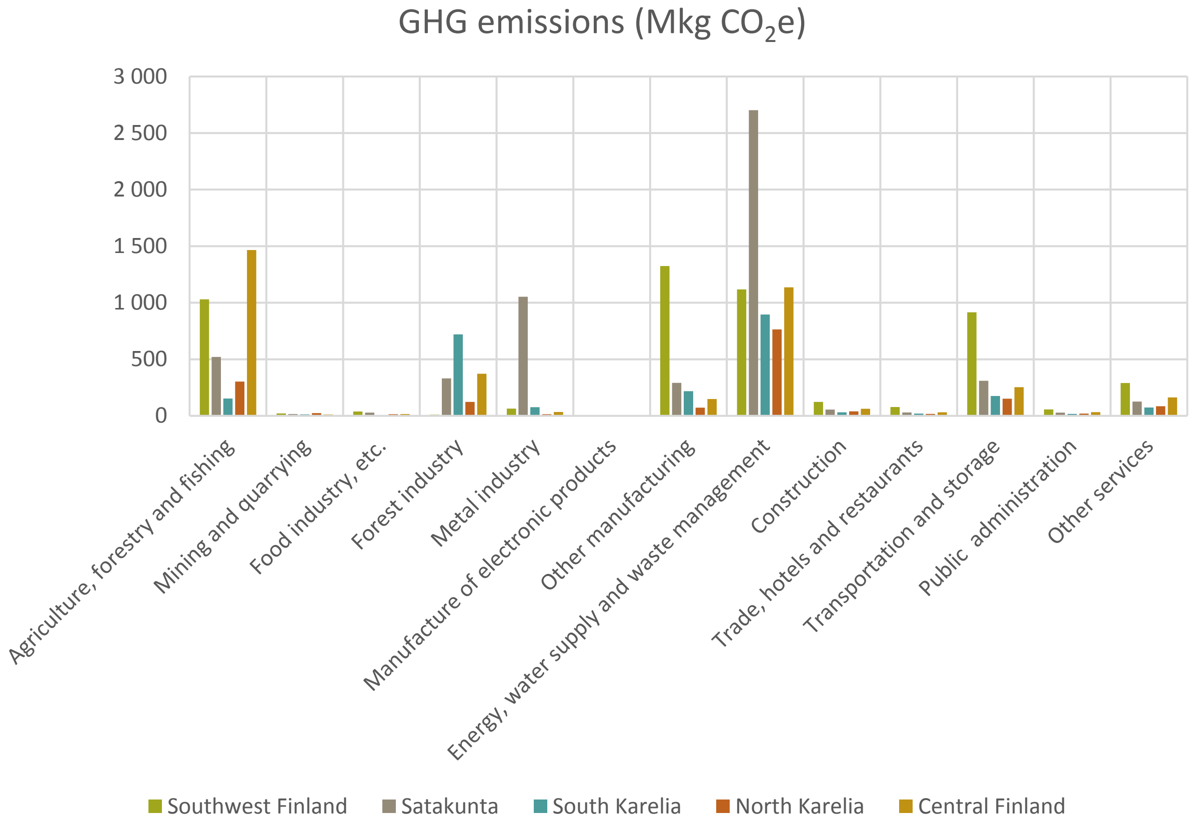


Figure 52. Example of results from the regional impact assessment model: greenhouse gas emissions in five key regions (aggregation to 13 industries) in 2015.

The use of an environmentally-extended IO model relies on environmental load coefficient data. In Finland this kind of data was gathered in 2010 and some load categories (e.g. greenhouse gas emissions, raw material use) are available for 2015 (Savolainen et al. 2019). The use of this data implies some uncertainty in the results, since the environmental loads of the industries in Finland have changed and the environmental data might be somewhat outdated. This is recognised in the results and communicated when displaying the results. Unfortunately, updating all environmental load data is an extensive task and not within the scope of this project. Therefore, the results are presented with a remark about the possible biases resulting from this. Another challenge regarding the environmental load coefficients is that they are national and there is no region-specific coefficient data available for all five regions. Producing complete regional coefficient data is also a considerable task and it is not possible to complete it within the scope of this project. These weaknesses are communicated when presenting the results.

To test the model for analysing the impacts of NWP measures, system level impacts of changes to the service economy were modelled in the Satakunta region with enhanced input-output methodology: The scenario included cutting the output of the textile, cloth and leather industry by half and transferring the output to renting and leasing services in the same region. This scenario resulted in a 3.4% decrease in the regional total carbon equivalent emissions. More scenarios of both NWP measures and actions promoting circular economy through their impacts on customer behaviour and industries will be modelled later. These scenarios might include, for example, cutting edible waste food amounts by half, increasing the maintenance of electric appliances, consuming bioplastics or fibre products instead of plastic ones etc. The regional monetary tables will be investigated in more detail and a regional, more detailed product-by-industry model will be created to get more insights into the structure of regional economies.

5.3 Impact assessment of communication activities and project visibility

Good and active dissemination and communication might be the most important part of a project that aims at general influencing and raising public awareness. Dozens of partners and actions are underway and producing interesting new results from the different areas of circular economy at the same time. Disseminating all these results nationally and within the consortium is what gives meaning and volume to this valuable research work. The task has included defining communication objectives and building a sustainable communicative infrastructure, along with the content production processes together with the project partners. Without partners' investment in dissemination work, the content of the work would have remained too flat and one-dimensional. Key regions have created wide networks during the project's first phase. They have arranged a lot of events, seminars and workshops, allowing them to reach citizens and circular economy operators from the region. Every region has its own strengths and dissemination focuses.

The entire communicative infrastructure of the Circwaste project functions as a comprehensive system, with each communication product being considered part of an overall concept with several channels. The core of the communication infra is the materiaalitkiertoon.fi website, launched in May 2017. The website was constructed at the same time as the Circwaste magazine (Finnish Environment Institute 2017), which allowed for the materials created in the process to be published through both channels. The number of visitors to the project's website has grown steadily. During 2019, almost 11,500 people visited the materiaalitkiertoon.fi webpage.

Project communication activities also included cooperation with circular economy themed event at the Finnish Science Centre Heureka in October 2019. This event attracted around 600 attendees and the content produced for the event by the Circwaste project included an interactive puzzle building game (a picture of the puzzle can be found in Attachment 4), which showed the variety of critical metals needed in constructing a mobile phone and how these metals must be extracted from all over the world. The materials that are needed for the game can be found on the project website.

Media activities related to waste streams and recycling rates in different regions have generated good media visibility. Widespread media coverage has resulted from co-operation with project partners and regions. The competition Kiertotalouskunta ('the circular economy city') and Kiertopalkinto award have also produced media coverage and visibility for organisations working with circular economy.

Social media channels like Twitter and Facebook are used as teasers and incentives for visitors to get to know the online service where all the communication materials produced in the project are placed. The number of Twitter followers has increased rapidly. Active use of Twitter also facilitates Circwaste project profiling and networking with those working with circular economy. Twitter is also a place where policymakers and experts find current information. For these reasons, Circwaste decided to participate in a Twitter experiment to see how Circwaste is linked to the conversation on circular economy and what can be done to add to the visibility. The experiment was considered successful, and it offers several paths for progress, such as joint Twitter campaigns.

5.4 Study of hazardous characteristics of waste and circular economy

In order to reach a circular economy that is not harmful to people or the environment, actions are needed in different parts of product and waste life cycles. In a sustainable circular economy, we must also manage substances that give desirable qualities to products, but that may cause problems when products are reused or recycled (Kauppi et al. 2017). It is important to make sure that materials and waste containing or contaminated with hazardous substances are identified and hazardous substances are eliminated from the cycles. That means we must strive to reduce the use of hazardous substances throughout the entire product life cycle: from design to production, use, maintenance, reuse and recycling (Kauppi et al. 2017). A safe and sustainable circular economy requires harmful substances to be controlled in all activities, from collection to processing of materials. The chemicals in waste-based materials must be taken into account in the manufacturing and uses of new products and their new uses.

One way of contributing to and confirming the non-hazardous nature of material cycles is to promote non-hazardous public procurements. In a chemical-wise procurement process it is possible to set criteria that take into consideration hazardous substances in products and materials (Kontturi et al. 2018). A guide to chemical-wise procurement for municipalities was published by Kontturi et al. (2018) by researchers at Turku University of Applied Sciences. In the Circwaste project, a series of podcasts on chemical-wise public procurement was produced and it is available on the project's website (Haitalliset aineet resurssitehokkaissa hankinnoissa 2019).

The easiest way to avoid hazardous substances in purchasing is to buy products and substances labelled with a Nordic or EU ecolabel. In these products, the most harmful substances to human health and the environment, which are persistent organic pollutants (POPs) and substances of very high concern (SVHCs), are forbidden. There are around 60 product groups covered by the Nordic ecolabel, from washing-up liquid to furniture and hotels. Already available criteria can be used as such or as a template for setting criteria for procurement. In Finland, these can be found on Motiva's website. In Sweden the National Agency for Public Procurement maintains a database of sustainability criteria and this is publicly accessible (The National Agency for Public Procurement 2020). The database contains proposals for environmental and social requirements to be used when purchasing goods, services and work contracts. There are three levels of environmental criteria: basic, advanced and spearhead. The European Commission has also developed more than 20 common GPP criteria. More in-depth information and experiences can be found in the aforementioned podcast series.

The Industrial Emissions Directive is the main instrument at EU level for controlling hazardous substances that are released from industrial sites. However, its reference documents, or BREFs, currently lack specific information on certain hazardous substances. The ongoing HAZBREF project aims to increase the knowledge base of industrial sources and reduction measures for hazardous chemicals released into the Baltic Sea. It also aims at finding out how to enhance the circular economy and waste recycling with improved information on hazardous substances in BREF documents. The HAZBREF case sectors are textiles, surface treatment of metals and plastics and production of polymers and fertilisers. The project will develop a tool for identification of substances that should be considered in the BREF process. The project ended in September 2020. (Dahlbo et al. 2020)

Materials and products that are already in use can be of different ages. Some cycles are rapid, but some products and materials can be quite old, e.g. building materials or furniture. They can contain substances that are forbidden nowadays but were commonly used at the time they were produced. Buildings can also contain materials from several different eras.

Most construction and demolition waste is generated by the renovation and demolition of entire buildings. The Ministry of the Environment published three guidebooks on increasing the effectiveness of the reuse and recycling of demolition materials and removing harmful substances from circulation. Demolition Work – a Guide for Operators and Contractors covers the realisation of the entire demolition process (Lehtonen 2019), Pre-demolition Audit – A Guide for Authors offers information on best practices in pre-demolition audits (Wahlström et al. 2019) and The Circular Economy in Public Demolition Projects – a Procurement Guide describes criteria for public procurement of demolition work (Kuittinen 2019).

In the Safe and Sustainable Circular Economy SIRKKUproject (Kauppi et al. 2019), hazardous chemicals were investigated with regard to their impact on people and the environment, occupational safety, waste-related processes, and legislation. Together with stakeholders from different industrial sectors, projects' target fields were selected for recycling of construction and demolition waste and plastics, particularly composite materials, and the focus was limited to brominated flame-retardants, phthalates and short-chain chlorinated paraffins. Several hazardous substances were identified in various building structures. Recommendations for management of hazardous substances in the circular economy were

given and some in particular for the construction sector. These recommendations stress the importance of better information on the presence of hazardous substances in products, waste streams and the environment, as well as the need to improve the flow of information on the material content of products throughout the product's life cycle, through to the waste phase and secondary products, is acknowledged, as also stated by Kauppi et al. (2017). Several technological development needs with financing needs were identified in analytics and material development. Methods for utilisation of waste materials must be expedited, whilst administrative processes should be simplified. The
predictability of decision-making would promote the circular economy, and the authorities require instructions and information on hazardous substances in waste streams to support their decision-making. Furthermore, the part of the waste stream that contains unidentifiable chemicals should be directed to energy production.

Interfaces between chemical, product and waste legislation are key to the circular economy and it is also essential that different actors are aware of relevant statutes at different stages of the material cycle. Particularly important is that hazardous wastes are identified and handled correctly. In the Circwaste project, hazardous substances lectures were given for environmental authorities on the interfaces between chemical, product and waste legislation and on the classification of waste as hazardous waste. Tailored guidance has also been given by e-mail to various bodies on these issues. Bodies producing secondary raw materials and recycled products should be aware of the requirements of chemical and product legislation as well as waste legislation.

Special attention should be paid to persistent organic compounds (POPs) and substances of very high concern, because old materials and substances and waste can contain these substances or be polluted by them. The Stockholm Convention stops or strongly restricts the production, trade, use and emissions of 28 persistent organic pollutants, and it demands the removal of these chemicals from the material cycles (Stockholm Convention 2020). Substances of very high concern may have serious and often irreversible effects on human health and the environment. Companies manufacturing or importing items containing Candidate List substances (in total 205) at a concentration above 0.1% of the weight of the item, are subject to legal obligations. Substances on the Authorisation List (in total 54) cannot be placed on the market or used unless a company has been authorised to do so.

Online shopping has increased significantly in recent times. Cheap products can be more easily abandoned, thus increasing the amount of waste produced. The products might also contain substances that are not allowed in the EU and that cause risks to health and the environment and problems in waste management and recycling. The 'At your own risk' (in Finnish Omalla vastuulla) campaign on the risks of purchasing a products and responsibilities when reselling products from outside the EU was a joint effort of 14 different bodies, both authorities and other organisations. The Circwaste project participated in this campaign with its main products – two videos and posters with a twist of black humour to catch the attention of the typical online purchaser. The videos were shown on TV for a short time and can be found on the TUKES website and YouTube. Short informational texts can also be found on the TUKES website. (TUKES 2018)

Waste recycling can also be enhanced with voluntary green deal agreements. A green deal is a voluntary agreement between the State and a business sector. Agreements can be concluded with public sector bodies as well. The aim is to take joint action to promote the Sustainable Development Goals by seeking solutions to mitigate climate change and promote a circular economy. The parties to the agreement make ambitious, measurable commitments aiming to improve implementation of current legislation or complement this. They may also set stricter targets and help to achieve certain targets without further regulation. The Ministry of the Environment and Environmental Industries (YTP) concluded the Green Deal on Developing National Waste Oil Management in 2019. The objective of the agreement is to increase the effectiveness of waste oil management and the recycling rate of waste oil throughout Finland. Awareness of this agreement was promoted with a blog post on the Circwaste website (Haavisto 2018).

5.5 **Study of cross-disciplinary sustainability assessment of selected good practices**

In order to identify the most effective circular economy practices, several aspects are to be considered. A good circular economy practice – in addition to its capacity to recycle materials – should also be economically, environmentally and socially sustainable. The objective was to select a set of success stories on circular economy to be distributed to municipalities for further development and use. In the process, the example cases from construction and zoning were selected as the first case study. The cases were collected both abroad and in Finland and described as precisely as possible, considering environmental, social and economic aspects.

A group of researchers and experts from SYKE were invited to participate in an action workshop to evaluate the cases using a framework. The goal of the workshop was also to provide an understanding of all circular economy dimensions in a theoretical framework of sustainable development. The groups were formed so that each group consisted of researchers and experts from various backgrounds: circular economy, biodiversity and environmental sciences, social sciences, zoning, hazardous substances. The idea was to assess real life examples within two hours. There were in total about 20 participants, plus facilitators, all divided into five groups.

The aim was to identify and evaluate the positive and negative impacts of the cases, as well as how well the practice could be replicated in other municipalities. Within ecological sustainability the categories were: sustainable use of natural resources, critical resources, biodiversity, GHG emissions, hazardous substances, recycling of nutrients and other environmental impacts. The economic sustainability categories included profits or investments, jobs created, local GDP, new business opportunities, different opportunities for the sharing economy, and digitalisation. The social sustainability category included justice and equality, feelings of relevance, sense of community and participation, increased knowledge, and physical and mental health.

Each category was weighted using a scale from -3 to +3 (--- / -- / - / 0 / + / ++ / +++); -3 being remarkably negative/harmful, -2 slightly negative, -1 mild negative impact and +3 being very positive, +2 slightly positive, +1 mild positive impact, whereas 0 is no impact or the effect is neither positive nor negative. The examples chosen were: a general example from wood construction compared to concrete construction and a soil recycling example from Helsinki: From old landfill to green park – the Alakivenpuisto case. The results are shown as bar graphs showing the highest and lowest estimates in different sustainability categories by different expert groups (Figure 53). Ecological, economic and social sustainability category results are also shown in separate figures (Figure 54–Figure 56) in which the justification for scoring for each group is given.

5.5.1 Case: From old landfill to green park by implementing soil reuse

A new green outdoor park was built in Myllypuro, Helsinki to replace a non-habitable residential area built on top of an old landfill with insufficient isolation structures. Large volumes of recycled soil were needed for the construction: In landscaping, 60,000 m^3 of surplus aggregates were utilised. For terrain design, 35,000 m^3 of mass-stabilised dredging spoil was brought from a coastal residential area expansion site (Jätkäsaari, Helsinki). In addition to this, 25,000 m^3 of topsoil was collected from other construction projects in Helsinki and utilised as fertile earth for growing plants. This also utilised the soils' own seed bank. Recycled crushed concrete and some of the area's own soil was utilised to build the area, too. A coordinator was hired to plan the soil recycling. The benefits were evident: savings of EUR 3.8 million, 400,000 litres of fuel and 1,000 tonnes of CO_2 were achieved compared to if the soil material had been delivered to external recipients and the topsoil procured from different suppliers.

The sustainability of the Alakivenpuisto case in each sustainability category was evaluated by four groups of SYKE researchers. Discussions showed that sustainability is a complicated challenge with no easy answers: the results in different sustainability categories varied from group to group, from a positive effect to a slightly negative one depending on the perspective of the groups on the topic. Some emphasised the risks of the harmful substances in the soil masses to a greater extent while some focused on social impacts and economic savings. Prior knowledge of the case may explain some of the differences in opinions. The main views and the grounds for scoring are shown in Figure 54. The score varies notably in some sustainability categories, with 'hazardous substances' and 'justice and equality' (Figure 54) ranging from a mildly negative (-1) to slightly positive (+2) impact. In the case of the hazardous substances category, the group that gave a score of +2 felt that harmful substances and risks are adequately controlled, while the other group noted that there is no guarantee that the base is safe with this kind of solution, which uses older technology. Both groups identified parameters that are not known and that may affect the outcome. In the categories 'biodiversity' and 'profits or investments' the score varies from 0 to +2, as one of the groups considered a park with grass not conducive to biodiversity, while another group thought that compared to former residential area located on the site, a park would be a significant improvement. It was also stated that more information is needed to assess the impact on biodiversity.

