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Textile, battery, and agri-food value chains

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Erika Winquist ORCID ID, orcid.org/0000-0003-2418-2956

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Authors: Erika Winquist, Susanna Horn, Hannamaija Tuovila, Sonja Lavikko, Jaana Sorvari, Vesa Joutsjoki, Marjaana Karhu, Patrycja Slotte, Petrus Kautto, Päivi Kivikytö-Reponen and Hannu Ilvesniemi
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Abstract

Erika Winquist[1], Susanna Horn[2], Hannamaija Tuovila[3], Sonja Lavikko[4], Jaana Sorvari[2], Vesa Joutsjoki[1], Marjaana Karhu[3], Patrycja Slotte[3], Petrus Kautto[2], Päivi Kivikytö-Reponen[3], Hannu Ilvesniemi[1]

[1] Natural Resources Institute Finland, Latokartanonkaari 9, 00790 Helsinki
[2] Finnish Environment Institute, Latokartanonkaari 11, 00790 Helsinki
[3] VTT Technical Research Centre of Finland, PL 1000, 02044 VTT
[4] Geological Survey of Finland, Vuorimiehentie 2, 02150 ESPOO

This report discusses the circular economy model through circular economy strategies, the R-strategies, in three different value chains: textile, battery, and agri-food.

The R-strategies can be classified under three approaches: 1) smarter product use and manufacture (R0 Refuse, R1 Rethink, R2 Reduce), 2) life extension strategies (R3 Reuse, R4 Repair, R5 Refurbish, R6 Remanufacture, R7 Re-purpose), and 3) creative material application (R8 Recycle, R9 Recover). Often, the impact on circularity and overall sustainability is likely higher in the beginning of the material value chain. However, the selection of the most optimal R-strategy is always case specific and should be based on a holistic, system wide approach.

The report gives several examples of business models applying different R-strategies in the selected value chains. The examples show the similarities and differences between the value chains and which strategies have more importance in which value chains.

In the textile value chain, currently the most important aim is to replace fast fashion with longer product use (R3, R4, R5) and essentially reduce production and consumption volumes (R0, R1, R2). Textile fibres can be circulated (R6, R7, R8) to some extent, but in every round, there is some wearing of the material and the quality of the recycled fibre deteriorates in comparison to virgin fibre.

In the battery value-chain, increased recycling of metals (R8) is crucial to meet the future need of batteries in various solutions including electric vehicles and energy storage. Thus, recycling technologies need to be further developed to meet the recycling targets. There is also active research and development activities in the field of substitution (R0) with new battery chemistries and even replacing graphite with renewable lignin-based material.

In the agri-food value chain, avoiding food loss and food waste (R0) is clearly a low hanging fruit since even one third of all food is estimated of being wasted. When it comes to circularity in the agri-food value chain, it is best supported by increasing local food production, where transport distances are short and do not create a barrier for efficient utilization of side-streams (R8, R9). The circulation of nutrients in manure is also essential.

Keywords: circular economy, R-strategies, textile, battery, agriculture, food, sustainability, drivers, barriers, business models

Contents

1. Introduction to circular economy concept

Circular economy (CE) as a concept is opposite to linear economy, which consumes natural resources and causes wastes and emissions. In a perfect circular system, products are used as long as possible, wastes are returned to raw materials, and economic growth is made possible without over exploitation of natural resources.

However, we are still far from that. The Circularity Gap Report shows that our world is only 9 per cent circular (CGRi 2022). Moreover, the Global Resources Outlook summarizes the use of natural resources (fossil fuels, biomass, metals, minerals), which is projected to more than double from 90 billion tonnes to 190 billion tonnes by 2060 (IRP 2019). Currently, the production and processing of materials, fuels, and food accounts for ca. 50 per cent of climate change impacts and more than 90 per cent of biodiversity loss.

Climate change, biodiversity loss, and overconsumption of natural resources are among the biggest global problems for which there is no single clear solution. Resolving them requires a systemic change in society. Circular economy offers an opportunity to tackle several of these challenges simultaneously. Through circularity economic prosperity can be generated within the limits of the Earth's carrying capacity by reducing the use of natural resources and creating new business models. The transition towards circular economy has only began, and there is a substantial potential in all levels of the value chains to improve circularity. This report addresses those possibilities through so-called R-strategies, i.e. circular economy (CE) strategies.