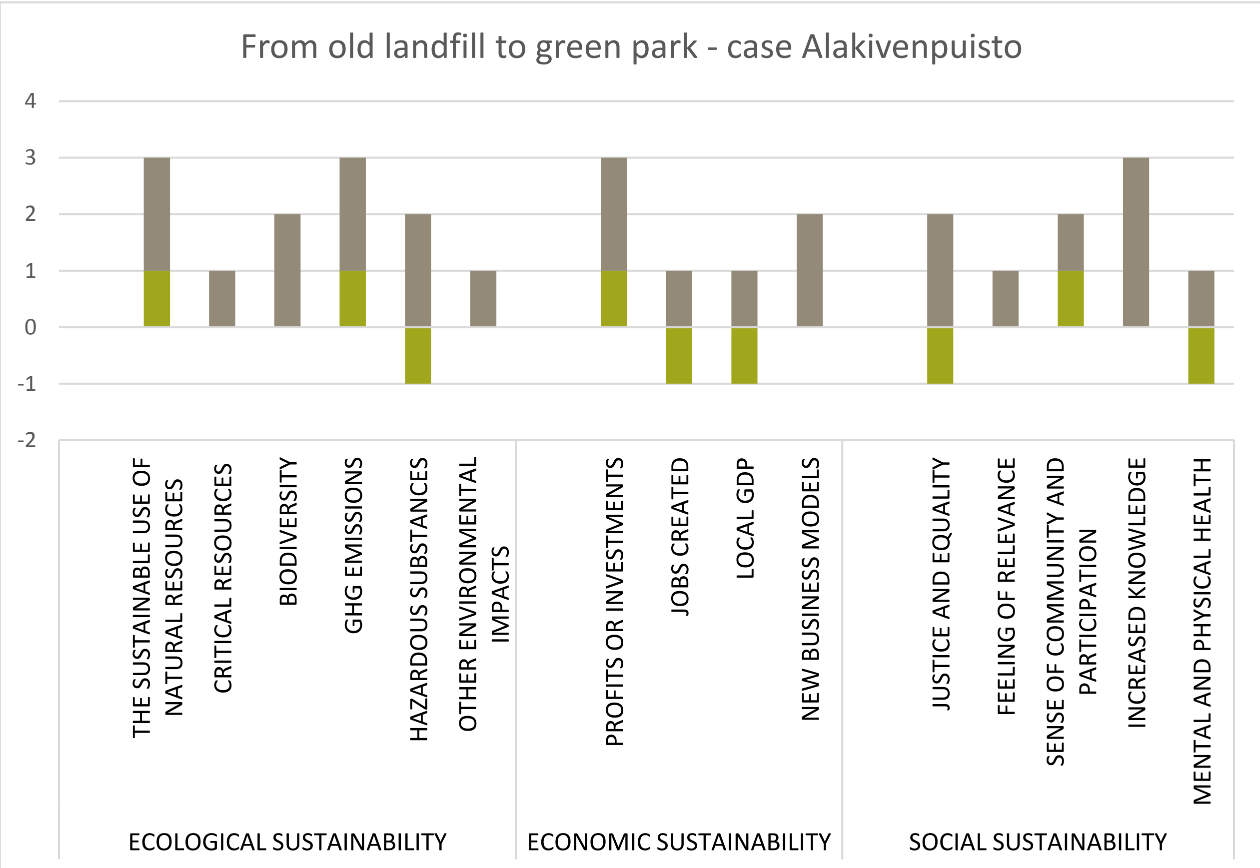
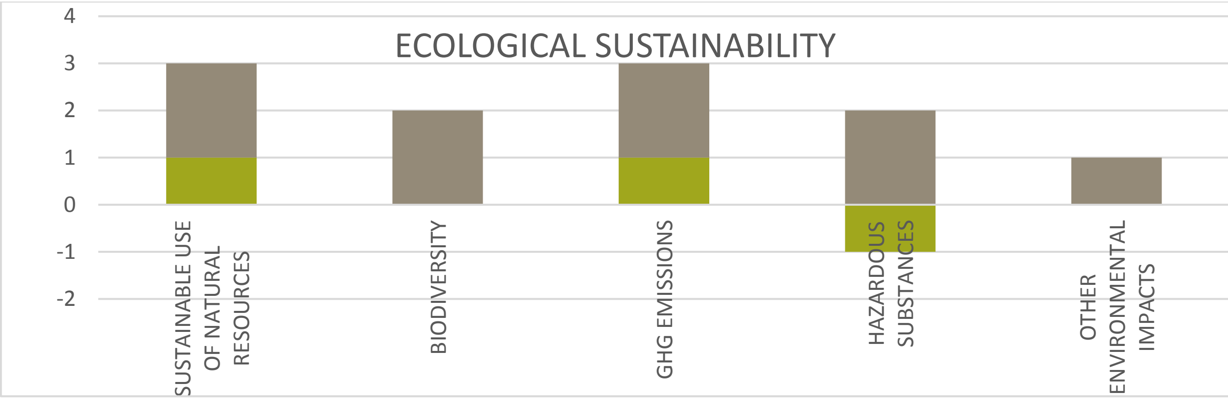
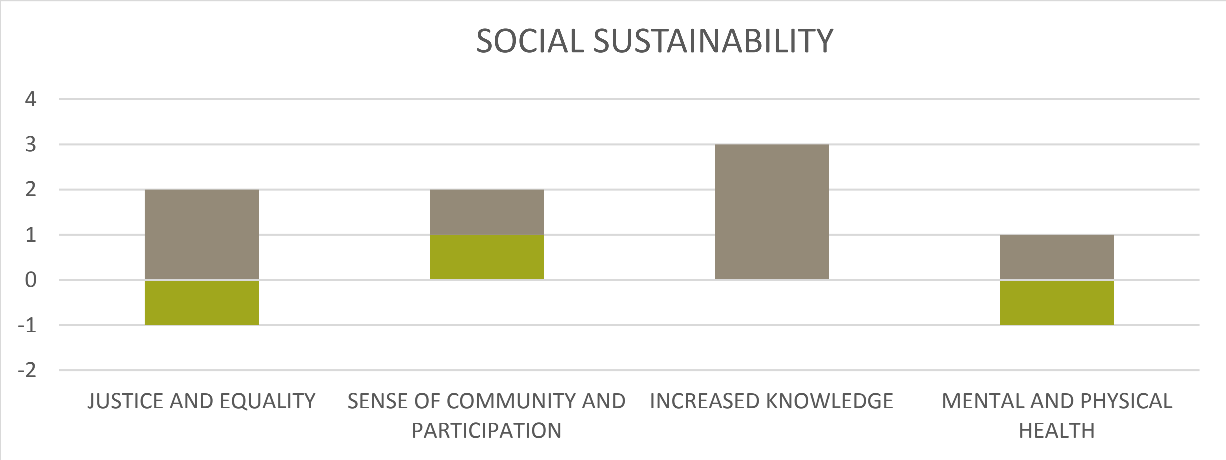


Figure 53. Sustainability aspects of the soil recycling case 'From an old landfill to a green park'. Each category was weighted on a scale from -3 to +3 (--- / -- / - / 0 / + / ++ / +++); -3 being remarkably negative/harmful, -2 slightly negative, -1 mild negative impact and +3 being very positive, +2 slightly positive, +1 mild positive impact, whereas 0 is no impact or the effect is neither positive nor negative. The bar graphs show the highest and lowest estimates for different sustainability categories as given by different expert groups.



Sustainable use of natural resources	**Biodiversity**	**GHG emissions**	**Hazardous substances**	**Other environmental impacts**
Positive aspects: • Use of recycled aggregates decreases the pressure on land use; saves pristine areas from soil excavation and landfill space. • Recycling and recovery of soil makes sense; it makes up a large part of recyclable materials • The use of fossil fuels is avoided when there is no thermal treatment. • Stabilised dredged material used; the stabilising material determines durability. Using concrete as a construction material causes significant emissions, the use of ash instead is much better.	**Positive aspects:** • Promotes diversity when the green environment is produced in the built environment. The topsoil may contain local species. • Green areas are good for diversity if implemented so that the environment is conducive to diversity (e.g. pollinators). Difficult to assess the impacts – more information on the impacts on diversity is needed. **Neutral or positive aspects:** • The end result is a grass field that may not significantly enhance diversity.	**Positive aspects:** • Saved fuel, less CO_2 emissions, because the disposal site is often further away than sites that utilise soil within the municipality. • Transportation may be the biggest GHG emitter. The proportion from stabilisation is likely to be lower. Stabiliser emissions are significant compared to the use of soil.	**Positive aspects:** • Harmful substances and risks are adequately controlled. The situation is well controlled vs. another disposal location. • Should organic contaminants have been cleaned up on site? e.g. POP. • This is a relatively suitable place for Jätkäsaari harbour's contaminated materials. It is better to place slightly contaminated dredge spoils in insensitive places. **Negative or positive aspects:** • The base must be stable. The case is older, nowadays better solutions are available: there must be monitoring to ensure that the area stays safe. If this is the case, the score is +1.	**Positive aspects:** • Nutrient cycle: better runoff water management? Vegetation in the park binds and maintains the circulation of nutrients and water. • Sustainable water management. • Decreases other emissions into the air and noise nuisances from transport.

Figure 54. Ecological sustainability categories. The main points of different groups and the grounds for the scoring.



Profits and investments	Jobs created	Local GDP	New business models
Positive aspects: • It is very economical if there is a need and demand in the same area, i.e. a new location can be found nearby. Saved labour costs might increase profitability. • Without the cone / a nother type of terrain shape design the park would have been cheaper – but what is the value added of a successful end result? Planning requires money compared to disposal. Landfilling of soils would be a more expensive option. **Negative or positive aspects:** • Savings are high, but the price of health cannot be calculated if the pollutant concentrations in the area are not safe • This was a measure that the municipality had to take in any case. **Negative aspects:** • Recovery and treatment would have been a better option. Creates new business.	**Positive aspects:** • Successful planning, coordination, and risk communication. • Planning and coordinating the recovery of waste materials has created jobs. **Negative aspects:** • Large savings may reduce jobs. • Can reduce transport jobs when the need for soil transport is smaller.	**Positive aspects:** • Positive regional image benefit – can raise the price of nearby housing. **Negative or positive aspects:** • No need to buy soil from outside, so a positive effect. On the other hand, jobs are declining. Reduces economic activity in the region when there is no need to buy soil. Input-output modelling needed. • At regional level, does not matter. • Big cost to the municipality – it was not possible to build new apartments to replace/use the old ones. • Housing prices may rise in the region, along with a decrease in the amount of rental housing. • Depends on what timeframe is examined.	**Positive aspects:** • Cooperation between different sectors and regions. • Locally operating soil coordination is a new type of activity – if the activity is widely taken into use, it will have a broader positive impact on the sharing economy. **Negative or positive aspects:** • Can promote the soil selling business.

Figure 55. Economic sustainability categories. The main points of different groups and the grounds for scoring.

Justice and equality	Sense of community and participation	Increased knowledge	Mental and physical health
Positive aspects: • Open and free entrance to the space for everyone, close to people. People from disadvantaged socio-economic backgrounds live nearby. • By recycling soil, it is possible to build green areas at a lower cost – more green areas can be implemented making the areas more accessible to different groups. **Negative or positive aspects:** • Before the park was built, there were major social challenges, and the residents were poorly informed and not heard. • Social value added depends on whether a park would have been created anyway somewhere. **Negative aspects:** • To better maintain justice, public administration must bear the responsibility for any harmful substances in the future. Open information on the history, rehabilitation and safety of the area must be provided.	**Positive aspects:** • The common park area may add a sense of community. • The more the users and locals been involved in the planning, the better. • The larger the variety of user groups are served, the better – e.g. those with an immigrant background. • More green space. • Meeting places for people/locals. • Regional uplift and image benefits (the example received a lot of visibility and awards). **Negative aspects:** • The municipality, on the other hand, has only compensated for the mistakes made in the past.	**Positive aspects:** • Competence and knowledge have increased. This is important for future projects. • More information, good practice in risk communication and communication skills have increased. • Experiences have changed policies.	**Positive aspects:** • Great park. Reduces the risk of traffic accidents. • Might reduce soil transport. • Green areas have positive health effects (assuming the soil is now clean). **Negative or positive aspects:** - Changes in transport depends on alternatives (where and to what extent). **Negative aspects:** - Many residents are negative towards the utilisation of contaminated soils, which may cause significant mental health impacts. The effect can be positive or negative depending on the point of view.

Figure 56. Social sustainability categories. The main points of different groups and the grounds for scoring.

5.5.2 Case: Cross laminated timber structured apartment building

The second real life example was from one of the Circwaste forerunner municipalities, Rovaniemi. The Domus Arctica institution decided to build an eight-storey cross laminated timber frame structure student apartment building in Rovaniemi. The ambitious goal was to build a communal apartment building with a small ecological footprint. The construction work was completed in summer 2019 and it is the first such large wooden apartment building in Rovaniemi and Lapland. In Finland there are only fewer than a hundred wooden apartment buildings in existence at the moment. Because detailed information about construction examples was not available for the workshop, the conversation was held on a more abstract level, comparing wood and concrete construction.

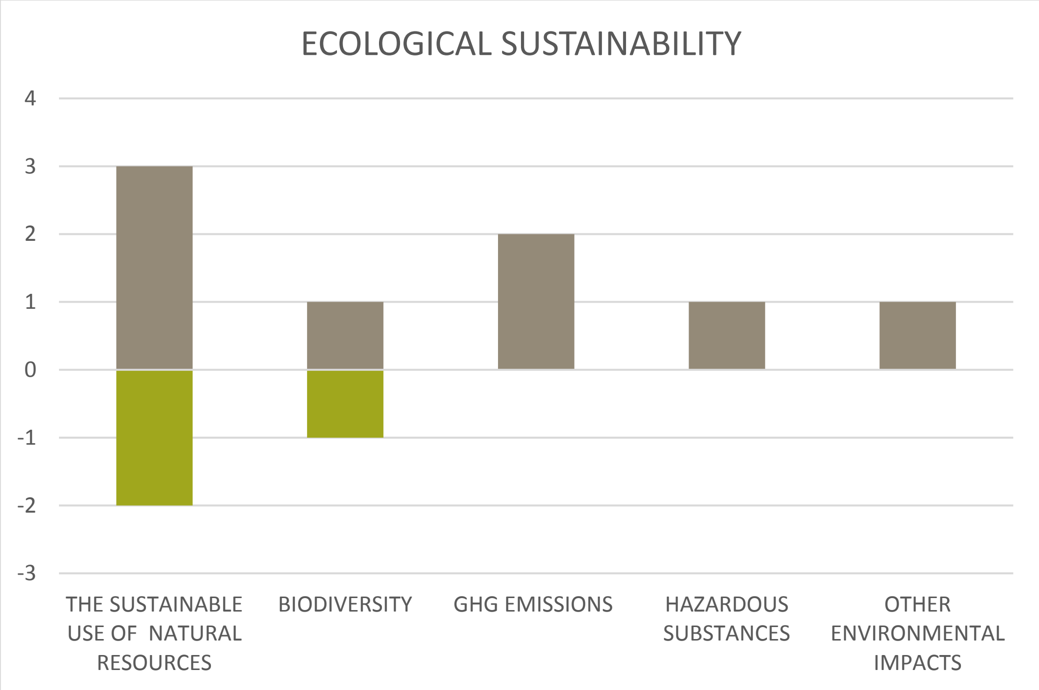
The sustainability of a wooden building was evaluated by four groups of SYKE researchers. The results in different sustainability categories varied somewhat from group to group, from a positive effect to a slightly negative one depending on the perspective of the groups on the topic (Figure 57).

The score varies notably in some sustainability categories with 'the sustainable use of natural resources' and 'biodiversity' even ranging from a negative (-2) to very positive (+3) impact (Figure 58). Using wood as a material offers great sustainability potential for the construction field but also creates risks if materials are generated without paying attention to nature values and biodiversity. Wood also works as carbon storage, but at the same time logging reduces carbon sinks. But on the other hand, limestone mining for concrete manufacturing decreases the specific biodiversity in the ecosystem created by the limestone deposit.

The economic sustainability of wood construction depends on the origin of the material used, which affects where the building site's labour comes from (Figure 59). Wood construction potentially creates more employment than concrete construction. As a negative aspect, wood construction was assumed to be 10–15% more expensive, but modular construction might cheapen the construction price of wood construction.

Social sustainability provoked a lot of conversation among researchers and the negative and positive viewpoints resulted in fluctuation between a negative (-1) and positive (+2) impact (Figure 60). The researchers pointed out that there are only a few benefits to deforestation or mining, but many suffer from the disadvantages stemming from construction material cutting or mining. Wood was considered an aesthetic material, which can also offer health-promoting effects.

Figure 57. Sustainability aspects of a wooden construction. Each category was weighted on a scale from -3 to +3 (--- / -- / - / 0 / + / ++ / +++); -3 being remarkably negative/harmful, -2 slightly negative, -1 mild negative impact and +3 being very positive, +2 slightly positive, +1 mild positive impact, whereas 0 is no impact or the effect is neither positive nor negative. Bar graphs show the highest and lowest estimates in the different sustainability category as given by different expert groups.



The sustainable use of natural resources	Biodiversity	GHG emissions	Hazardous substances	Other environmental impacts
Positive aspects: • Wood is a renewable natural resource. **Negative or positive aspects:** • Quality of construction and useful mileage. • Source of energy used (producing concrete consumes a lot of energy). • The role of subscriber. • How is the wood material processed and how easy is it to recycle afterwards? **Negative aspects:** • Multiplier impact of the increment of wood use. • Recyclability of wood in the demolition stage.	**Positive aspects:** • Concrete is made mainly from limestone: the limestone deposit creates specific biodiversity which might be lost during mining. **Negative or positive aspects:** • What kind of wood is used? (hardwood or wood with a certification). • Are we using land that has already been used for construction instead of clearing new green spaces? **Negative aspects:** • The pressure to use old forests in their natural state might grow as wood construction increases. • Clearing new green spaces reduces biodiversity	**Positive aspects:** • Wooden buildings have lower life cycle emissions compared to concrete element buildings. • Wood construction serves as carbon storage. • Wooden buildings have better value compared to pulp, for example. • Producing concrete causes lot of GHG emissions. • Wood is lighter to transport than concrete. **Negative or positive aspects:** • Wood might have a longer useful life span. • Concrete production is becoming more environmentally friendly, alternative materials with nanocarbon blends are being developed, which might moderate the manufacturing emissions compared to wood. **Negative aspects:** • Decreases carbon sinks.	**Positive aspects:** • Glued laminated timber has the M1 certificate. **Negative or positive aspects:** • Glued laminated timber might be problematic to recycle and cause contaminant problems. • Quality of indoor air could be better. **Negative aspects:** • Wood is a difficult material to recycle. • There is variation in wood's porosity and stamina.	**Negative or positive aspects:** • The cascading principle is easier to follow with solid wood than with glued laminated timber. • Even though wood is not easy to recycle afterwards, concrete is not accepted either as an admixture for new concrete, as there are no guarantees of homogeneity. The concrete often ends up in landfill or as a substitute for crushed stone, which is not efficient in terms of the circular economy.

Figure 58. Ecological sustainability categories. The main points of different groups and the grounds for scoring.