1.1. Circular economy perspectives

1.1.1. Global

Textile

The textile sector faces significant pressures to embrace circular economy, as it is currently still strongly based on linear material flows. As such, the global textile sector is the 4th highest primary material user, the 5th highest greenhouse gas emitter and 20% of water pollution arises from textile manufacturing (EEA 2022). Moreover, textile manufacturing uses significant amounts of chemicals harmful to humans and the environment, which affect the safety of consumers, workers, and products throughout the life cycle.

From a circularity viewpoint, it is notable, that the loss of non-sold products (during manufacturing, from retail and due to returns) is significant. The clothing sector is relying mainly on fast fashion trends and short product life spans (Niinimäki et al. 2020), which subsequently increase the demand for new garments. In Europe and globally, the consumption of textiles has been growing steadily, with currently about 100 billion pieces of clothing being sold each year, making it inherently difficult for the sector to become sustainable with mere technological improvements. Globally most of the materials are being either landfilled or incinerated, which means that the material value is lost for good. Only 12% of textiles are being recycled – mainly downcycled, as only 1% is being recycled to new textile materials. To address the current sustainability problems of the global textile industry, circular economy presents significant possibilities.

Battery

The climate change drives zero emission solutions and eMobility, electric vehicle (EV), sector as such as to decrease the dependence on fossil fuels. Transition to zero emission cars (General Secretariat of the Council of the EU 2022) influences the battery value chain and is going to increase the demand for raw materials for electric passenger car batteries, the battery materials, cells and battery packs and end-of-life recycling. For supporting sustainable development of this growing value chain, special attention is required to address voluntary and obligatory sustainability and circular strategies, such as use of recycled materials, extending the lifecycle of the batteries and closing the battery material loops. Battery chemistries and the need to reduce demand for battery raw materials is evolving both for improving performance of the batteries and for improving resilience regarding the raw materials criticality. Dominant type of EV batteries (lithium-ion batteries) supply chains are global ones, containing long value chains of actors starting from raw materials to batteries and finally towards recycling. Also, the complex value chains are influenced by local regulations, practices, and political conflicts.

Agri-food

In the global perspective, the issue of circularity in agri-food systems focuses to the flow of energy through the system and the circulation of elements. Energy is carried in the form of carbon compounds in food products and consumed by inhabitants while eating or decomposition of food loss. These processes return carbon to the atmosphere from where it was taken up in the photosynthesis and from where it is globally available. Energy is also used in cultivation and transport of the products and can be of biomass or fossil origin. The role of the energy used in the transportation of food products can be essential, when looking at the sustainability of the system.

In the global system where food and feed products are transported worldwide, the nutrients of the products do not return to the sites from where they were initially taken off, but to the sites where they are consumed. In the best case, in respect of circularity, they return to agricultural soils, but they can also return to other types of soils, landfills and aquatic ecosystems. Both international food and feed trade generate imbalanced nutrient flows between regions and countries, resulting in excess accumulations of nutrients in regions with net imports (Koppelmäki et al. 2021). The circularity in the agri-food value chain is best reached by combining local production with local consumption. In this way, side-streams along the whole value chain (food production, food consumption and waste management) can be used locally for production of energy and recycled fertilizers.

When looking at the use of agri-food products from the point of view of circular economy the food loss and waste in the supply chain is an important part since it has been estimated that one third of all food is lost or wasted (FAO 2011). The foremost goal is avoiding food loss and food waste and after that using biomass first for higher value-added products before finally exploiting it as an energy source. The expansion of sustainable business models in the agri-food sector is essential and needs to be based on social acceptance. In sustainable business models, stakeholder acceptance of the circular economy and mitigation strategies and political approach need to be considered.

1.1.2. National

Textile

Based on the recent study by Dahlbo et al. (2021), the Finnish textile sector is highly linked with the international markets, as 67% of the net supply of new textile products and garments in Finland are imported. Within one year, an average Finn purchased approximately 7 kg of clothes and 2 kg of household textiles; some 17% of the consumption being caused by the public sector or companies. The collection of end-of-life textiles is occurring in Finland either by charities, by waste management companies for textile recycling or as part of mixed municipal solid waste. However, much of the collected end-of-life textiles are exported, especially to countries such as Estonia, Lithuania, Oman, and Turkey.

Even though the material flows have remained relatively unchanged during the last few years, the textile and fashion industry in Finland is currently going through a transition period towards sustainability in raw materials, production processes, design, and the whole life cycle of textiles (Kamppuri et al. 2021). In the beginning of year 2023, Finland took a head start in starting the mandatory separate collection of textile waste, which is to be started in all EU member states by the year 2025 (Directive (EU) 2018/851, article 10). According to the EU directive, municipalities are responsible for organizing the collection with separate collection points for the textile waste originating from households. Companies and public organizations oversee arranging the collection of their textile waste by purchasing the service from private waste companies. Two mechanical recyclers of textile waste in Finland, Lounais-Suomen Jätehuolto and Rester, are identified as forerunners in Europe, as they function as part of a textile recycling ecosystem enabling both post-consumer and industrial waste streams to be covered in their facilities (Kamppuri 2022).

From a commercial viewpoint, industrial projects have been initiated around the production of bio-(cellulose-)based and recycled textile fibres in Finland, as well as multiple rental-, repair and second-hand stores. Furthermore, Finland has strong competencies in design, data and digitalization in the context of garments. There is a variety of on-going publicly funded research projects related to circularity of textiles (e.g. Finix, Telavalue). Since 2017, a cooperation network called Telaketju[1] has been promoting textile recycling and developing the collection, sorting, and refining processes of end-of-life textiles, as well as business models. As for the consumers, it has been found that even though most of the Finnish people are interested in sustainable fashion and aware of the sector’s negative sustainability impacts, their consumption habits are not greatly affected by these ethical and environmental factors (Federiko 2022, Vehmas 2021).

Battery

The battery sector is developing at a fast pace due to increasing market demand. In Finland, there are ongoing activities at many stages of the battery value chain, starting from mining of raw materials to battery production and batteries reuse and recycling. The state of expertise and operations seems to be largest in Finnish battery value chain in raw materials, followed

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[1] https://telaketju.turkuamk.fi/en/about-telaketju/

by expertise and operation in chemicals and compounds, as well as OEMs end users.[2] These Finnish activities are guided by the battery strategy of Finland[3] and supported by Business Finland[4] national activities in European countries are driven by new EU battery rules[5] targeting stronger sustainability, performance and labelling requirements, due diligence policy to address social and environmental risks, targets for waste collection, recycling efficiency and material recovery, and easier replacement of portable batteries.

There is active research and development in mining, current and new battery chemistries, and related recycling technologies (i.e., new battery chemistries have a crucial impact on value chains), the type of raw materials needed, and the set of competences and skills required.

Agri-food

The food self-sufficiency in Finland is high. Finland is almost self-sufficient in terms of meat, milk, and cereals (Luke 2022a). However, the agricultural production, i.e. primary production, relies still heavily on imported fossil energy and mineral fertilizers. At the same time there is a great unused potential for production of biogas and recycled fertilizer products from agricultural side-streams and underutilized biomass such as manure, grass, straw, and crop residues. Almost the entire agricultural energy consumption (2020: 9.3 TWh) could be covered by domestic biogas production from agricultural biomasses (potential in agricultural biomasses 8.8 TWh, total potential 10.2 TWh, and the annual biogas production in 2020 only 0.9 TWh) (Luke 2022b, TEM 2020). The Finnish government set a national target in March 2022 to reach 4 TWh biogas production by 2030. Simultaneously with biogas production the nutrient rich biogas plant digestate could be processed to recycled fertilizer products. It is estimated that the phosphorus content in manure alone would be sufficient to satisfy the needs of cereals and grasses in whole Finland (Ylivainio et al. 2014).