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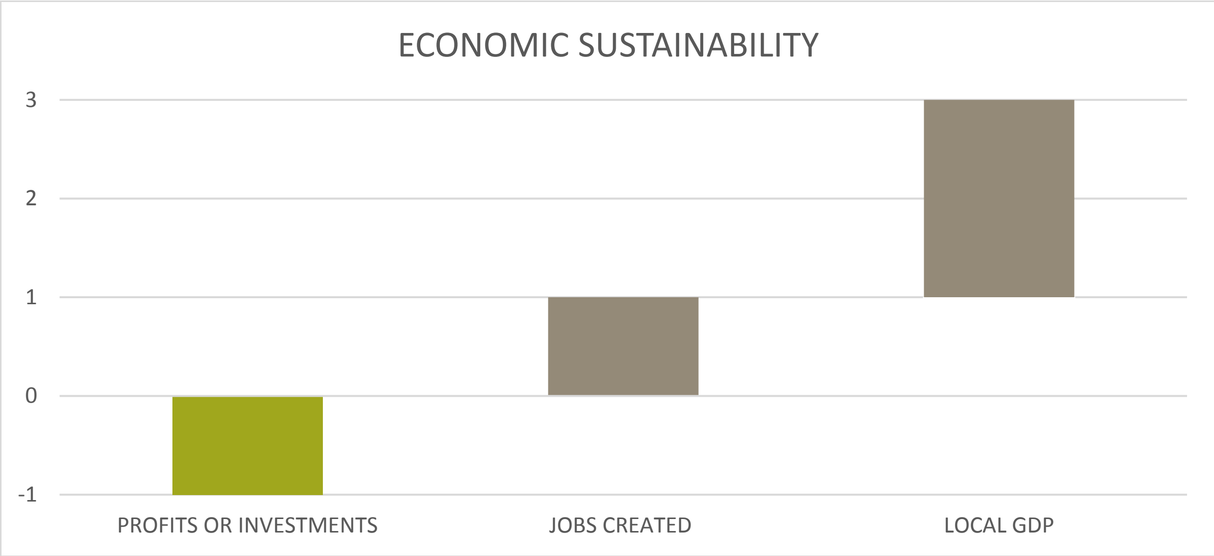
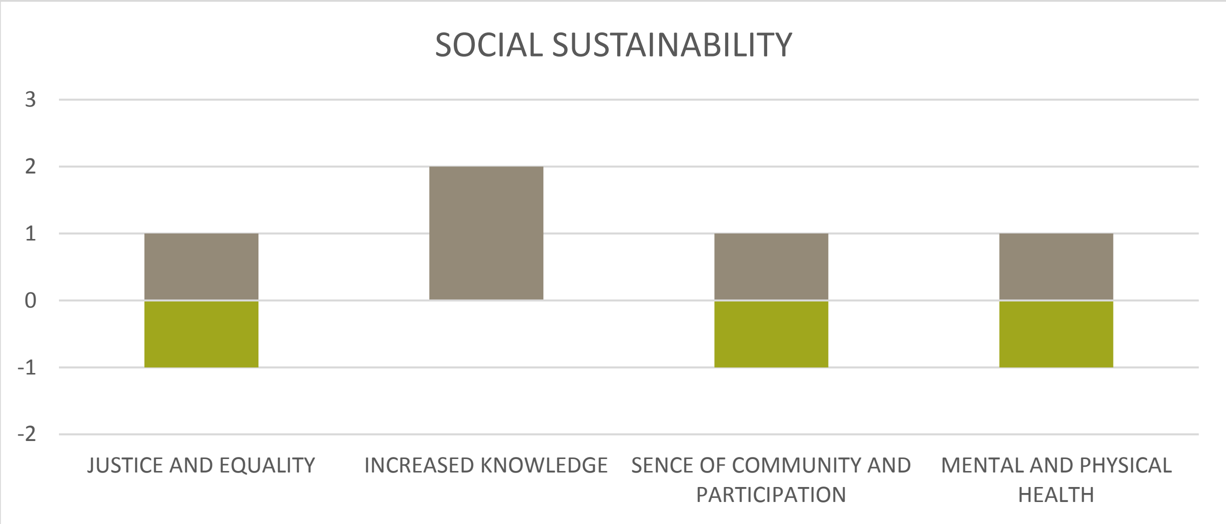


Profits or investments	Created jobs	Local GDP
Negative aspects: • Wood construction is 10–15% more expensive than concrete construction (The Ministry of the Environment: financial report), but research results indicating the opposite have also been obtained. • Old investments are tied to the previous technology, willingness to use new technology may be limited if new methods require initial investments. **Negative or positive aspects:** • Modular construction might reduce the construction price of wood construction. • People might have greater willingness to pay more for wooden buildings, if the operating profit were the same as for concrete construction. • Nature and forests also have value, but how can we measure that? • Deviations from conventional models could make progress with financial investment support.	**Positive aspects:** • Wood construction potentially creates more employment than concrete construction. • Creates a need for a new kind of design. • Creates local wood industry jobs.	**Positive aspects:** • Wood can be a domestic material, possibly even 'a local product'. **Negative or positive aspects:** • The origin of the wood material affects where the income goes. • Are local workers used as the labour force? Although all kinds of activity increase the positive effects on the regional economy.

Figure 59. Economic sustainability categories. The main points of different groups and the grounds for scoring.



Justice and equality	Increased knowledge	Sense of community and participation	Mental and physical health
Positive aspects: • Nature recovers better from deforestation than from mining, especially if the forest has been harvested without breaking ground. **Negative aspects:** • There are only a few benefits from deforestation but many suffer from the disadvantages.	**Positive aspects:** • Branding and raising awareness of wood construction. • Spreading of good practices is needed.	**Positive aspects:** • Natural forests offer positive experiences and logging decreases. • Wood construction is a part of Finnish culture.	**Positive aspects:** • Wood materials have proven health promoting effects (relieve stress and lower the heart rate). • Wood materials offer aesthetic value. **Negative or positive aspects:** • Decreasing natural value can also decrease the perceived health experience. • Wood construction can be healthier than concrete buildings if done correctly (indoor air). **Negative aspects:** • Sensitivity to odours could be a problem with wood construction.

Figure 60. Social sustainability categories. The main points of different groups and the grounds for scoring.

Lessons learned

The assessment and reliability of good practice sustainability assessment results was found to be sensitive to the precise description of the cases. The reference situation to which the case is compared must also be well defined – everything is relative. In addition to this, it was noted that the extensive knowledge and different backgrounds of the participants facilitated the evaluation: it was possible to look at the cases from many different perspectives. This might also explain the variation in the scoring between the groups. And serves as proof that sustainability aspects are complicated.

The feedback from the workshop was positive and the participants felt the approach worked and should continue to be used. Some suggestions for improvement were also given. In some participants' opinion the indicators should have been chosen together in the group based on the case. Furthermore, a wider group of stakeholders should be included in the evaluation and discussion. Group leaders have an important role to play in ensuring adherence to the schedule, as the discussion tends to be plentiful. The method allows for a broad assessment of the impact of circular economic measures from environmental, social and economic points of view and highlights the positive and negative effects of the measures. Weighting impacts also makes it possible to assess the significance of different impacts. However, it does not allow for a comparison of the effectiveness of different circular economy measures. Nevertheless, assessing the example cases from construction and zoning in terms of sustainable development is challenging, and our observation was that more discussion is needed to establish the pros and cons of different circular economy practices.

5.6 Study of critical factors for enhancing the circular economy in waste management

In a circular economy, the objective is to maximise value at each point in a product's life, and waste management is part of the performance economy where the manufacturer retains ownership of the product and its embodied resources and thus retains responsibility for the costs of risks and waste (Stahel 2016). The current economy is not circular (de Witt et al. 2018). Many barriers exist and in previous studies several different barriers to the circular economy have been identified. However, most of the studies were not based on empirical data. The Circwaste project provided a valuable platform where a significant number of practitioners from various sectors could operate. The aim of this study was to increase understanding of the critical factors faced by practitioners in the transition towards a circular economy. The research questions were as follows (Salmenperä et al. 2021):

- What kinds of critical factors are identified by developers and intermediaries that promote the circular economy through waste prevention and recycling pilots?
- How can waste management contribute to the transition towards a circular economy?

The data was gathered from 25 waste-focused pilots implemented through the Circwaste project. The focuses of these pilots were construction, biodegradable waste, industrial waste, strategic development and networking, and municipal waste. Semi-structured interviews were performed and thematic analysis using a coding framework (economic, technological, regulatory and socio-cultural barriers) for critical factors was used. Interviewees were also divided into intermediaries and developers. The transition to a circular economy is facilitated by developers such as businesses and R&D organisations that create solutions, as well as intermediary organisations such as business innovators and public organisations that build networks, increase knowhow and promote common strategies. (Salmenperä et al. 2021)

The results provide useful knowledge for the whole community and key stakeholders. The main results show that implementing circularity by developing waste management is felt to be hindered mostly by socio-cultural (e.g. attitudes, norms and practices), economic (e.g. investments, raw material prices, waste management fees) and institutional factors (e.g. regulations, taxation, administration). Developers and intermediaries do not share the same vision on the barriers. Developers of circular products and activities are concentrating mainly on solving their everyday practical problems instead of looking widely at the whole of society and complex challenges in material use. Generally, information-related enablers were found to be important in finding solutions, as more accurate and open data on waste was found to be needed to boost innovative business. Actors also found that there is a lack of operators enhancing the processing of waste-based materials.

The results show that there is also a need for more stringent co-operation and dialog between actors along the material value chains. Many of the enablers identified were connected to increasing and developing communication. (Salmenperä et al. 2021)

6 Study of innovative processing technologies for closing material loops

To be able to prepare for more circular material cycles, information on new technologies is needed for next generation processes. The transformation of current facilities is a slow process, so decisions on investing new facilities and technology must be prepared in advance.

Official waste management operations and legislation were originally introduced to protect the environment and health. In Finland, the initiating forces for waste management development were the urbanisation and population growth in 1920s (Suomen kiertovoima ry KIVO 2019). The first law on waste management was introduced in 1978 and the Waste Act came into force in 1994 (Suomen kiertovoima ry KIVO 2019). Statistics Finland has compiled data on waste statistics since the mid-1990s, and the first NWP until 2005 in Finland was approved in 1998. The target setting for decreasing waste related problems has included the amount of waste and the municipal waste recycling rate.

Even though the basis of waste management lies in environmental and health reasons, important drivers in developing waste management processes and systems have been the perspectives of business liability, regional political acceptance and waste fees.

The basic waste management processes have remained relatively similar for decades. Processes have been intensified and adjusted, but for the most part, they include mechanical, biological and thermal treatment. Economic viability including markets and R&D financing, the lifespan of existing facilities, EU legislation and policies create the operating environment for waste management, setting limits for possibilities for active technology and systems development.

Technologies applied in other industrial sectors might offer potential for waste material management, too and provide possibilities and options for executing the next generation of waste management processes. To be able to prepare for a more circular economy, information on new possibilities is needed for next generation processes and decisions on investing in new facilities and technology. Therefore, existing data on novel process technologies and their costs was collected. The work focused on novel chemical and thermal processes that are based on converting and fractioning the elemental content from different mixtures of materials and that could at the same time safely destroy the use history and the possible hazardous nature of materials. New technologies were found in particular for recovering plastics, nutrients, textiles and MSW.

6.1 **Plastic recycling processes**

6.1.1 Depolymerisation of PET with microwave technology

Depolymerisation with microwave technology (Demeto) is an innovative PET recycling technology developed by Swiss-based company gr3n recycling. The technology is based on a direct alkaline hydrolysis reaction of ground post-consumer PET in a microwave reactor. The products are the monomers of PET: terephthalic acid (TPA) and ethylene glycol (EG), which can be repolymerised back into high purity PET. (GreenBlue 2017)

The DEMETO process starts with grinding the PET waste followed by a hydrolysis reaction in alkaline conditions under microwave radiation (Figure 61, Parravicini et al. 2013). This process occurring in microwave reactor is the key element, where PET, EG, water and sodium hydroxide (NaOH) or potassium hydroxide (KOH) react together to form alkaline TPA salt and glycols. The microwave radiation serves as a catalyst and accelerates the speed of the reaction to around 10 minutes, compared to other similar solvolysis reactions, which can take from one to four hours on average to complete. The reaction occurs in mild conditions of 180–200 ˚C and 0.6 MPa (Crippa 2017a). Unreacted materials are filtered out before EG is distilled as a product. More waste is removed and some EG is cycled back into the system. The leftover TPA stream is precipitated via neutralisation by the addition of hydrochloric acid (HCl) into the stream. Afterwards, the precipitate is filtered, washed and dried to gain pure TPA. Precipitation process byproducts – sodium chloride (NaCl) or potassium chloride (KCl) – are converted back into NaCl or KCl via chlor-alkali electrolysis. The Cl_2 and H_2 gases formed are reacted together to generate more HCl, which is fed into the precipitation process.

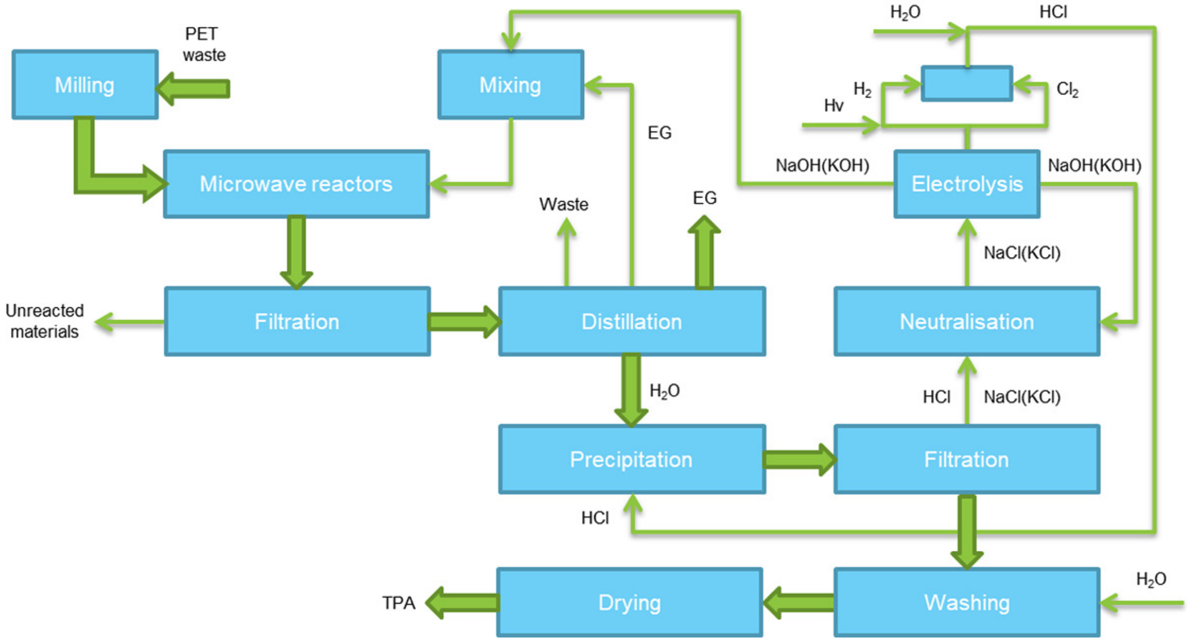


Figure 61. Simplified process scheme of the depolymerisation process of plastic with microwaves. Reproduced from (Parravicini et al. 2013).

As a chemical recycling method, microwave technology has various strengths compared to the commonly used mechanical recycling methods for PET. Chemical recycling can produce pure/nearly pure PET without additives such as plasticisers and pigments. Mechanical recycling degrades the polymer by reducing intrinsic viscosity (Oromiehie & Mamizadeh 2004), which is not a problem with a chemical recycling process. The company behind the process claims they also can recycle multilayered plastics, which have become a problem for recycled plastics treatment (Kaiser et al. 2017). Potential disadvantages of the process are the byproduct and waste water production and their disposal or utilisation. Additionally, using HCl might be problematic with possible Cl-leaks from the system and corrosion within the process.

gr3n recycling is planning to operate reactors with a minimum productivity of 15 kt of PET waste per year. The simplified overall mass balance is shown in Figure 62. This process would consume 2 kWh/kg of energy and have a production cost of EUR 400–700 per tonne of PET produced. The company claims it can sell the recycled PET for up to 57% cheaper than mechanically recycled mixed PET (assuming a recycled feedstock price of EUR 0/t and 2017 PET prices). According to the LCA, the process has a ~67% lower non-renewable energy requirement (NREU) and ~38% lower global warming potential (GWP) than PET production processes from traditional oil-based production (Crippa 2017b). Compared to mechanically recycled PET processes, the process offers a ~17% reduction in NREU and ~42% reduction in GWP (Crippa 2017a). It should be noted that the LCA was carried out using preliminary data with assumptions based on the purification process.

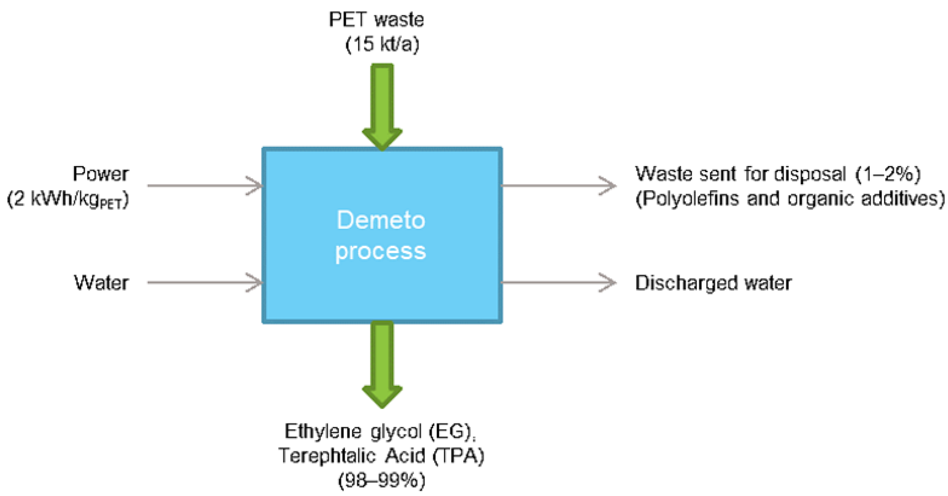


Figure 62. Simplified overall mass balance of the Demeto process.

The DEMETO process is currently being tested in a full scale pilot plant and with a demonstration plant on an industrial scale (European Union 2019b). The process seems promising and technologically feasible with most of the process consisting of already commercialised technology, with the exception of the microwave reactor. Compared to mechanical recycling and fossil-based production of PET, the process seems to be the superior choice, even with errors in approximations and calculations bringing their positive values down. Being a part of a large, EU-funded consortium gives the process even more credibility (European Union 2019b) At the moment the largest problems with the process are likely related to feedstock availability, as well as the purification and extraction processes for the monomers. The economic calculations given assume free PET feedstock, which might not be possible with the trend of circular economy and the development of competing recycling methods.

6.1.2 Chemical depolymerisation of PET plastic with solvents

The idea of chemical recycling of polyethylene terephthalate (PET) is an old one and has already been commercialised by major companies such as DuPont (Ragaert et al. 2017). Nevertheless, the need for better recycling technologies has risen with the increase in plastic waste and PET production. Old technologies have also been limited by the heterogeneous nature of the feedstock and by the impurities present in it. Loop Industries is a company founded in 2010 to find a solution to the problem of PET waste. Loop Industries has developed a new technology for recycling PET plastic waste that is based on chemical depolymerisation of PET via hydrolysis, producing the building blocks of PET: terephthalic acid (TPA) and ethylene glycol (EG). This generation one technology differs slightly from generation two technology already in development. The difference in generation two is the depolymerisation via methanolysis producing dimethyl terephthalate (DMT) and mono ethylene glycol (MEG). The monomers are then, in both generations' processes, further processed back into pure PET plastic resin or products. (GreenBlue 2017b; Loop Industries 2019)

Figure 63 shows the simplified process scheme for Loop Industries' generation one facility. First, the feedstock consisting of PET waste is inserted into the system. The plastic can be of any colour, shape or polyester plastic type. PET in the feedstock is then selectively dissolved using various solvents, leaving all other plastics intact. Other plastics are float-sink separated and harvested for possible additional value. The PET solution is then depolymerised using Loop Industries' patented technology. The technology consists of an extruder followed by supercritical fluid treatment, which executes the depolymerisation (Allan et al. 2010). Liquids and solids are separated, followed by the separation of MEG and TPA. These product streams are further purified, precipitated and separated multiple times to gain pure

TPA and MEG monomers that can be further repolymerised into Food and Drug Administration (FDA) approved virgin-like PET products. (GreenBlue 2017b; Loop Industries 2018)

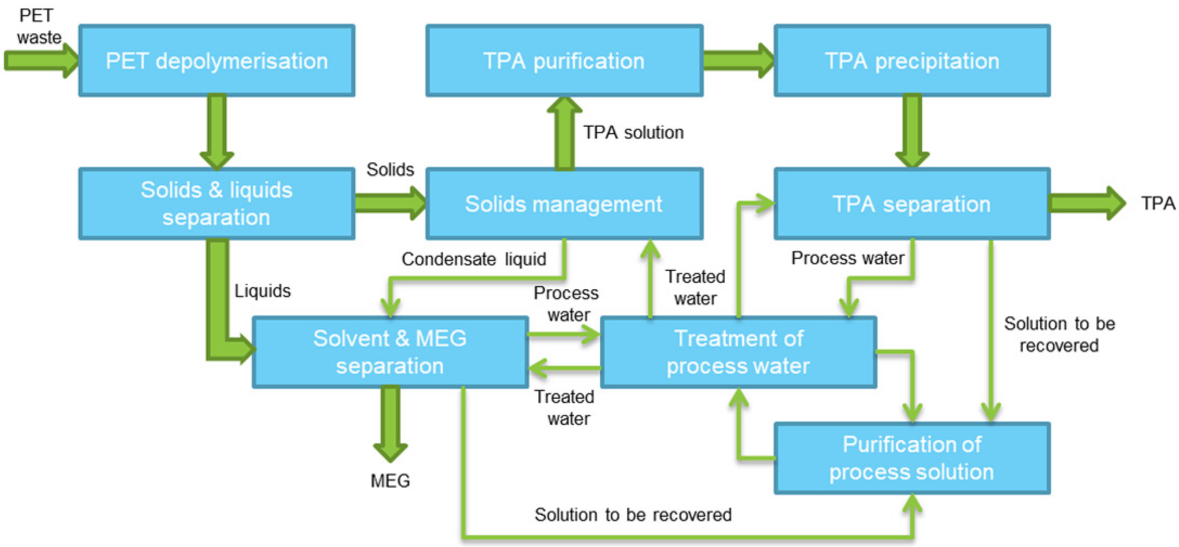


Figure 63. Simplified process scheme of the Loop Industries PET recycling process based on solving of PET with solvents. Reproduced from (GreenBlue 2017b).