The following step after food production is food consumption. Silvennoinen et al. (2022) followed the amount of food waste in Finland between 2015–2019 and in their study the average amount of total food waste varied between 53–62 kg/cap/y and the amount of originally edible food waste between 23–28 kg/cap/y. On a national level, when extrapolating the climate impacts of edible food waste, the climate impact was ca. 0.31 Mt CO_2eq/y which corresponded driving an average of 139,000 passenger cars a year. Finland's goal is to halve food waste by 2030. Yet another goal is to increase the amount of separately collected biowaste from current 44% to 60%. Separately collected biowaste is a valuable resource for production of biogas and recycled nutrient products.

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[2] https://www.businessfinland.fi/en/for-finnish-customers/services/programs/ended-programs/smart-mobility-finland

[3] https://tem.fi/en/-/battery-strategy-to-strengthen-finland-s-position-as-a-pioneer-in-sustainable-battery-manufacturing

[4] https://www.businessfinland.fi/en/for-finnish-customers/services/programs/smart-mobility-finland

[5] https://www.europarl.europa.eu/news/en/press-room/20221205IPR60614/batteries-deal-on-new-eu-rules-for-design-production-and-waste-treatment

1.1.3. Circular economy focuses on the strategies of the research institutes

Natural Resources Institute Finland

The underlying goal of the research done by Natural Resources Institute Finland (Luke) is to support sustainable use of natural resources. In the current strategy period (2020–2025), Luke has four strategic research programs: Climate smart carbon cycle, Adaptive and resilient bioeconomy, Profitable and responsible primary production, and Circular bioeconomy. As being one of the strategic research programs, circular bioeconomy has a central role in Luke's research. Furthermore, the Circular bioeconomy program has three strategic focus areas: 1) Optimized material cycles focus area manages food waste and nutrient loss and develops recycled fertilizer products, 2) Added value and new products focus area maximizes the added value from main and side streams though innovative material use, and 3) Transition to circular bioeconomy focus area supports competitiveness and market penetration of circular economy processes and products by developing new business models. All in all, the circular bioeconomy research increases circularity to the sectoral research areas of agriculture, forestry, and fishery. Luke is governed by the Ministry of Agriculture and Forestry.

VTT Technical Research Centre of Finland

VTT's strategic purpose is to bring together people, business, science, and technology, to solve the world's biggest challenges, creating sustainable growth, jobs, and well-being. VTT researchers work for to create systemic and technological breakthroughs that bring fundamental transformation and renewal to industries and societies. VTT's ambition is to bring exponential hope to a world that needs to deal with the climate crisis, achieve resource sufficiency, drive industrial renewal, provide safety and security, and enable good life for all.

In VTT's vision, circular economy is an important step towards a sustainable economy in which material, value and information are truly integrated. VTT develops technologies, processes, and business models to suit the transition from a linear economy to a circular one and beyond. VTT's strength is the multi-disciplinary knowledge-base and a versatile research infrastructure. The raw materials, such as minerals, ores and metals, biomass, and fossil raw materials, are all very different with respect to chemical and physical characteristics. The scales of interest range from micro-level up to system-level, and therefore different viewpoints are necessary towards the realisation of their circular economy potential.

Finnish Environment Institute

The Finnish Environment Institute (SYKE) offers expertise and independent information on global phenomena such as climate change, biodiversity loss, overconsumption, pollution, and eutrophication. Apart from advancing the transition to a sustainable circular economy, as one its cornerstones, SYKE also focuses on enhancing climate change mitigation and adaptation, supporting urban areas on their way to sustainability, promoting well-being through nature-based solutions, preventing biodiversity loss, and developing new approaches for reaching a good state of the seas and inland waters. The importance of circular economy is emphasized in SYKE's organizational structure, in which one of the units focuses solely on circular economy solutions and covers circular economy related topics around policies, consumers actions, industrial value chains, waste management, hazardous substances and use of natural resources. SYKE is one of the coordinators of Circular Economy Finland (Kiertotalous-Suomi), which is a hub for circular economy expertise and information, connecting various participants of the Finnish circular economy network. SYKE is governed by the Ministry of the Environment and the Ministry of Agriculture and Forestry.