Loop Industries' take on the PET recycling process has many advantages over the traditional equivalents, especially when compared to fossil-based PET production. The company claims that it can process contaminated, opaque, thermoform, polyester fibre and other challenging PET feedstocks. Other claims include the removal of all colours; dye agents; and contaminants such as PVC, EVOH and antimony, as well as fulfilling the requirement of no water or external electricity in the system. According to the company, their process can have a PET yield of 89%, compared to conventional recyclers' yield of ~65%. An LCA of the generation one process shows a 63% reduction in global warming potential compared to virgin PET and a 26% reduction when compared to mechanically recycled PET. Significant reductions in ecosystem toxicity, ozone depletion, acidification and respiratory effects, for example, were also reported (GreenBlue 2017b)(Loop Industries 2018)

Despite the extensive list of favourable qualities, more detailed technical and economic details of the process are not made public, which makes the overall assessment of the process challenging. The promise of a high yield and pure PET without the need for external heat is unheard of, and if successful, it could potentially revolutionise the PET recycling industry. With these promises, Loop Industries has gained the interest of large companies such as PepsiCo, L'Oréal and Nestlé. Nevertheless, the company has not provided clear evidence publicly of its processes' operability. Information is vague, especially on the generation two process, which has been addressed publicly by a comprehensive third party analysis (Chow 2018) with information from a former Loop Industries employee. If Loop Industries can follow through on their promises about their technology, despite the uncertainties, they may have developed a very promising technology.

6.1.3 Polyester (PET) and cotton textile blend separation and dissolving for separate fractions

Worn Again Technologies (Worn Again) is a UK-based company founded in 2005. The company started by processing waste and scrap materials into clothing and accessories (Worn Again 2019). In 2012, Worn Again started developing a circular method for textile recycling, which resulted in their innovative process that separates end-of-life textiles' PET (polyester) and cellulosic (cotton) fractions into reusable PET pellets and cellulosic pulp (GreenBlue 2017c). The feedstock the Worn Again process uses can be made of pure polyester, pure cotton and/or any combination of the two with a maximum of 20% impurities (Rhoades 2018).

The process starts with dye removal and purification, followed by the PET dissolution shown in Figure 64. The PET is pushed through an extruder, filtered and pelletised, while the solvent used in the earlier part is cleaned and recycled back into the process. The leftover mass, with the cellulosic fraction, has its molecular weight reduced followed by dissolution and filtering of the cellulose pulp. The used solvent is again cleaned, recovered and recycled back into the process, while the cellulose pulp is ultimately de-colourised to gain clean cellulosic pulp as the second end product. (GreenBlue 2017c)

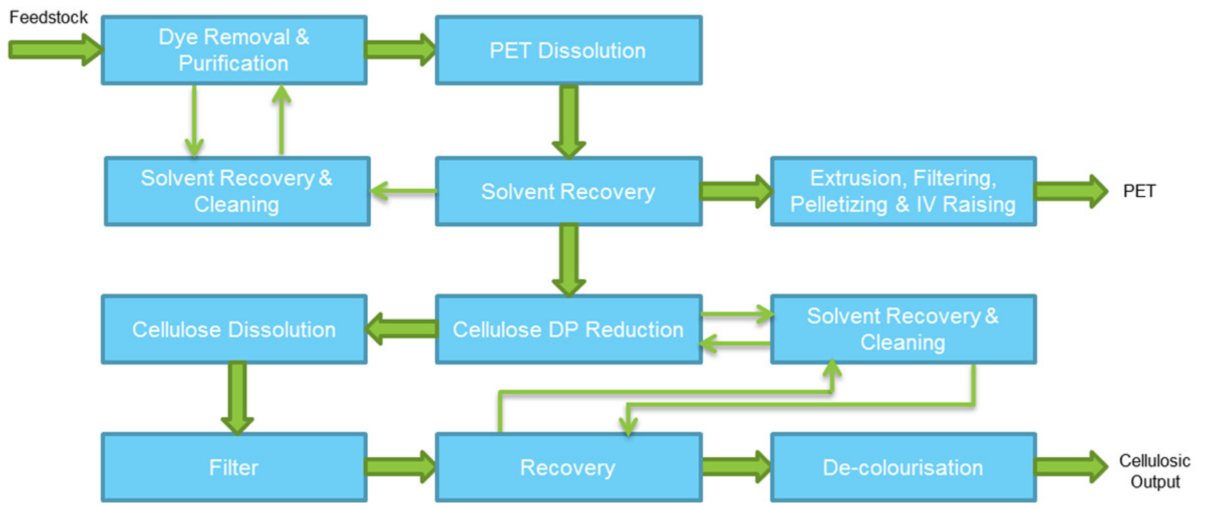


Figure 64. Simplified process scheme of the Worn Again Technologies textile recycling process, where polyester (PET) and cotton textile fractions are separated and dissolved. Reproduced from GreenBlue 2017c.

Worn Again estimates that the first industrial demonstration plant will be launched in 2021, with full scale commercialisation following soon after (Rhoades 2018). Once research on the process is complete and it is successfully scaled up, Worn Again plans to offer licenses to its technology to commercial recyclers (GreenBlue 2017c). Besides the main recycling process, Worn Again is also conducting research on processing its byproducts, such as dyes and non-target fibres. These byproducts could be used as dyes or as an alternative energy source (GreenBlue 2017c).

6.1.4 Chemical depolymerisation of PET with ethylene glycol glycolysis

Garbo is an Italian company founded in 1997. Garbo started the development of a recycling method for the chemical polyethylene terephthalate (PET), ChemPET, in 2006 (Garbo 2019). ChemPET has been developed in collaboration with the University of Modena and Bologna. (Garbo 2019) The company originally started out developing a process for recovery of silicon carbide and polyethylene glycol (Garbo 2019).

ChemPET is a depolymerisation process that breaks down PET polymers via glycolysis. The end product is the monomer bis-2-hydroxyethyl terephthalate (BHET). The ChemPET process also involves a product purification process that allows the BHET produced to be used in the chemical industry or as an ingredient in new PET plastics. The total process time is approximately six hours. The process depolymerises PET waste selectively with ethylene glycol, allowing heterogeneous and impure PET waste streams to be used as a feedstock. (Garbo 2019b)

Garbo has tested its processes' feasibility at a 10 kg/day laboratory scale unit as well as with a 3 tonne/day pre-industrial product line (Closed Loop Partners 2019). Garbo (2017) is currently scaling up its technology and planning to build a large-scale PET processing plant in Italy (Plastoc News Europe 2019), which could have a capacity up to 100 tonnes/day. In the future, Garbo (2017) is planning to expand its process around Europe and is aims to include a waste-to-energy gasification in its process to improve its sustainability further.

6.1.5 PET plastic depolymerisation with ionic liquid and metal catalysed glycolysis

Ioniqa Technologies is a Netherlands-based company founded in 2009. It is a cleantech spin-off company from Eindhoven University of Technology, specialising in magnetic separation processes and magnetic smart materials. Ioniqa recently developed a PET recycling method using magnetic metal catalysts and ionic liquids in a glycolysis reaction, depolymerising the PET feedstock back into its monomers. The technology developed accepts all kinds of PET feedstocks, as well as coloured PET. (Ioniqa Technologies, 2019)

Ioniqa has been testing its technology in a 1,000 litre batch reactor and is currently constructing a 10,000 tonne/year pilot plant in Geleen, the Netherlands. The company claims that a 50,000 tonne/year plant could also be feasible with a conversion rate of above 90% while still being profitable. The platform technology could be used to recycle other plastics in the future (Ioniqa Technologies 2019). An LCA (Lindgreen and Bergsma 2018) was conducted and determined the technology, as a PET producer, to have 75% lower CO_2 emissions than conventionally produced PET. Mechanically recycled PET had slightly lower CO_2 emissions but the end-product is of a lower quality. (Ioniqa Technologies 2019b)

6.1.6 Depolymerisation of PET and biorenewable oils and sugars with glycolysis into polyols

Resinate Materials Group (Resinate) is a US-based company founded in 2007 (Resinate Materials Group 2019). It specialises in producing polyols from plastic waste streams using its proprietary Recycolysis process. Recycolysis converts PET, PETG and PBAC plastics into polyols, which can be further processed into polyurethane-based adhesives, sealants, elastomers, coatings, foams and lubricants (GreenBlue 2017d).

The Recycolysis process is based on glycolysis of the feedstock. It primarily uses recycled PET as a feedstock, but PETG, PBAC, recycled glycols and biorenewable materials can also be used. Biorenewable materials can be plant-based oils or fermented sugars. Resinate can use recycled plastics from PET bottle bales, PET or PTT carpets, vehicle industry PET scraps and medical PETG packaging waste, as long as the PET content is over 97%. (GreenBlue 2017d)

Resinate has a 200-tonne pilot-scale and 4,500 tonne production scale plant using Recycolysis technology. The company plans further expansion via stronger branding in North America by licensing its technology. Expansion on a global scale has also been planned. (Closed Loop Partners 2019)

6.1.7 Polystyrene plastic pyrolysis into styrene monomers

Agilyx is a US-based alternative energy company founded in 2004. Agilyx focuses on plastic recycling technologies, such as their polystyrene-to-styrene monomer (PSM) technology. PSM technology consists of feedstock sorting and preparation, pyrolysis reaction and product recovery process units. The system accepts all kinds of polystyrene waste as feedstock and it produces styrene monomer oil as well as other hydrocarbons. (Agilyx 2018)

Agilyx has its technology in the early commercialisation phase with three commercial scale facilities, including a facility in Tigard, Oregon, with a capacity of 10 tons/day of polystyrene. The company claims the technology is modular and easily scalable as well as having 50% lower greenhouse gas emissions than virgin polystyrene production. Currently, Agilyx is the one of the only companies with commercially proven technology that converts waste polystyrene back into styrene monomers. (Agilyx 2018; Closed Loop Partners 2019)

6.1.8 Catalytic microwave depolymerisation of polystyrene (PS) into monomers

Pyrowave is a Canadian company founded in 2013. Pyrowave has developed a modular and continuous process that depolymerises polystyrene (PS) back into monomers using microwaves as a catalyst in the reaction. The process accepts both post-consumer and post-industrial polystyrene waste (Pyrowave 2019). The end products are mainly monomers but also include waxes and oils. The end products can be used to synthesise new polystyrene polymers or in other applications in the petrochemical industry.

The process consists of a preconditioner/extruder, microwave generator and reactor followed by condensation and cooling units (Doucet 2018). The process works by mixing conditioned polystyrene waste with silicon carbide in the reactor. Meanwhile, microwaves heat up the particles and break down the bonds in the plastic polymers, producing monomers. Pyrowave has constructed a working unit able to process 100–200 kg of PS waste per hour. The process is able to reach conversion rates of over 90% from plastics to monomers, with a low energy consumption of a 1–1.5 kWh/kg of feedstock (Pyrowave 2019). The company is currently conducting more research on the process to further optimise it and searching for partners to eventually commercialise the technology. In the future, the process could be modified to process other types of plastics, too.

6.1.9 Enzymatic PET depolymerisation into monomers

Carbios is a France-based company founded in 2011 specialising in the use of enzymes in plastic recycling and production. Carbios has developed a new polyethylene terephthalate (PET) recycling process that depolymerises PET back into its monomers terephthalic acid (TPA) and ethylene glycol (EG). The biorecycling process consists of pretreatment of the PET waste, depolymerisation via enzymatic hydrolysis and separation and purification of the TPA and EG monomers which can be turned back into pure PET products. (Carbios 2019)

In 2017, Carbios completed a five-year R&D programme for its PET biorecycling process, achieving a yield of 90% up to 97% of monomers in 10 and 16 hours respectively. The process can recycle any kind of PET plastic including textiles, coloured, opaque and multi-layered plastics, eliminating the need for advanced sorting systems. Currently, Carbios is piloting its biorecycling process at a 1–5 m^3 scale with a demonstration plant. The company plans to negotiate its first industrial licenses by 2022–2023. (Denoizé 2019)

6.1.10 Recovery of all plastics with pyrolysis into oils

Pyrolysis is one of the chemical recycling processes in which the polymer structure of a plastic is broken down by heating in an oxygen-free state and condensing into oils, other liquids, and solids. The composition of the final products is determined by the process temperature, the delay time, and the purity and quality of the feed. Commonly used pyrolysis technologies include thermal cracking, catalytic cracking, and hydrocracking. (Teittinen et. al 2019)

The pyrolysis process generates several products that are utilised in the chemical and oil industries, such as pyrolysis oil mixtures and waxes, coal and gases. These materials are generally utilised in the process's own heat production. The most industrially significant product is a pyrolysis oil blend that can be used as a fuel in diesel engines or utilised in the petrochemical industry to produce fuels and chemicals, or used as a feedstock in the manufacture of plastic materials. (Teittinen et. al 2019)

PMMA, PA, PE and PP plastic grades can be used to produce monomers of these plastics with a good efficiency ratio, which can be polymerised back into virgin plastic materials. One significant advantage of the pyrolysis process, chemical recycling, is the preservation of the original material's properties, the material can be recycled almost indefinitely without compromising its properties, unlike in mechanical recycling, where the material's properties worsen in quality with every recycling cycle, which limits the number of mechanical recycling cycles to a maximum of four. (Teittinen et. al 2019)

The utilisation of plastic waste as a recycled material in the pyrolysis process is still in the development stage and commercial activity is in the start-up phase, so there are no general standards or quality criteria for the process or the resulting end products so far. In addition to this, the current EU EoW legislation does not yet recognise the chemical recycling process as an actual process generating new material. (Teittinen et. al 2019)

The overall supply of plastic waste in Finland has been considered too small for pyrolysis treatment, estimated at about 100,000 t/a. It has been estimated that on a Finnish scale, a network of about ten pyrolysis plants could operate profitably if the pyrolysis of waste plastic and waste were combined. The location of the pyrolysis plants would be ideal in the case of waste recycling plants, where it would be possible to utilise the materials discarded in mechanical recycling (estimated at about 86% of the total amount of recycled plastic) in chemical recycling. (Oasmaa 2019)

Pohjanmaan hyötyjätekuljetus Oy And Fenergy Oy are private, independent developers of material collection and chemical recycling. Pohjanmaan hyötyjätekuljetus is the biggest collector of waste materials in the region, separating and further processing materials for recovery. The company's waste treatment line separates plastics from mixed waste, which are primarily intended to be utilised in mechanical recycling. Plastic waste that cannot be recycled mechanically is transferred to Fenergy's chemical recycling processes. For years, Fenergy has been developing a pyrolysis process that can utilise all engineering and packaging plastics. Consumer plastic waste consists mainly of PP, PE, PET, PA and multilayer materials. Plastic waste is liquefied through chemical recycling processes into oils and distilled liquids suitable for use as fuels or intermediate materials for the chemical and petrochemical industries, such as virgin plastic processing lines. (Lammi 2020)

6.1.11 Depolymerisation of any plastic with the Hydrocarbon Recycling Process

Fenergy's latest technology focuses on the development of the depolymerisation process. Depolymerisation is suitable for use with any type of plastic or plastic compounds or multilayer materials, and the final product is purer than in the pyrolysis process. The process is called the hydrocarbon recycling process (HRP). (Lammi 2020)

In the HRP, the plastic materials are heated rapidly to the gasification temperature of the material, whereby the material liquifies and gases such as butane gas, propylene gas and hydrogen are released from the feed. Gases act as the main energy source for the process and hazardous gases, such as the halogens, are neutralised. The liquid circulates at different stages of the process, where the material is broken down into hydrocarbons. The process generates wastewater that can be converted into hydrogen by electrolysis. The gas reacts with the catalyst and hydrogen, whereby the polymer chains are cleaved, and the conversion of the hydrocarbon monomer occurs, including the removal of double bonds and aromatics, which eliminates the need for post-treatment of liquids. Byproducts of the process steps are waxy products that circulate in the process, releasing heat to the material to be gasified. The final product is pure hydrocarbon, clear liquid (76–78%), gases (12–20%), small amounts of sodium chloride, calcium chloride (in various forms depending on the feed), and carbon black. (Lammi 2020)

The resulting liquid is suitable for use as a feedstock for the production of new virgin plastics, with a purity level suitable for the food industry. The HRP process is much more efficient than the pyrolysis process, the efficiency of the fraction is as high as 76–78%, and the final liquids do not need to be purified as pyrolysis oils, for example, do. Fenergy has a 300 m^2 protolaboratory for the HRP. (Lammi 2020)

Fenergy's existing Pyrolysis and HRP lines are capable of processing approximately 10,000 tonnes of plastic waste per year. The companies have plans to expand their operations to the annual treatment of up to 200,000 tonnes of plastic waste. The common vision of the companies is that there would be four or five similar chemical recycling plants in Finland, which would handle 10–20 tonnes of plastic waste per day, this would be enough for a 100% recycling rate of plastics in Finland. (Lammi 2020, Oasmaa 2019)

6.2 **Phosphorous Recovery processes**

6.2.1 Thermochemical recovery of phosphates from organic waste into thermophosphates

The AshDec process was first developed by the Federal Institute for Materials Research (Berlin) and ASH DEC Umwelt AG (Vienna) starting in 2004 (Hermann and Schaaf 2019). The technology was developed for a number of years and eventually sold to Outotec in 2011 (Outotec 2011). AshDec is a thermochemical process that treats manure, sewage sludge ash (SSA) or other nutrient-rich organic waste in a rotary kiln to produce inorganic calcined phosphates (thermophosphates). At high temperatures (800–900 ˚C), the newly formed phosphates react with alkaline compounds mixed in during the process. Bioavailable alkaline phosphate compounds are formed and simultaneously heavy metals and other hazardous substances evaporate from the reactor and are filtered out. The end products are citrate soluble Ca-K/Na-PO_4-compounds that can be used as fertilisers. Phosphorous recovery from SSA in this form is unique (P-REX 2017a) and the high nutrient concentration of the end product could be beneficial.