Geological Survey of Finland

In its strategy, Geological Survey of Finland (GTK) has acknowledged, and highlighted, the current situation considering battery minerals and circular economy (GTK 2020). These issues present two out of four central focus areas and are considered to have significant potential and role in the economic transition. GTK is striving to innovate new ways to enhance battery mineral exploration, increase know-how as well as to promote responsible mineral systems and business. GTK is an internationally acknowledged actor in the research field of sustainable mineral-based materials. The main objectives in the current circular economy strategy include process optimization, valorisation of raw materials, and sustainable side stream solutions.

1.2. Drivers to circular economy

1.2.1. Environmental

The current environmental concerns cover many wicked – complex and extremely hard to solve – problems such as climate change, biodiversity loss and water scarcity, which are becoming increasingly relevant on all levels of societal decision-making (IPCC 2023, Dasgupta 2021, IPBES 2019). In addition, resource scarcity, pollution, waste generation, deforestation, habitat loss, land use change, land degradation, and chemicalization are regarded as significant environmental issues requiring novel solutions and systemic changes. Since 1950, the global population has tripled to 7.5 billion and the economic output has multiplied by a factor of 12, matched by a similar increase in the use of resources (energy, water, fertilizers etc.) and consumption in general (EEA 2019). At the global scale, the use of natural resources has more than tripled since 1970 (IRP 2019). The trends visible in many sectors (see section 2.) are likely to continue to put increasing pressures on the environment.

The EU environment and climate policies have delivered benefits over recent decades, but persistent problems in areas such as biodiversity loss, resource depletion, climate change impacts, risks to ecosystems and human health are continuing. These problems require a transformation of societal systems that drive environmental and climate pressures as well as health impacts, altering technologies and production processes as well as consumption patterns and ways of living (EEA 2019). The circular economy (EC 2020a, Ellen MacArthur Foundation 2020) is currently one of the main sets of solutions mainstreamed in the EU and international policy-making with the aim at addressing these environmental concerns. In opposition to a linear make-use-waste economy, the circular economy is about reducing inputs (material, energy) and outputs (waste, emissions) in production and consumption systems.

1.2.2. Technological

Digital product passport

One of the technological initiatives enhancing circular economy is a digital product passport (DPP). The European Commission has introduced in its recent circular economy and sustainability-related policy documents DPP as a possible means for providing structured product-related information.

The DPP is an initiative that will play an important role in reaching the goals of the European Green Deal (EC 2019) by harnessing essential data to enable the circularity and sustainability of all products placed on the EU market (TAIEX 2022). In the European Green Deal, it is stated that a DPP could provide information on the origin, composition, repair and dismantling possibilities of a product and end-of-life handling. Further attributes of the DPP named by the EC-funded CIRPASS[6] project include recycled content, substances of concern, environmental footprint profile (based on LCA), classes of performance and other technical parameters. At this point of the DPP development, social attributes are often not included, as they are complex, context-specific and may rely on non-digital datasets. The DPP development has been very fast since 2019 and even though the development is highly dependent on top-down steering instruments, a large variety of bottom-up solutions have also emerged. According to Jansen et al. (2022) there are currently 76 individual corporate, policy, and research activities that exist in the context of DPP development.

As for textiles, the EC’s Textiles strategy (EC 2022a) as well as the proposed Ecodesign regulation (EC 2022b) include requirements for introducing DPPs for textiles conveying information about product-specific circularity and other key environmental aspects. Also, for batteries, the regulation of sustainable batteries, published by the EC in December 2020, includes an article concerning the battery passport, which requires that industrial batteries and electric vehicle batteries have an electronic record (battery passport) for each individual battery placed on the market.