The AshDec process starts with introducing feedstock, potassium or sodium compounds and reducing agents (e.g. dried sewage sludge) into the rotary kiln in at 900–950 ˚C for 15–20 minutes. This thermal treatment removes hazardous substances and increases phosphorous bioavailability. Off-gas is filtered out, evaporated substances are filtered and/or precipitated out in an electronic static precipitator and the end product is cooled and dried in the form of granules. Purified gas is used to preheat sodium or potassium compounds, which are funnelled into a rotary kiln. A simplified process scheme of the AshDec process is shown in Figure 65. (Hermann and Schaaf 2019; P-REX 2017a; Stemann et al. 2015)

AshDec could be operated as a greenfield facility, but the process is more ecological and economic when integrated with mono-incineration. The main advantages of an integrated plant would be the feeding of hot ash from the incinerator, thus ash would not need a heater unit and additional electricity. Additionally, the off-gas processes could be integrated in such plant. (Hermann and Schaaf 2019; P-REX 2017a)

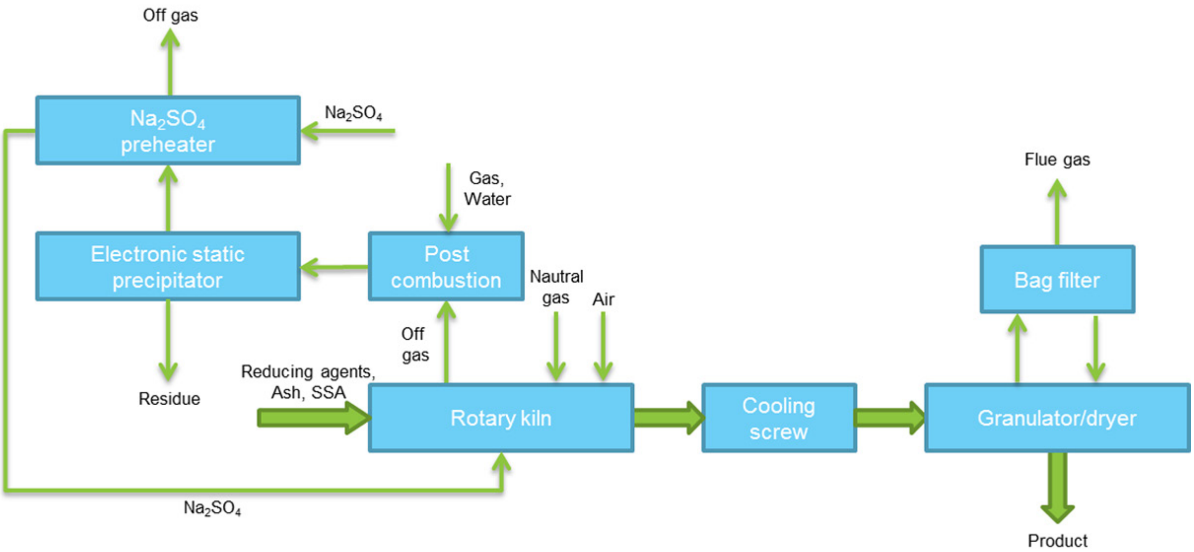


Figure 65. Simplified process scheme of the process of recovering the phosphates from organic waste into thermophosphates (AshDec process). Reproduced from Hermann and Schaaf 2019.

The AshDec process is already a well-established and known process. It has been studied extensively during its years in development and most of its subprocesses are standard processes used in the industry commercially. Multiple pilot plants with AshDec technology have already been built and tested: in 2008–2010 a plant using $MgCl_2$-additive (1,500 t ash) and a pilot study in 2014 using Na_2SO_4-additive (4 t ash).

A mass and energy balance of the system was calculated in the P-REX consortium's report on innovative and available phosphorous recovery methods (P-REX 2017a). The data used is a mixture of laboratory and demonstration trial data, making the results an estimation of a plant with a 1,725 kg/h ash input. The overall mass balance is shown in Figure 66. The results show a low amount of waste generation (2–3% of the ash) and a high P recovery rate of 98%. Additionally, the average total electricity demand was relatively low, compared to other P recovery processes (0.8–0.9 kWh/kg $P_{recovered}$ vs. 1.2–10.3 kWh/kg $P_{recovered}$) (P-REX 2017b).

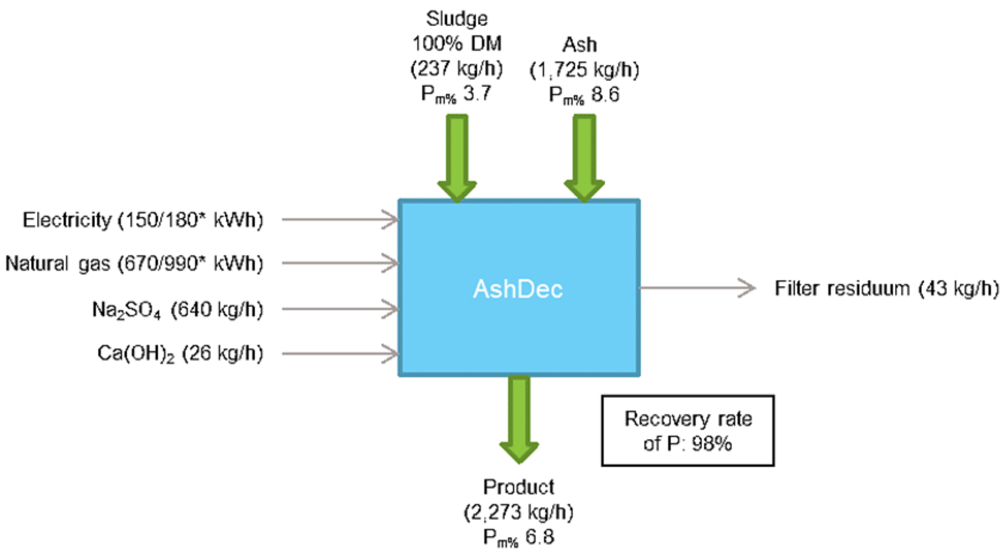


*Figure 66. Overall mass balance of the AshDec process. P-REX, 2017a. * Integrated plant and standalone plant simulation data respectively.*

In their report, the P-REX consortium had conducted an LCA as well as a lifecycle cost (LCC) analysis comparing different P recovery methods, including AshDec. According to the LCA, the AshDec process has a positive impact on the environment by most parameters compared to the reference model sludge treatment and disposal plant. The AshDec process had considerably higher eco- and human toxicity parameters, though, because of the high amount of Cu and Zn in the end product (P-REX 2017c). The LCC analysis results show that a 13,800 tonne/year plant size (2.5 million person equivalent) would have a cost of EUR 2.38/kg P produced, which is too high for profitability (P-REX 2017d).

The AshDec process is a novel technology offering high phosphorous recovery, which will be needed in the future when phosphorous rock is not readily available anymore. At this time, it seems that the process is still slightly too expensive compared to P production from phosphorous rock. Compared to other current phosphorous recovery processes, and those still in development, it has many positive qualities, such as the low energy requirement, low waste generation and high P recovery rate. A substantial problem with the AshDec process is the amount of Zn, Cu and Cr in the end product, making it suboptimal for use as a fertiliser. With more development cutting down the running costs of an AshDec plant, finding a solution to the metal remains in the end product and the inevitable rise in the cost of P will make AshDec a promising process.

6.2.2 Phosphorous and nitrogen recovery from wastewater with metal salt precipitation into phosphoric acid and ammonium phosphate

RAVITA is a new technology developed by the Helsinki Region Environmental Services Authority (HSY). RAVITA combines the recovery of phosphorus (P) and nitrogen (N) from wastewater as a part of the operations of a wastewater treatment plant (WWTP). The process is scalable and thus suitable for WWTPs of all sizes, compared to conventional P recovery methods from wastewater, which are more applicable to larger plants. The RAVITA process is based on precipitation of metal salt, with the end products being phosphoric acid (H_3PO_4) and ammonium phosphate ($(NH_4)_3PO_4$). (Rossi et al. 2018)

A simplified process scheme is shown in Figure 67. The main idea behind the process is that the recovery of P is carried out after the typical wastewater treatment process, when the effluent is post-precipitated using metals salts (e.g. Al and Fe). The chemical sludge formed is separated from effluent via sedimentation, flotation or filtration. The sludge can be further processed to reduce the water content. The next step is the dissolution of the chemical sludge with phosphoric acid. Acidic conditions promote the separation of dissolved P and metals salts. Separation can be carried out with ion exchange or solvent extraction processes. The chemical precipitant is then recycled back into the post-precipitation process and the phosphoric acid formed is partly recycled into the dissolution process. (Rossi et al. 2018)

The RAVITA process can also be combined with a nitrogen recovery system. This system would recover nitrogen from waste water treatment reject water. The reject water stream contains ammonium (NH_4), which can be recovered with a stripping process. Ammonium can be further processed into ammonium phosphate with an air washer unit using recycled phosphoric acid from the separation process. (Rossi 2018; Rossi et al. 2018)

The RAVITA process has many positive qualities compared to other phosphorus recovery processes from waste water. For example, the process does not require sludge incineration or digestion, it allows for nutrient harvesting and chemical circulation in the system, and it is suitable all kinds of WWTPs with its size neutrality (Vilpanen 2018). RAVITA has low energy requirements and chemical costs compared to other WWTP processes (HSY 2017). RAVITA has been tested at laboratory scale as well as pilot scale (1,000 PE) (Rossi et al. 2018). Studies on a demo plant have also been proposed and started (HSY 2017) and the results are promising: The recovery rate of P was reported to be high (>70% of inlet P). Laboratory scale recovery rates of 95% and 98% were reported for P and Al, respectively, from the chemical sludge formed. The heavy metal content of the RAVITA-sludge was found to be low in the preliminary results. (Rossi et al. 2018)

The development of the technology is still in the early stages and more research has yet to be conducted. Studies should be carried out at a larger plant and further optimisation is needed on issues such as floc formation. Additionally, the number of hazardous substances in RAVITA sludge raises questions as it has not been studied extensively. An LCA of the process has not yet been conducted and the economical evaluation performed is limited.

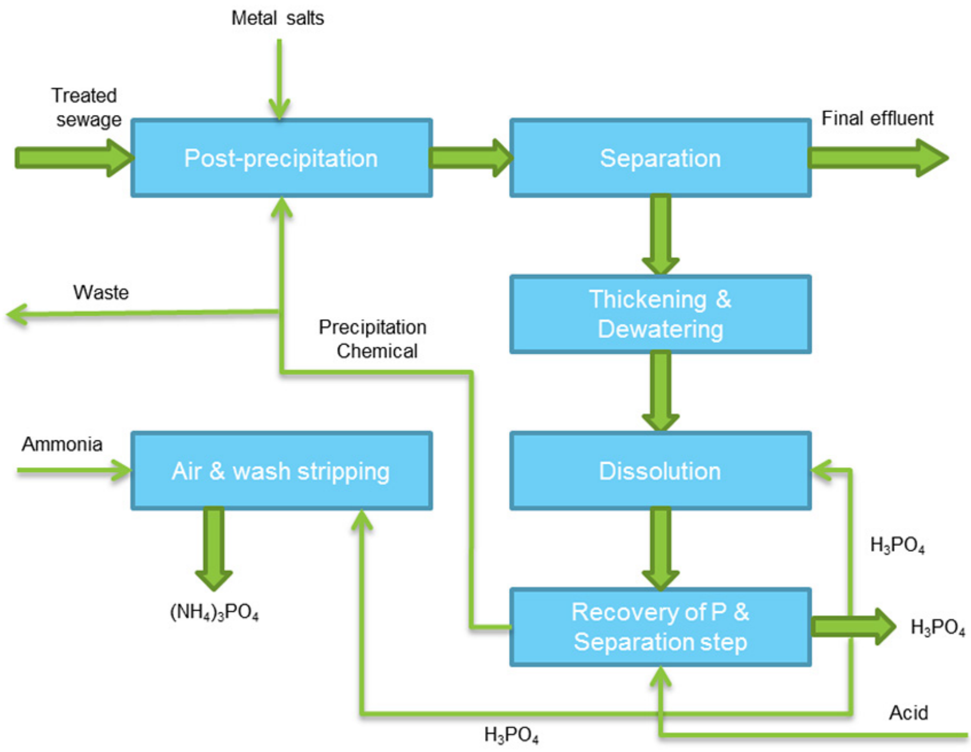


Figure 67. Simplified process scheme of the RAVITA process. Reproduced from (Rossi et al. 2018).

6.2.3 Biogas & fertiliser production from manures with microbiological fermentation of ammonia and acid treatment of phosphorus

Ductor is a Finnish company founded in 2009. Ductor has developed a technology that allows for biogas production from poultry manure containing high levels of nitrogen. Ductor's biogas process has solved the problem of nitrogen inhibition of methane production by removing the nitrogen via microbiological fermentation prior to the anaerobic digestion process of biogas production. Nitrogen is first turned into ammonia and then into ammonium sulfate – a compound used as a fertiliser. (Ductor 2019)

The process starts with feedstock preparation to improve digestibility. Feedstock preparation is followed by the ammonification process in anaerobic and mesophilic conditions. The liquid and solid phases are separated and the liquid phase is directed to a stripping unit to remove nitrogen as ammonia gas. Ammonia gas is then recovered by scrubbing. Solid digestate is delivered to a phosphorous recovery system and treated with acid to produce liquid fertiliser containing phosphate and solid calcium fertiliser as a side product. After stripping and scrubbing, liquid digestate is pumped into a biogasification reactor for anaerobic mesophilic biogas production. Biogas is collected and the digestates' solid and liquid phases are separated. The liquid phase, the reject water, is partly recycled back into the ammonification and biogasification reactors, where it is used to obtain the desired total solids content. The remaining solid phase is collected and it can be used as a fertiliser or soil improver. A process scheme of the process is shown in Figure 68. (Ketola et al. 2017; Virkajärvi 2016)

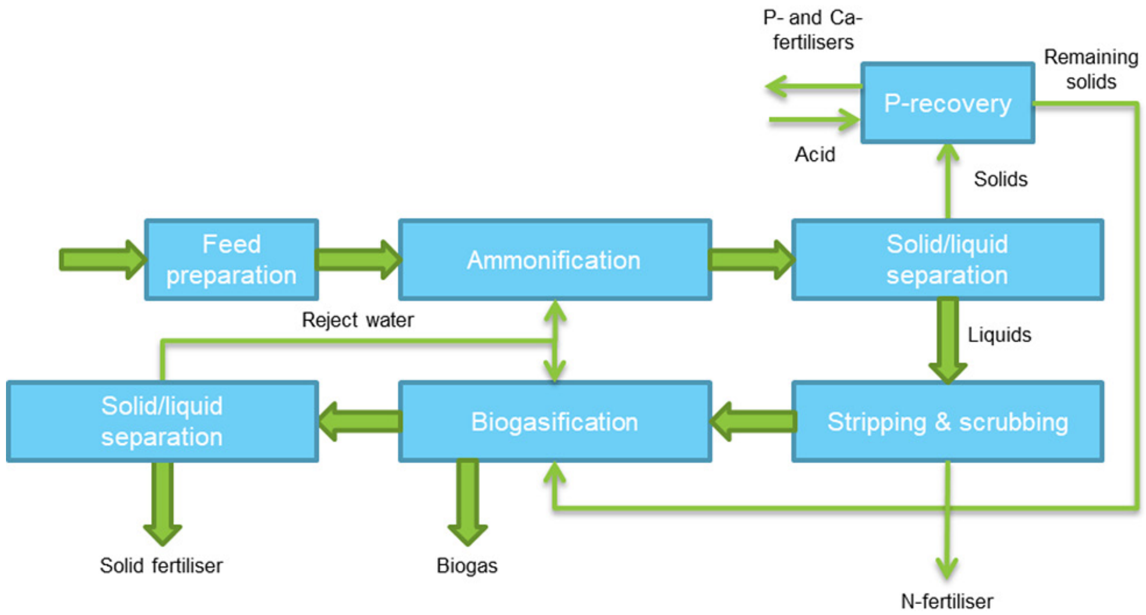


Figure 68. A simplified process scheme of the Ductor biogas production process. Reproduced from Ketola et al. 2017.

Ductor's work on biogas processes development started in 2009, a pilot plant study was run in 2014 and a full scale commercial plant has been built in Mexico, with more plants planned in the future (Ketola et al. 2017; Sinivirta 2019). The feasibility of the technology has been confirmed by a third party, Fraunhofer UMSICHT, using data from a pilot plant study in Helsinki (Leppikorpi 2017).

The amount of detail shared on Ductor's process is minimal. Some of these details include the yields for methane production of 65% (169 m^3/t), N-fertiliser (80 kg/t) and P-fertiliser (350 kg/t). The process is said to be energy self-sufficient and to have 0% CO_2 emissions. The process also recycles part of the water it uses, utilises some as dilution water, and partly denitrificates the waste water, raising its sustainability further. As an example, Ductor claims that a plant processing 30,000 tonnes of chicken manure per year would cost approximately EUR 4.9 million and have a payback time of five years. (Virkajärvi 2017)

6.2.4 Recovering phosphorus from sludge via incineration into ash fertiliser

The PAKU process is a technology developed by the Finnish company Endev in co-operation with Lappeenranta-Lahti University of Technology (LUT). PAKU processes mechanically dried sludge via incineration, producing energy and phosphorous rich ash, which is usable as a fertiliser. (Endev 2017)

The PAKU process consists of a dryer, water condenser, the main reactor, heat exchangers and finally a cyclone for ash recovery, followed by gas washing units. The mechanically dried sludge is first further dried and then burned at 850 ˚C to destroy harmful organic compounds such as drugs and microplastics. This produces heat electricity (1 MWh/tonne of sludge), which can be partly recycled back into the system, making the process energy self-sufficient. The leftover ash is ultimately cycloned to separate out inorganic metals, followed by cleaning of the gases produced. Approximately 95% of the ash is so called product ash with a high phosphorous content, which can be used as a fertiliser according to the Finnish food authority. (Laasonen 2017)

In July 2019, Endev completed construction on its first commercial unit based on the PAKU process in Rovaniemi, Finland (Setälä 2019). Endev claims that in the future, the PAKU process could be applied in locations such as a pulp mill or a bioethanol plant, to utilise their side waste streams. The process could also be further developed to recover nitrogen from the feedstock sludge (Laasonen 2017). Currently, only phosphorus is recovered.

6.3 Lithium-ion battery metal recovery with mechanical and thermal dimethyl-carbonate extraction

The LithoRec lithium-ion battery (LiB) recycling process is a result of two collaborative research projects. The first project's consortium in 2009 included multiple industry partners, such as Audi, as well as the universities Technische Universität Braunschweig and the University of Münster (Hanisch et al. 2015). The second project (2012) had the same scientific partners with various industry partners, such as Opel and Audi (Kwade&Diekmann 2018). The main goal of the projects was to develop a combination of mechanical and hydro-metallurgical LiB recycling processes that could recycle most of the materials in the batteries (Rothermel et al. 2016). The LithoRec process is designed mainly for recycled electronic vehicle (EV) batteries. Current commercial recycling uses pyro-hydrometallurgical recycling methods, which are energy inefficient and recover just the main transition metals (Rothermel et al. 2016).

The LithoRec process starts with pretreatment of the feedstock, as shown in Figure 69. Pretreatment consists of discharging and short circuiting the battery system to lower the possible electrical hazard and allow for safe disassembly of the battery. Batteries are stripped of system peripheries, such as cables, and crushed under an inert atmosphere. (Kwade&Diekmann 2018)

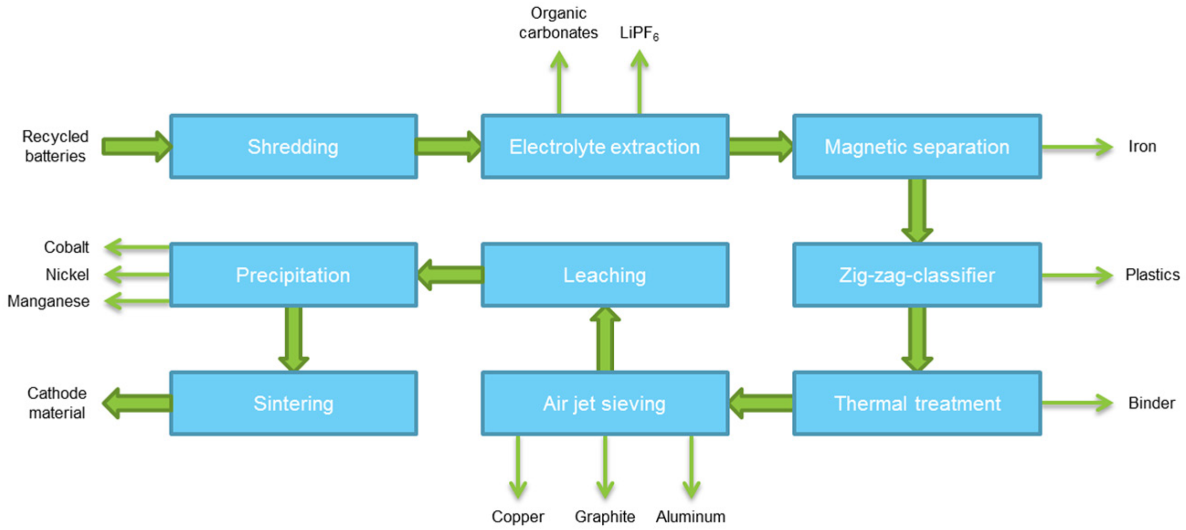


Figure 69. A simplified process scheme of the recovery of battery metals with a mechanical and solid-liquid extraction (LithoRec) process. Modified from (Rothermel et al. 2016).

The next part of the process is the removal of the electrolyte parts of the crushed batteries, which usually consist of different carbonites and conducting salts. The removal can be done with multiple technologies. The first option is a solid-liquid extraction with dimethyl carbonate in a rotary kiln, followed by drying of the shredded material, evaporation of solution to obtain electrolyte components and recycling of the used dimethyl carbonate. Another possibility is removing the electrolyte solvent and conducting salts via thermal drying. This method uses temperatures of 80 to 140 ˚C and decreased pressure to evaporate solvents, which can be later condensated to recover them, while producing the conducting salt lithium hexafluorophosphate ($LiPF_6$). The salt formed can decompose and generate hydrogen fluoride (HF), which leads to the process of having a mandatory gas scrubber application. The last possible technology is using supercritical carbon dioxide (CO_2) at high pressure (120 bars) to extract different electrolyte components and fluidise the solvents so they can be recovered while the shredded fragments remain dry. (Kwade&Diekmann 2018)

The leftover feed is then separated mechanically via air-sifting, crushing and sieving processes. Before anything else, a combination of magnetic and air separation processes recovers iron and other heavy parts. This is followed by homogenisation of the material flow by cutting mill and air classification via zig-zag-sifting to separate the materials into two fractions. The first fraction is made of current collector foils containing aluminium and copper, which can be sorted using optical sorting methods. The second fraction contains separator/coating materials, which are further processed using a vibration sieving process to recover separate anode and cathode materials from each other. This coating material powder contains transition metal oxides, such as lithium nickel cobalt manganese oxide (NCM) and graphite, which is processed hydrometallurgically to recover the metals it contains. (Kwade&Diekmann 2018)

The coating material powder is first leached, and graphite is filtered out. Metals such as manganese, cobalt and nickel are precipitated out by pH manipulation. The remaining liquid containing lithium is cleaned using multiple cleaning steps and then crystallised to produce lithium hydroxide or lithium carbonate. These compounds can then be used for new batteries. (Kwade&Diekmann 2018)

LithoRec is a novel process that can be used to recycle up to 75–80% of the material in battery systems. A modelled mass and energy balance flow of the process can be seen in Figure 70. The recycling rate is the result of the processes pilot plant implementation that ran for four months and recycled 1.4 tonnes of battery systems. LithoRec is described as a safe process, because it does not have any pyrometallurgical subunits and it is well suited to the needs of the circular economy, which the current LiB recycling processes do poorly with low total material recycling rates. (Kwade&Diekmann 2018)

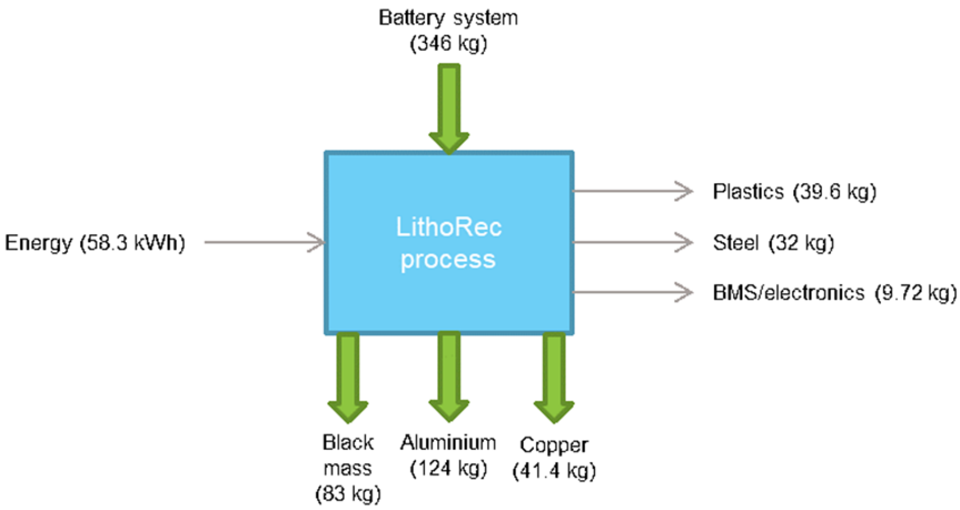


Figure 70. Modeled mass and energy balance sheet of the LithoRec process. (Kwade and Diekmann 2018)

An economic assessment of the LithoRec process has been carried out to determine the economic feasibility of the system (Kwade&Diekmann 2018). The assessment used an optimisation model with pilot plant data, market prices and literature values. A major inconvenience of the assessment was the lack of hydrometallurgical process assessments it included. Nevertheless, the results were promising. A process plant would require an investment of ~EUR 6.5–10 million (depending on the size, 6,000 vs 30,000 EV eq/a) and the operating costs would be approximately EUR 430,000–750,000 annually. The most optimistic scenario had a system payback time of one year, a realistic scenario five years and even the pessimistic scenario was profitable with the addition of toll gates to the process plant. Thus, the LithoRec process will be profitable in most cases. (Kwade&Diekmann 2018)

An LCA (Buchert&Sutter 2017) of the process has been realised from an environmental perspective. The global warming potential and cumulative energy demand were found to be approximately 50% with the LithoRec process of what they would be when producing virgin materials. The acidification potential was significantly lower due to primary nickel production having high SO_2 emissions, which are obsolete in the LithoRec hydrometallurgical recovery processes.

Overall, the LithoRec process seems promising, with its high recovery rate of various materials in the batteries, economic profitability and low environmental impact. A process like this is especially important with global LiB and electronic vehicle production rising rapidly (Curry 2017), lithium and cobalt resources are becoming depleted and current recycling methods are limited as well as inefficient. Uncertain details of the process are the possible impurities in the products, as well as the challenge of predicting new battery technologies and whether the LithoRec process will be suitable for them.

6.4 Recovering methanol and other chemicals from sorted MSW with gasification and catalytic synthesis

Enerkem is a Canada-based company founded in 2000 and specialising in producing renewable chemicals and biofuels from non-recyclable and non-compostable household waste. Enerkem has developed a waste-to-methanol (WtM) process that can be divided into four parts: feedstock preparation, gasification, a cleaning and conditioning process, and lastly catalytic synthesis and product purification, as shown in Figure 71. The feedstock used can be very heterogeneous and a mix of sorted municipal solid waste (MSW), residual biomass or other non-homogeneous waste feedstocks. As a product, WtM produces methanol (and/or ethanol) as well as small quantities of other biochemicals and solids. (Schofield 2017)

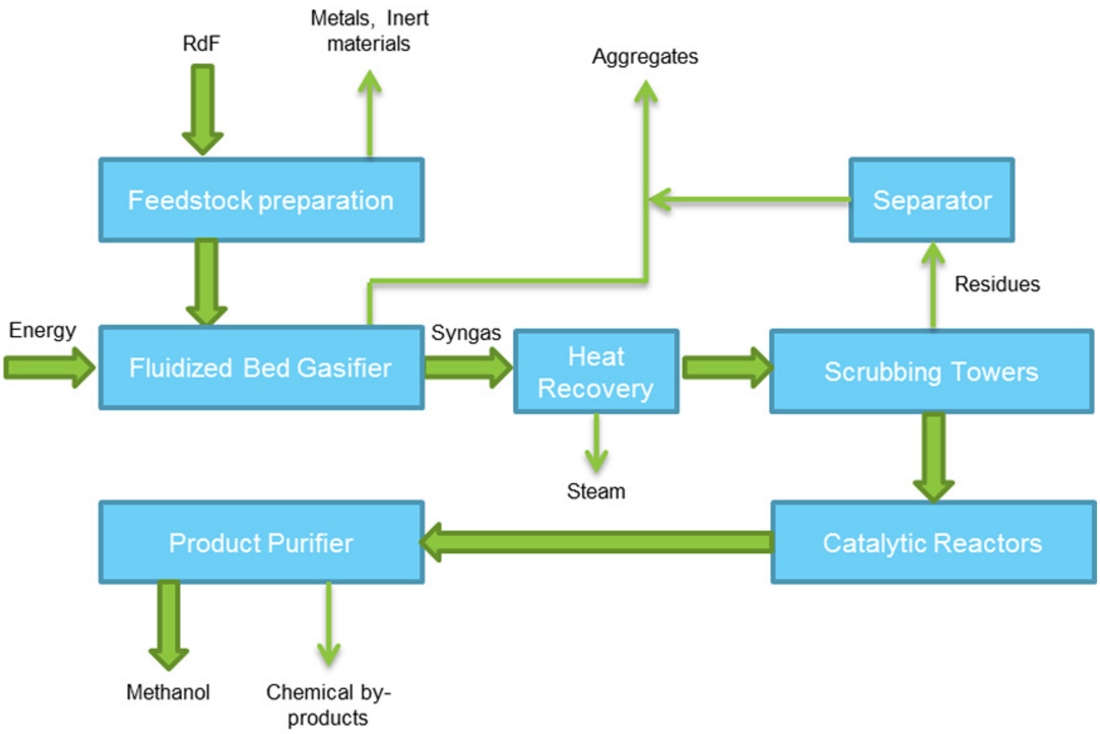


Figure 71. Simplified process scheme of Enerkem's WtM process. Reproduced from (Shareefdeen et al. 2015).

The first part of the process is sorting the feedstock both mechanically and manually, removing inert and compostable materials, as well as metals. Leftover material is then shredded and moved into a fluidised bed gasifier. The gasifier produces syngas and solid residue, which can be used as aggregates and construction materials (Schofield 2017). Syngas goes through a heat exchanger to acquire its heat energy, and is then transferred to a scrubbing tower to remove any leftover impurities. Impurities are moved to a separator where solids are collected, and gaseous compounds are recycled back into the gasifier. The cleaned syngas is transferred into a catalytic reactor, where the gas is synthesised into methanol and other chemicals. Lastly, the products are cleaned and separated. The newest development by Enerkem in this process has been the production of ethanol from methanol on site with a modular upgrade to the plant. (Chornet et al. 2016; Shareefdeen et al. 2015)

Enerkem does not report their process details or economic data publicly and there is little or no literature on the topic. However, Enerkem has released a simplified process scheme setting out the main process components mentioned earlier. This makes an approximate economic and process assessment possible. Iaquaniello et al. (2017) simulated a similar process with data from a RdF (refuse-derived fuel) thermogasification plant in use in Malagrotta (Italy). The results of the simulation are shown in Figure 72. The yield of methanol was calculated to be 40–42%, which is close to the 43% reported by Enerkem (Vierhout 2016). A simulated plant running at 300 t/d methanol production was able to produce methanol with a price of EUR 111/t_{MeOH}, which is an impressive result compared to average methanol prices of EUR 250–300/t in 2017 and the price peak of EUR 600/t in 2014. Fossil- and bio-based production of methanol is estimated to be two to three times more expensive. The return on investment (ROI) for this plant was calculated to be 28.7%, making the payback time for the investment around four years. According to these calculations, a biomethanol plant of this size would be a respectable investment. The greenhouse gas emissions of the process were also estimated; reductions of approximately 40% and 30–35% were determined in emissions with respect to methanol production from fossil-based fuels and bio-based fuels, respectively. (Iaquaniello et al. 2017)

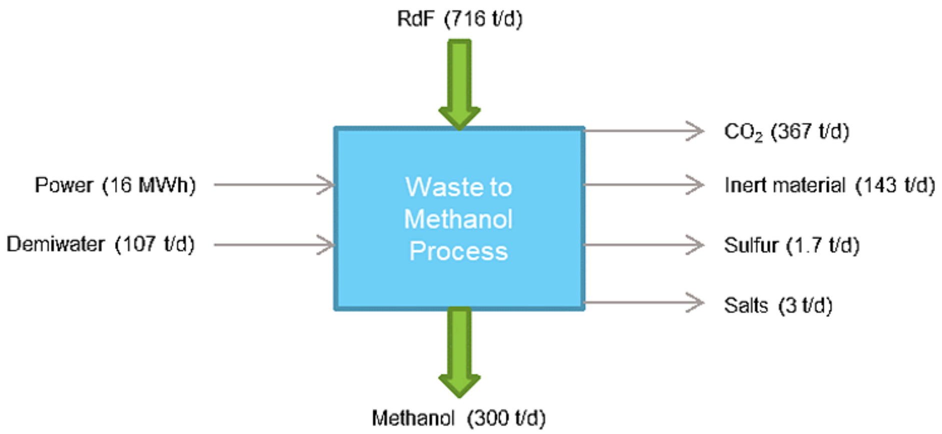


Figure 72. Estimation of a waste-to-methanol (WtM) process's overall mass balance for Recovering methanol and other chemicals from sorted municipal solid waste (MSW) with gasification and catalytic synthesis. Reproduced from (Iaquaniello et al. 2017).

Enerkem's promising waste-to-methanol technology seems to be a great alternative to fossil-based methanol production, offering lower GHG emissions as well as being economically feasible, but it does raise some questions. With only a simplified process scheme from Enerkem, the evaluation of the system is difficult. Iaquaniello et al. (2017) pointed out technicalities in the process schemes published that would make the process unworkable or at least hinder its efficiency considerably. It is not known how Enerkem has solved these problems. The problems mentioned could have a moderate effect on the GHG emissions or the economical side, compared to the simulated approximations, which seem to be the process's main selling points.

6.5 Recovering nitrogen into urea from sorted MSW using gasification to hydrogen and ammonia synthesis

Urea is one of the most produced (190 Mt/a) chemicals in the world and usually involves the synthesis of ammonia. This process has the highest energy consumption (~2.5 EJ worldwide) of any chemical synthesis processes (Antonetti et al. 2017). Thus, it is one of the most important processes to address and one of the key targets for reducing global energy consumption and greenhouse gas emissions. One way of solving this problem is the waste-to-urea (WtU) process. This is a novel technology that converts sorted MSW, such as RdF, into urea. The technology is not yet widely known or researched, but multiple companies have shown interest (Proton Ventures 2019; UreaKnowHow 2015). Multibillion EUR investments have also been considered quite recently to develop and commercialise it (Port Technology 2017). Since the technology is new and companies are just starting to commercialise it, the technical details and financial information publicly available is very limited. However, most of the individual processes in WtU are already commercialised and research on those is available. Thus, this paper discusses the WtU process via simulated data and estimates gathered by Antonetti et al. (2017). Therefore, it is important to view this paper's information as an approximation of a real-life process plant.

Urea can be produced from RdF with the process shown in Figure 73. The feedstock is first converted to syngas in the presence of oxygen in a high temperature gasifier. The leftover solids and salts are removed from the system while the syngas is quenched with water and moved through multiple cleaning and purification steps, removing particulates, salts and HCl, for example. The gas is further purified with a dual sour shift and CO is converted with water into CO_2 and H_2. Sulfur is removed using a redox sulfur removal unit and a H_2S deep polisher. H_2 (after its own purification process) is then moved to ammonia synthesis and the leftover purge gas is cycled back to the waste conversion unit. Finally, urea is synthesised under high pressure with CO_2 and ammonia.

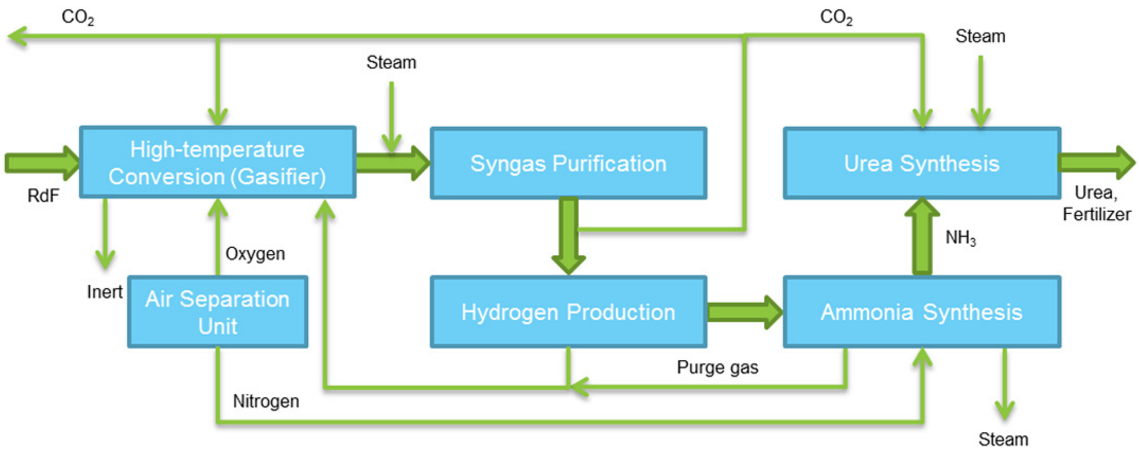


Figure 73. Simplified process scheme of an example waste-to-urea (WtU) process from sorted municipal waste, gasification to hydrogen and ammonia synthesis. Reproduced from (Antonetti et al. 2017).

Antonetti et al. simulated a plant producing 500 Mt/d of urea from 700 Mt/d of RdF, as shown in Figure 74. The technical feasibility should not be a problem with WtU, since all the sub processes are used commercially and have proved effective on their own. This should still only be a baseline to improve from, as they have not been tested together in the setting of producing urea from waste. The economic assessment of the process in question was conducted by Antonetti et al. (2017) and the cost of a plant of this size would be around EUR 350 million. The cost of production of urea per tonne was estimated to be around EUR 135, which is respectable compared to the price of urea in 2019, which was ~EUR 220 per tonne (Index Mundi 2019). The internal rate of return (IRR) was estimated to be in the range of 11–12%. Compared to traditional production of urea from natural gas, the WtU process saves 0.113 tonnes of CH_4 per tonne of urea and 0.78 tonnes of CO_2 per tonne of urea. (Antonetti et al. 2017)

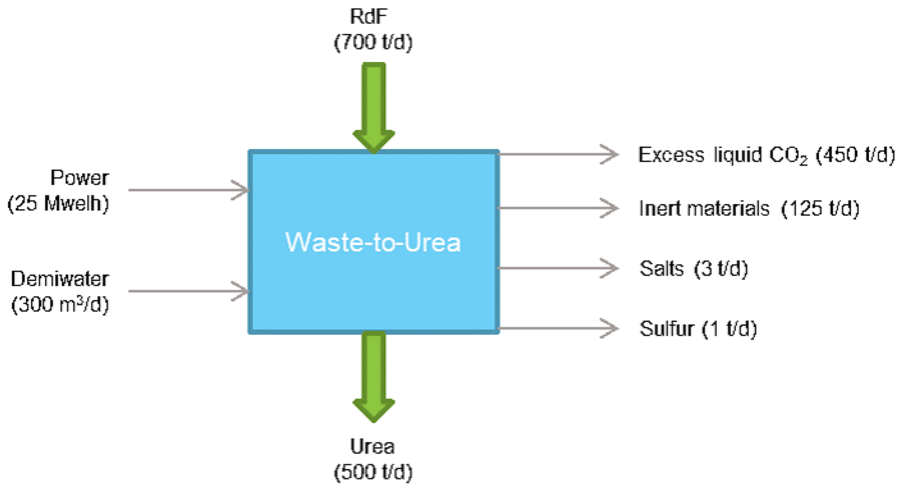


Figure 74. Overall mass balance of an example waste-to-urea plant. Reproduced from (Antonetti et al. 2017).

As of now, the waste-to-urea process has potential for competing against traditional urea production from natural gas. The WtU process has lower GHG emissions, it reduces waste incineration, it offers competitive profits and there is room for improvement in the process. For example, developing new catalysts specific to this process could have a significant impact on profits or yields. The price of natural gas price is also more prone to fluctuation than RdF prices, making RdF theoretically a safer feedstock material economically. The largest negative aspect of WtU was determined to be deprecation and maintenance of the process, which could account for up to 70% of the overall costs (Antonetti et al. 2017). Thus, WtU is a promising technology, but as always with new technologies, an extensive amount of research must be done before commercialisation is feasible.

6.6 Biodegradable MSW recovery into biofuels and ammonia with gasification and pyrolysis

An integrated hydropyrolysis and hydroconversion process called IH^2 is a novel biofuel production process in development by the Gas Technology Institute (GTI). IH^2 is a catalytic thermochemical conversion process with the ability to use a wide range of different biomass feedstocks. The process can use crop residues, wood/forest residues, municipal waste (up to 15% plastic), energy crops, algae and mixtures of these (Narasimhan&Del Paggion 2016). A simplified schematic of the process can be seen in Figure 75.

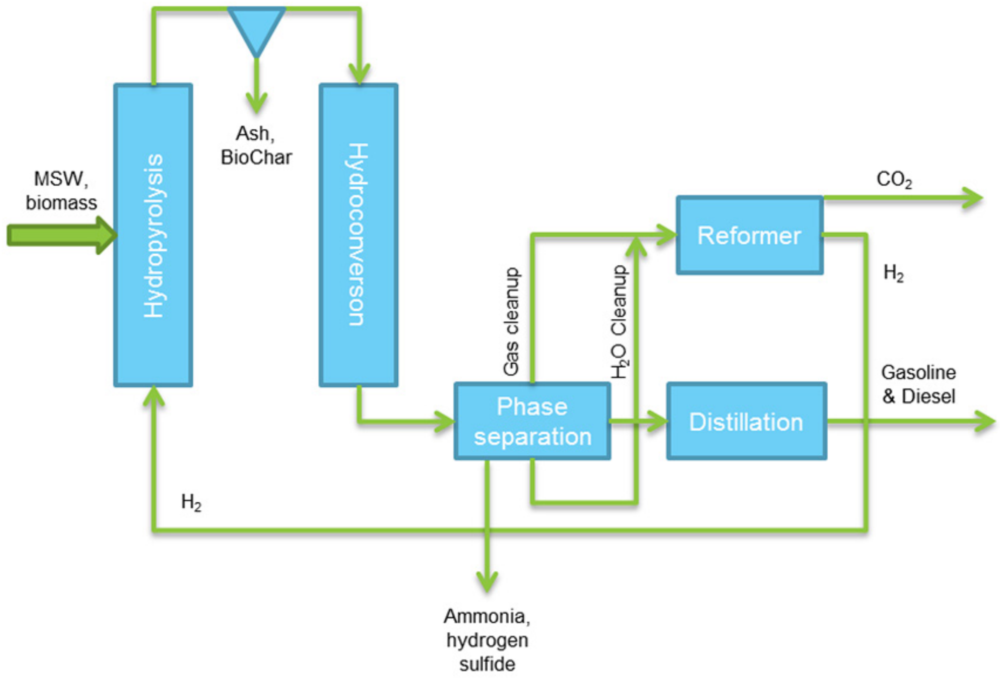


Figure 75. A Simplified schematic of producing biofuels from biodegradable municipal solid waste (MSW) with hydropyrolysis and hydroconversion processes (IH² process). (Reproduced from Ragaert et al. 2017).

The IH² process consists of three subprocesses: hydropyrolysis, hydroconversion and reforming. The first step is hydropyrolysis in a pressurised fluid bed under the presence of hydrogen, where the biomass is converted to gas, liquid and char. The gas continues to hydroconversion, while the ash and char are removed from the system or burned for energy. The hydroconversion process removes oxygen (into water and CO_x) and produces oxygen-free petrol and diesel products. The process produces C_1-C_3-gases, which are directed to a gas reformer once all the phases are separated in the phase separator. Ammonia and hydrogen sulfide condensate from the separator and are further processed to make ammonia/ammonium sulfate products used as fertilisers. With optimal conditions in every process, the steam reformer produces all the hydrogen necessary for the other processes. (Marker et al. 2013b; Roberts et al. 2015)

The operating temperatures and pressures of the processes are in in the range of 400–500 ˚C and 14–35 atm. The temperature is similar to a typical fast pyrolysis, making the volatile biomass undergo rapid devolatilisation in the hydropyrolysis reactor. The difference compared to typical fast pyrolysis is that the gases formed react with hydrogen and the catalyst exothermically. This is referred to as hydropyrolysis and it releases more energy than required to sustain endothermic pyrolysis of the initial feedstock biomass (Linck et al. 2014). Other differences compared to typical fast pyrolysis and catalytic cracking are the effluent having a lower oxygen content, an acid number of less than 1 instead of ~200 and the suppression of acid catalysed polymerisation, aromisation and coking reactions by hydropyrolysis (Ragaert et al. 2017).

Marker et al. (2013a) have investigated the process with a 50 kg/day pilot plant and multiple feedstocks, which has produced promising results. The Wt% C4 + liquid hydrocarbon yields (moisture ash free) ranged from 21% with corn stover feed to 46% with aquaflow micro-algae feed. Liquid hydrocarbon feeds had an oxygen content of less than 1 wt % and a total acid number of less than 1. Technoeconomic work and an LCA analysis on the IH² process (Marker et al. 2013a) shows its potential for turning biomass into diesel and petrol components for less than ~EUR 1.80 per gallon or ~EUR 0.48 per litre, which is competitive with fossil based fuels. Figure 76 shows a simulated mass and energy balance of a 2,000 tonne/day IH^2 plant with 20% moisture corn stover feedstock with an energy allocation factor (EAF) of 0.755. A 90% reduction in greenhouse gas (GHG) emissions was also determined compared to traditional fossil/based fuel production.

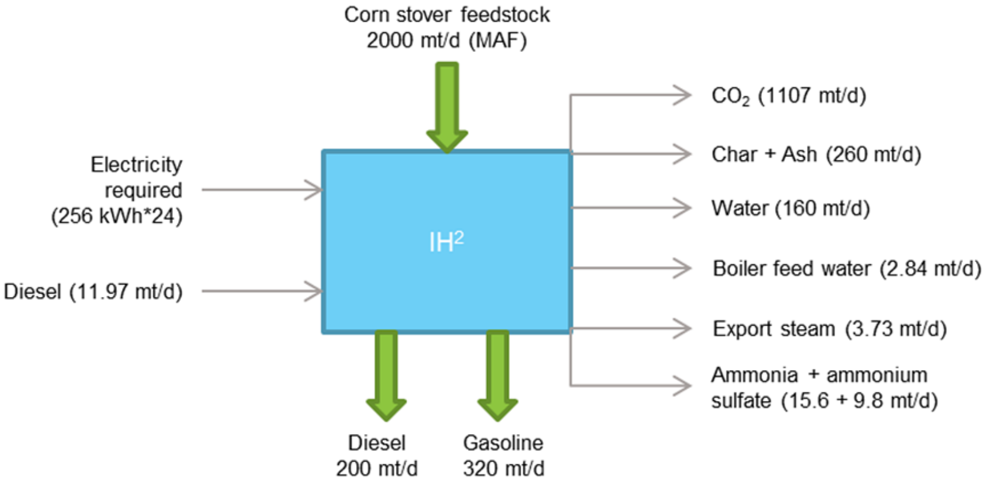


Figure 76. Overall mass balance of an Integrated hydropyrolysis and hydroconversion process IH^2. (Marker et al. 2013a).

The IH^2 process is an innovative technology with economic potential, with all three of its main sub processes already commercialised. The pure products, low GHG emissions and the possibility of using many types of feedstocks, including plastic waste, make it a sustainable way to produce biofuels. The process produces all the hydrogen and water it requires, which increases its sustainability further. Tests in a laboratory and at pilot scale plant have been promising but more research and optimisation is still required, especially on plastics as a feedstock and mixtures of feedstocks, before industrial scale plants can be built.

6.7 Processing textile, cardboard and agricultural waste into new natural fibres

In the process created by Infinite Fibre, textile, cardboard and agricultural waste can be reprocessed into new natural fibre. The process includes a fibre separation phase, turning the material into liquid and turning the liquid back into fibres. The process is based on carbamate technology. The company claims that the process can be used at existing pulp and viscose fibre factories, thus saving on investment costs and lowering the investment risks. Viscose fibre manufacturers can also use the process to get rid of carbon disulphide – the most challenging and hazardous chemical involved in their processes. Infinite Fibre Company has found that the new product is highly interesting and meets customers' future needs – with a higher margin potential both for pulp and viscose fibre producers. The company has recently been able to create new business cooperation with several large chains selling cloth, which seems promising for the future of the technology.

The environmental claims made by the company include closing the loop of textile materials and the calculations indicate that the process consumes 20,000 litres less water use per kg of new fibre than cotton does, and less than viscose, too. Savings are also reported in land use (160,000 ha less than viscose) and in the use of chemicals, dyestuff, water and energy, due to higher colour uptake than other fibres.

The company opened a new pilot plant in 2020 and intends to open an industrial size plant in 2022. (Infinite Fibre Company 2020)

7 Discussion and conclusions

Circular economy has since the 2010s been a widely used, well-known and broadly discussed concept in environmental science policy discussions and communication. It is also the focus of a strategic policy programme launched by the European Commission in 2014. It has been compiled to involve very comprehensive impacts and dimensions of sustainable development. The Circwaste project is constructed to implement these targets. The aim of the Circwaste project has been to implement these targets. During 2016 – 2020, the project has produced monitoring data on the development of circular economy and the sustainability of waste management, highlighted circular economy concept, promoted stakeholder collaboration, supported strategic national processes, strengthened know-how and mainstreamed and concretized circular economy thinking.

The EU is aiming for sustainable growth and a climate neutral, resource efficient and competitive economy, where the value of products, materials and resources is maintained in the economy for as long as possible; economic growth is decoupled from resource use; generation of waste is minimised; the Earth's resources, climate, biodiversity and energy are saved and carbon dioxide emissions and air, soil and water pollution are minimised. It is stated that half of the global greenhouse gas emissions and more than 90% of biodiversity loss and water stress come from resource extraction and processing.

The expected social impacts generated from the transition towards circular economy include creating jobs for all skill levels, social integration, cohesion and fairness. Due to its multidimensional nature, the circular economy concept can easily be misused to promote partial optimisation. Therefore, it is very important to produce understanding and monitoring data of the bigger picture on implementing the circular economy. Implementation requires systemic changes in society, with evident connections to use of natural resources, land use and biodiversity – saving natural resources also saves ecosystems and biodiversity. However, more information from connections and reflections is needed.

Use of natural resources is one of the key parameters in assessing the environmental performance of circular economies, connecting the impact chain to the land use and biodiversity. The European Commission has suggested the following indicators for member countries to measure sustainable resource use: material footprint (domestic material consumption DMC), and resources productivity (DMC/GDP or total amount of materials used directly by an economy RMC/GDP), and the circular material use rate (CMU, contribution of recycled material use to total raw material demand). Quantitative national targets for natural resources are needed. The starting goal set by the European Commission is to double the circular material use rate by 2030.

The national indexed trends of DMC, TMR, GDP, MSW in Finland in 2000–2018 show quite clear coupling of economic growth to the use of natural resources. The current circular material use rate of about 7% can be considered modest. This confirms the need to further accelerate efforts to achieve a circular economy and set clear targets for decreasing the use of natural resources.

Monitoring is needed to create basic information for decision making. The comparison between countries might be complicated, however, while the main influencing factors affecting the indicators on use of natural resources are the industrial structure and economic conditions. Therefore, one observation and recommendation concerning the national indicators is to focus instead on monitoring national trends rather than comparing countries. Trends should be monitored to learn from the past and to identify the policy instruments needed to achieve the level aspired to.

Regional indicators are needed for efficient monitoring and leadership

One of the key findings is that the need for further development of the circular economy indicators arises from the critical and practical needs to have sub-national data for decision making in regions, municipalities, waste management companies and other companies. All the European indicator work is carried out to produce indicators at national level. The work done within Circwaste is the first effort towards a systematic monitoring scheme for monitoring circular economy sub-nationally in Finland. However, monitoring on a regional basis has turned out to be challenging due to the limited statistical information and data available. There is a clear need for more detailed information in the future.

Waste indicator results show that the estimated recycling rates have not increased adequately over the monitoring period of 2016–2019 for the regions around nine forerunner municipalities in Finland. In the regions with the most positive trend, the increase in the recycling rate was 1–2%. In order to meet the EU targets for recycling rate of MSW, a more rapid increase is needed. In most of the regions, a moderate decrease (1–12%) in the total amount of household waste was observed, yet there is significant fluctuation from one year to another. There was also some increase in the separate collection of biowaste from households in most of the forerunner municipality regions. Increasing the separate collection of biowaste is crucial in increasing the recycling rate of household waste, since biowaste is by far its heaviest source-separated fraction.

Due to uncertainties in data collection and production methodologies, these results must be considered estimates for monitoring local trends. The study has shown that there are considerable challenges in producing sub-national waste data with the current reporting tools and obligations. At the same time, the forerunner municipalities in particular are increasingly keen to get more exact monitoring data for policy discussions and decision-making. More comprehensive monitoring of different waste and material streams is constantly being developed. In addition to this, monitoring of a circular economy needs to cover different themes to showcase the transition steps.

The transition to circular economy is also a profoundly social transformation that necessitates the participation of citizens and has important social consequences. Citizens take part in circular economy, among other things, as consumers, users and maintainers of circular economy goods and services, as well as through reselling and returning unwanted items and sorting and delivering waste for recycling. It is expected that the transition to the circular economy will promote the wellbeing of people by increasing employment and job creation through emergence or transformation of existing businesses and technologies. On the other hand, if social justice and fair distribution of the benefits and disadvantages is not taken into consideration, the circular economy transition might also have adverse social impacts.

To monitor the social consequences of the circular economy transition in the Circwaste key regions, a set of social indicators was developed. The indicators chosen for measuring different types of social impacts and prerequisites were: circular economy employment in different income and education categories and employment possibilities for vulnerable groups, the availability of public shared resources, circular economy capacity building and education, and accessibility of recycling services and sustainable vehicle fuel sources. Although only the baseline data for the indicators has been produced, the first results of the social indicators show initial advances towards the circular economy on many fronts. For example, the accessibility of waste management services has improved, and the Finnish educational system has been able to respond quickly to the need for capacity building and circular economy education, with it now being offered throughout the country. Similarly, circular economy activities and work can have high potential for the employment of vulnerable groups and people with limited professional skills through the development and growth of economic activities related to recycling, repair and reuse. Many existing public sector services and infrastructures, such as libraries, are already aligned with the sharing economy and with some fine tuning and service design the sharing economy potential could be increased. The regions and municipalities emerge as key actors in facilitating a fair and socially just transition to the circular economy through their existing services, infrastructures and social mandate in promoting the wellbeing of all citizens.

Producing all the indicator results has expanded understanding of the synergy of the different themes measured (attachment 6) and required strong cooperation with municipalities and other stakeholders. Furthermore, the data has provided a good basis for fruitful discussions, which have also generated growing understanding and capacity building.

Promising new technologies being developed for increasing recycling

The study on innovative processing technologies found that there are several competing technologies for elemental recycling of plastic waste. Nearly all these technologies are concentrated on PET plastics. It seems that PET bottle manufacturers have been searching for more efficient raw material recycling opportunities for some time. Promising technologies have also been studied for making new fibres from textiles waste. Financial issues are key to the survival of these technologies in the future. Large investments in the new technologies will be needed and support for these processes allowing closed loop circulation would be a good position for the governmental role in supporting the transition to a circular economy.

Life cycle impacts of municipal waste management operations

The LCA methodology was used for monitoring the environmental impacts of circular economy activities, more precisely the waste management system, in municipalities. The results do not show any clear trends after two years of monitoring. However they do show that mixed waste, paper and metals are the main contributors to environmental impacts. Particularly, focusing on impacts avoided might mislead readers to the conclusion that the more waste produced the better the environmental performance. So, it must be emphasised that, regardless of how efficient the recycling system is, the most effective action for preventing environmental impacts of waste management is minimising the generation of waste.

Municipalities as key players

Public procurers can be considered key players in the circular economy due to their key role as purchasers, creating demand for environmentally better products, services and solutions. Implementing circular economy in municipalities requires adoption, commitment, financial planning on circular public procurements and extensive interaction with regional actors. Targets for sustainable procurements should be set and representative indicators and monitoring methods established. Employing circular economy experts in each municipality to work as cross-administrative experts and coordinators could also enhance the transition. In addition to this, circular economy, sustainable development and resource efficiency should be included, accompanied by financial rules, in financial management and decision making.

Decisions related to construction have major impacts on use of natural resources. Municipalities have effective means for creating a more sustainable building field through public procurements and planning: as buyers, they not only decide the materials, sizes and energy sources, but they can also require the use of recycled raw materials in their construction projects and the use of recycled soil materials in infrastructure construction projects. Obligations for ecologic compensation and quantitative no net loss goals for biodiversity would also decrease the pressure on natural resources.

Even before the actual construction phase, circular economy strategies and targets should be implemented at all plan levels: in regional, master, component, zoning and interim town plans. Binding obligations are needed in plot allocation conditions or in instructions on construction methods and in the building code. The challenge is to produce concrete examples of how to realise these goals in practice.

In MSW management, municipalities could offer more ambitious services and wider cooperation with all the actors of municipal waste management operations. There could also be municipal-level targets for waste recycling.

To support municipalities in their work, our suggestion is to establish a national organisation for providing municipal auditing, development, education and business support services.

Next steps

Later in the Circwaste project, there will be a great deal of data to be gathered and analysis to be done. The more indicator data gathered, the more will be learned on the correlations between the factors and impacts. The future development work covers attitudes and values of people and how they are connected to the circular economy, waste management and recycling rates. The correlation between regional recycling rates and average income, education levels and distances to collection points, for example, will be studied. It would also be interesting to look for synergies between leasing and hiring and other sharing concepts and the impacts they have on use of natural resources.

Circwaste is a long-lasting research project with the results obtained through pilot projects and experiments. How can we utilise and disseminate all the results and lessons learned from the project? Disseminating information through different communication channels and informing the relevant parties about the results of the project will promote the development of project results in the future.

This project has created a lot of political, theoretical and practical content on the concept and field of circular economy, and we strive to further develop and widen as well as deepen the results and implications in the last three years of the project. A follow-up report can be expected in 2023. Household waste recycling has not yet reached the necessary level, the use of natural resources is increasing and the development of GDP has not been decoupled from use of natural resources or amounts of waste. The aim of the project is to provide national support in searching for answers and solutions for decreasing the use of natural resources, achieving the MSW recycling targets and creating a more sustainable society.

Lexicon

BHET	Bis-2-hydroxyethyl terephthalate
BJOE	Business Joensuu
C&DW/CDW	Construction and demolition waste
CE	Circular economy
CEI	Circular Economy Indicator
DMC	Domestic Material Consumption
DMT	Dimethyl terephthalate
EG	Ethylene glycol
EV	Electronic vehicle
ELY centre	Centre for Economic Development, Transport and the Environment
FDA	Food and Drug Administration
GDP	Gross domestic product, i.e. the monetary value of all final goods and services produced and bought in a country (in a given time period, for example a quarter or a year).
GHG	Greenhouse gas
HDPE	High-density polyethylene
HHW	Household waste
HHBW	Household biowaste
HRP	Hydrocarbon Recycling Process
JKL	City of Jyväskylä
JSP	Joensuu Science Park
KI	Key indicator
LUKE	Natural Resources Institute / Luonnonvarakeskus
MEG	Mono ethylene glycol
MSW	Municipal solid waste
N	Nitrogen
NCM	Lithium nickel cobalt manganese oxide
NWP	National Waste Plan
P	Phosphorus
PA	Polyamide
PET	Polyethylene terephthalate
PE	Polyethylene
PMMA	Polymethylmethacrylate

PP	Polypropylene
PS	Polystyrene
PSM	Polystyrene-to-styrene monomer
RdF	Residue derived fuel
RMC	Total amount of materials directly used by an economy
RWP	Regional Waste Plan
SYKE	Finnish Environment Institute
TMR	Total material requirement
TPA	Terephthalic acid
TE office	Employment and economic development office
TUAS	Turku University of Applied Sciences
YLVA	Environmental compliance database (environmental permit and emission data control system)
WEEE	Waste electrical and electronic equipment
WSI	Waste specific indicator
WtU	Waste-to-urea process
WWTP	Waste water treatment plant

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Attachments

Attachment 1. Resource efficiency Scoreboard Indicators set in the first European Commission Circular economy package (European Commission 2015) and maintained by Eurostat (2020).

Resource efficiency Scoreboard Indicators	Theme	Indicator
Lead indicators	Resource productivity	Resource productivity GDP/DMC
Dashboard indicators	Materials	Domestic material consumption per capita
	Land	Productivity of artificial land
	Water	Water exploitation index
		Water productivity
	Carbon	Greenhouse gas emissions per capita
		Energy productivity
		Energy dependence
		Share of renewable energy in gross final energy consumption
Transforming the economy	Turning waste into a resource	Generation of waste excluding major mineral wastes
		Landfill rate of waste excluding major mineral wastes
		Recycling rate of municipal waste
		Recycling rate of e-waste
	Supporting research and innovation	Eco-innovation index
	Getting the prices right	Environmental tax revenues
		Energy taxes
		Energy taxes by paying sector
Nature and ecosystems	Biodiversity	Common bird index (EU aggregate)
		Area under organic farming
		Landscape fragmentation
	Safeguarding clean air	Urban population exposure to air pollution by particulate matter
		Urban population exposed to PM10 concentrations exceeding the daily limit value (50 µg/m3 on more than 35 days in a year)
	Land and soils	Estimated soil erosion by water area affected by severe erosion rate (source: JRC)
		Gross nutrient balance on agricultural land
Key areas	Addressing food	Daily calorie supply per capita by source
	Improving buildings	Final energy consumption in households
		Final energy consumption in households by fuel
	Ensuring efficient mobility	Average carbon dioxide emissions per km from new passenger cars
		Pollutant emissions from transport
		Modal split of passenger transport
		Modal split of freight transport

Attachment 2. Map of Finnish regions

Attachment 3. Life cycle inventory data on waste management operations

Municipal mixed solid waste energy recovery

Mixed municipal solid waste (MSW) in Finland cannot be landfilled and instead it is incinerated and the energy from incineration recovered. A complete unit process dataset for municipal solid waste incinerator (MSWI) from Ecoinvent was selected to represent this treatment (*Municipal solid waste {FI}| treatment of, incineration | Cut-off)*.

Heat and electricity generated through energy recovery of mixed MSW is modelled as burden free in the Ecoinvent v3.4 Cut-off system model. Therefore, the amounts of heat and electricity are not specified in the Ecoinvent incineration unit process. Instead, the burdens avoided were calculated with data provided by Helsinki Region Environmental Services Authority HSY (Sundström et al. 2014). In this data, incineration of a kilogram of mixed MSW generates 4.1 MJ of electricity and 6.6 MJ of heat. Avoided burdens were calculated by using modules of market mix electricity in Finland (unit process *Electricity, low voltage {FI}| market for | Cut-off*) and district heating from natural gas combustion (unit process *Heat, district or industrial, natural gas {FI}| heat and power co-generation, natural gas, combined cycle power plant, 400MW electrical | APOS*).

Municipal biowaste composting

Industrial composting is one way of treating separately collected biowaste. Household composting is also a common practice, especially in smaller settlements, but it is not included in the assessment.

The process of industrial composting was modelled according to a process described in Haupt et al. (2018)(unit process *Compost, from industrial composting, household waste)*. The amount of energy used per kilogram of biowaste was about 42 kJ. The only modification made to the process was replacing Swiss electricity as one of the inputs with the Finnish electricity grid mix. Composting of a kilogram of municipal biowaste, according to Haupt et al. (2018) produces 0.5 kg of compost that is assumed to replace peat. Nutrients in the compost produced are assumed to replace industrial fertilisers (for amounts see Table 17) The process produces compost, which is assumed to replace peat and industrial nitrogen, phosphorus and potassium fertilisers (NPK).

Table 18. Industrial composting, avoided products per kg of biowaste (Haupt et al. 2018)

Products of industrial composting	Yield per kg of biowaste	Process assumed to be avoided
compost	0.5 kg	Peat {NORDEL}| production | Cut-off
nitrogen fertiliser	0.002 kg	Nitrogen fertiliser, as N {GLO}| market for | Cut-off
phosphate fertiliser	0.003 kg	Phosphate fertiliser, as P2O5 {GLO}| market for | Cut-off
potassium fertiliser	0.01 kg	Potassium fertiliser as K2O {GLO}| market for | Cut-off

Municipal biowaste anaerobic digestion

Anaerobic digestion is another way of treating biowaste. The process generates biogas as the primary product and liquid and solid digestates as secondary products. Biogas from anaerobic digestion is further refined for use as a transportation fuel. A combination of Ecoinvent v3.4 unit processes and data from Haupt et al. (2018) was used in the model. The energy use of anaerobic digestion was assumed to be 7.7 kJ electricity/kg of biowaste and 242 kJ of heat per kg of biowaste. A process called *Biogas, from anaerobic digestion of household waste* in Haupt et al. (2018) was used as a source of data for processes from the reception of biowaste in the digester until the point of biogas production. An Ecoinvent v3.4 unit process called *Methane, 96% by volume {CH}| biogas purification to methane 96 vol-% | Cut-off* was used to describe the refining step from biogas to biomethane as transportation fuel. Both processes were modified in the same way as the composting unit process: Swiss electricity as one of the inputs was replaced by the Finnish electricity grid mix.

Anaerobic digestion treatment of a kilogram of municipal biowaste yields approximately 0.1 m^3 of biogas which needs to be further refined (Table 18). To produce 1 m^3 of biomethane 1.5 m^3 of biogas is needed. Therefore the reference flow that is used for calculating the inventories and impacts of anaerobic digestion treatment of a kilogram of municipal biowaste is set to 0.0667 m^3 in the unit process *Methane, 96% by volume {CH → FI}| biogas purification to methane 96 vol-% | Cut-off*, which is the modified version of its original.

Table 19. Products of anaerobic digestion, avoided products.

Products of anaerobic digestion	**yield per kg of biowaste** (Haupt et al. 2018)	**process assumed to be avoided, Ecoinvent database** (Wernet et al. 2016)
biomethane	0.0667 m^3 (i.e. refined 0.1 m^3 of biogas)	Petrol, low-sulfur {Europe without Switzerland}| market for | Cut-off
nitrogen fertiliser	0.001 kg	Nitrogen fertiliser, as N {GLO}| market for | Cut-off
phosphate fertiliser	0.002 kg	Phosphate fertiliser, as P2O5 {GLO}| market for | Cut-off
potassium fertiliser	0.006 kg	Potassium fertiliser as K2O {GLO}| market for | Cut-off

Plastics recycling

It is estimated, that about 74.7% of collected consumer plastic waste is recycled and the remaining 25.3% is recovered for energy, because it is not suitable for recycling (Koivuniemi 2020). The efficiency of plastics recycling was considered to be 95%, as it is modelled in an Ecoinvent v3.4 unit process that models recycling of HDPE (to produce a kilogram of recycled HDPE 1.0585 kg of sorted HDPE is needed).

As the proportions of different types of plastics in mixed postconsumer plastic packaging for different municipalities are unknown, the same default composition was defined in the model for all municipalities (Table 19).

Table 20. Default composition of postconsumer plastic packaging waste (//xxx 20zz).

Type of plastic	**Proportion in mixed postconsumer plastic packaging waste**
polyethylene (PE)	29.6%
polypropylene (PP)*	23.3%
polyethylene terephthalate (PET)	14.4%
high-density polyethylene (HDPE)	7.4%

*Due to unavailability of suitable data, recycling of PP was approximated as recycling of PET in the model.

Recycling of polyethylene was modelled according to Haupt et al. (2018), while recycling of polypropylene, polyethylene terephthalate and high-density polyethylene was modelled according to the Ecoinvent v3.4 database. The Finnish electricity grid mix was used in the model where inputs of electricity were required.

Energy from plastics that are not mechanically recycled as materials, but are incinerated, was assumed to substitute for the Finnish electricity grid mix and district heat from natural gas combustion. A kilogram of plastics recovered for energy generates 7.6 MJ of electricity and 12.7 MJ of heat. Mechanically recycled plastics were considered to replace virgin plastics (HDPE, LDPE, PP and PET) in the same proportions as they occur in the collected mixed plastic waste.

Metals recycling

It was not possible to find out even an approximate composition of metal scrap originating from municipal waste, therefore metals recycling was modelled as recycling of steel and aluminium (later referred as Al) in the 50:50 share. It is possible, however, in future calculations to change the share to test the sensitivity.

Steel recycling was modelled by using a unit process called *Steel, low-alloyed {RER}| steel production, electric, low-alloyed | Cut-off, U*, with a modified electricity input to (Finnish grid mix). It represents both the burdens of sorting and pressing scrap iron, as well as re-melting scrap iron in an electric arc furnace. Al recycling was modelled by using a unit process called *Al, cast alloy RER}| treatment of Al scrap, post-consumer, prepared for recycling, at refiner | Cut-off, U* which has been modified in the same way as the steel process.

According to the Ecoinvent v3.4 documentation, 1.105 kg of scrap iron is needed to produce a kilogram of steel, low-alloyed and 1.03 kg of scrap Al is needed to produce a kilogram of Al, cast alloy. These values were used in the model.

The substitution was modelled so that recycled low-alloyed steel replaces converter steel on the market. The oxygen converter process is a method of primary steelmaking, i.e. it uses pig iron as feedstock. Possible quality differences between primary and secondary steels are not considered in this model. Recycled Al was considered to replace primary Al cast alloy ingots. As default settings, a kilogram of recycled steel and Al was considered to substitute for 1 kilogram of virgin steel and Al.

Paper and cardboard recycling

Paper recycling was modelled based on an Ecoinvent v3.4 unit process called *Deinked pulp, wet lap {RoW }| treatment of waste paper to pulp, wet lap, totally chlorine free bleached | Cut-off, U*. The electricity input was modified to the Finnish grid mix. According to the documentation, 0.929 kg of waste paper is needed to produce a kilogram of wet lap totally chlorine-free pulp. The water content of pulp produced by the unit process above is 40%, therefore in order to produce a kilogram of dry pulp, 1.548 kg of waste paper is needed.

Cardboard recycling was modelled as a mix of recycled linerboard and fluting production in the 50:50 share. The unit processes that were used are called *Linerboard {RER}| treatment of recovered paper to, testliner | Cut-off, U* and *Fluting medium {FI}| treatment of recovered paper to, wellenstoff | Cut-off, U*. The unit processes were modified to utilise the Finnish grid mix. According to the documentation, 1.05 kg of waste paperboard is needed to produce a kilogram of linerboard and 1.04 kg of waste paperboard is needed to produce a kilogram of fluting. These numbers were used in the model.

The potentially avoided impacts of paper recycling were calculated based on the assumption that recycled pulp can replace primary pulp (unit process *Sulfate pulp {RER}| production, totally chlorine free bleached | Cut-off, U*). The potentially avoided impacts of cardboard recycling were calculated based on the assumption that recycled liner and fluting replaces kraftliner and semichemical fluting medium (unit processes *Linerboard {RER}| production, kraftliner | Cut-off, U* and *Fluting medium {RER}| production, semichemical | Cut-off, U*)

Glass recycling

Glass recycling was modelled according to the unit process of treating municipal origin glass (*Glass cullet, sorted {RER}| treatment of waste glass from unsorted public collection, sorting | Cut-off, U)*. The unit process has limited coverage as it mainly describes sorting of collected waste glass. It was modified to utilise energy from the Finnish grid mix.

Potential benefits of glass recycling were not calculated due to the lack of data. In Finland, about 82% becomes new glass packaging in the UK and in the Netherlands and about 18% is turned into products such as glass wool, flat glass and building blocks (RINKI 2019). If the data gap can be filled in the future, the model will be updated.

WEEE recycling

Complete processing data for WEEE recycling was not available in Ecoinvent at the time of the creation of the model. In order to at least partially fill the gap, data on carbon dioxide emissions (CO_2e) of WEEE recycling, as well as on potential CO_2e savings, collected in the NeReMa project (Dahlbo et al. 2012, unpublished), were used. The potential benefits are approximately twice the impacts of recycling.

Transport of waste

Transport distances (Table 20) were roughly estimated. They were calculated in Google Maps as distances between biggest towns and cities of Hyvinkää, Riihimäki, Joensuu, Jyväskylä, Kuopio, Lappeenranta and Porvoo and the nearest facility treating each waste fraction. Transport distances were not estimated for the following fractions: glass, metals and WEEE. This is due to the lack of clarity as to where each fraction is treated. Especially for metals and WEEE, the value chain is global, and waste is often treated abroad.

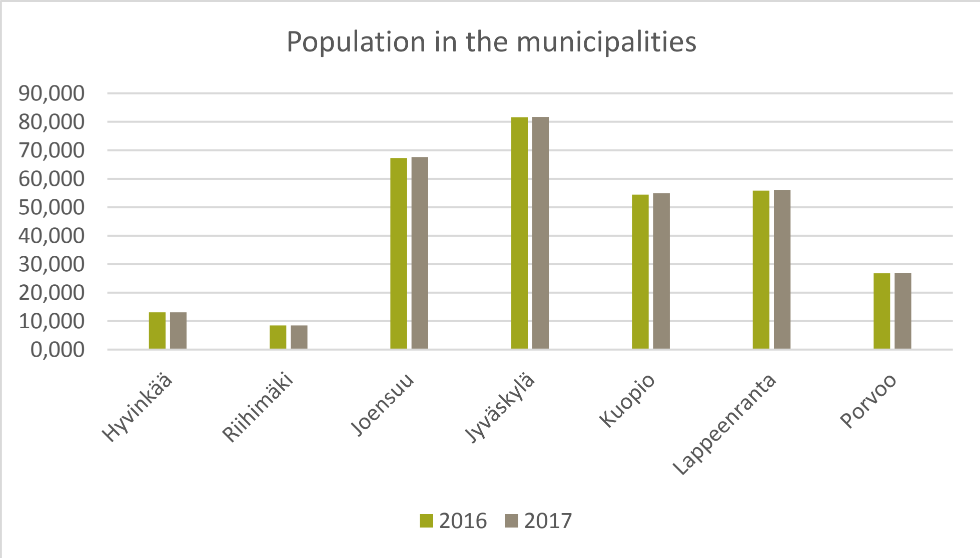
Table 21. Transport distances applied in the model.

Municipality, transport [km]	Mixed waste	Biowaste	Cardboard	Paper	Plastic packaging
Hyvinkää and Riihimäki	20	10	300	180	20
Joensuu	130	10	125	310	400
Jyväskylä	160	10	130	65	230
Kuopio	40	10	80	210	350
Lappeenranta	220	10	200	260	200
Porvoo	40	10	300	200	80

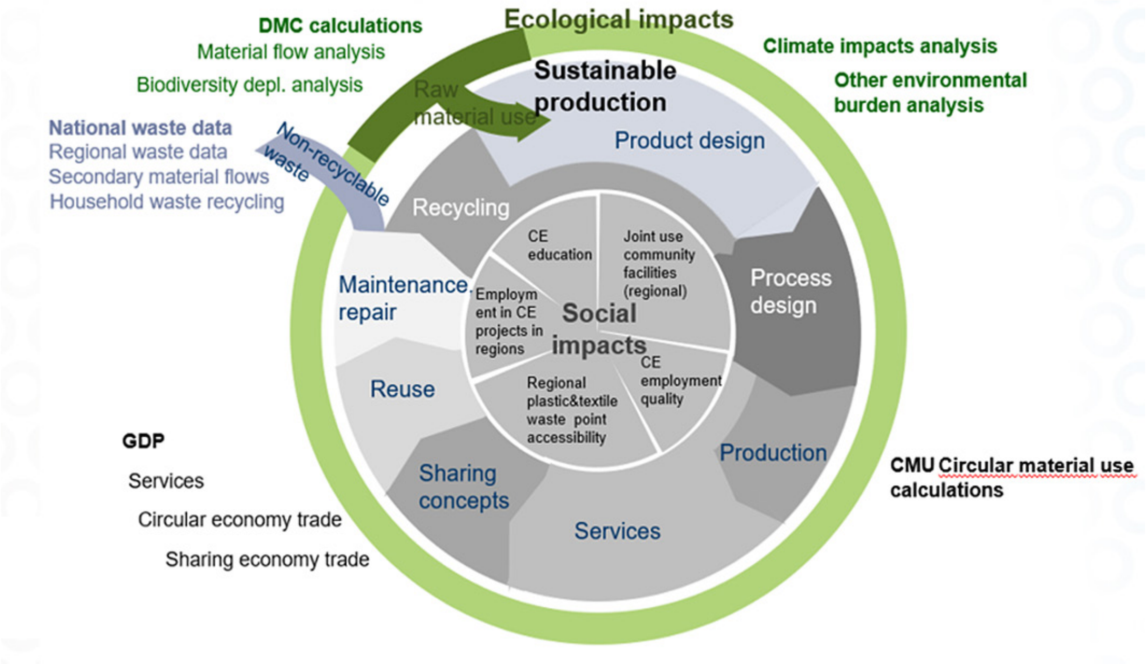
Attachment 4. Puzzle game on constructing a cellular phone. Graphics design by Luukas Myller.

Materials (in Finnish) available in https://www.materiaalitkiertoon.fi/fi-FI/Ajankohtaista/Logot_ja_materiaalit/Matka_puhelimeen_peli(52417)

Attachment 5. Population statistics in selected municipalities in 2016 and 2017 in a graph.



Attachment 6. Circular economy indicator development in Finland by Finnish Environment Institute, Statistics Finland, the Natural Resources Centre Finland and municipalities.



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