Improved traceability would also help to solve many large problems in the food sector. The report by the World Economic Forum (2019) shows that by increasing transparency into food value chains, traceability could affect food systems in the following ways: 1) Meet consumer demand for food production transparency, 2) Further enhance the ability to identify, respond to and even prevent food safety issues, 3) Support supply-chain optimization and reduce food loss, and 4) Validate sourcing claims to support sustainability goals. Lately there has been debate in the media how difficult it is for a consumer to know the origin of fish in the food products sold in Finland (HS 2023a). Even many food retailers in Finland declared soon after beginning of the war in Ukraine that they will remove food products of Russian origin from their stores, most frozen fish products still contain fish of Russian origin after one year of war. The fish is captured in Russia but processed either in South-Korea or China and after that the origin of the fish can no longer be seen in the product.

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[6] https://www.digitaleurope.org/digital-product-passport/

Textile

Regarding textile recycling, different technologies and processes to manufacture bio-based and recycled fibres have gained much attention during the recent years. Utilizing recycled fibres e.g. from textile waste can help replacing the use of primary raw materials in textile production. Textile products consists of many different materials (cotton, polyester, blends), which is why several technologies are needed to recycle textiles to fibre level. The textile material originating from consumers and organizations can be processed via for example mechanical recycling (tearing, opening and unravelling textile structures into fibres based on physical forces), thermo-mechanical recycling (melting to polymer level to form granulates, which can be re-spun into new fibres) and chemical recycling (dissolving and spinning e.g. cellulosic natural fibres into man-made cellulosic fibres for textile production) (Heikkilä et al. 2023, Duhoux et al. 2021).

A lot of technological development related to fibre recycling and manufacturing has been occurring in Finland. There are various emerging manufacturing technologies for novel cellulose-based fibres, e.g. wood-based textile fibres (Spinnova); regenerated textile fibres from recycled cotton or wood-based cellulose carbamate (Infinited Fiber Company); and regenerated textile fibres from wood (Metsä Spring) (Kamppuri 2022). All of these technology companies have invested or are planning to invest in industrial scale fibre production, and there are many commercial collaboration activities already on-going with large textile brands, such as H&M, Bestseller and Adidas. From a sustainability point-of-view, it is difficult to assess the environmental impacts of these emerging technologies at a very early phase of technology development. However, it must be kept in mind, that they may yield varying environmental benefits when implemented.

In addition, active development of technology innovations for alternative cellulosic fibres is ongoing in Finnish companies, research centres and universities, These innovations are for example Ioncell by Aalto University (ionic liquid-based fibre spinning of ligno-cellulosic material including textile waste); Biocelsol by VTT and University of Tampere (enzyme-aided cellulose modification method for producing cellulosic textile fibres); Bio2™Textile by Fortum (production of pulp from straw for textile fibre spinning); and AaltoCellTM and Norratex by Nordic Bioproducts Group (chemical cellulose modification method for producing cellulosic textile fibres and novel process for regenerating wood-based feedstock to produce sustainable fibres) (Kamppuri 2022).

Another example of a technological driver for increasing sustainability in the textile industry is the digitalisation of fashion, enabling an alternative to “consume” clothing in an immaterial way. In digital fashion, the garments have no physical form, and therefore require no traditional raw materials, manufacturing, or logistics, which have various negative impacts. From a consumer perspective, digital fashion is changing entirely the way clothing can be bought, worn, and owned. Especially among young consumers who spend a lot of their time on different digital platforms, new technologies such as non-fungible tokens (NFTs) provide a way of purchasing luxury clothing, which have no physical form, but enable self-expression online (Joy et al. 2022). The digital clothing item can be e.g. placed on a virtual avatar or on a picture of the owner. While digital fashion provides an alternative to buying new physical clothing and contributing to fast fashion consumption, it does not occur totally without environmental impact since NFT transactions are described to be very energy-intensive and contributing to significant CO_2 emissions (see e.g. Truby et al. 2022).

Battery

In the context of batteries, electric vehicles (EV) will take the major share of lithium-ion batteries in the coming years. When batteries are reaching their end-of-life in EV applications, they can be reused or repurposed (tested, repacked, and utilized in less-demanding applications such as stationary energy storage). The economics of second-life battery storage depends on the cost of the repurposed system. To be used as stationary storage, used batteries must undergo numerous process that presently are costly and time intensive. (BCC 2022)

Recycling is seen one of the most promising end-of-life management options for batteries because it holds both economic and environmental benefits. It also assists in avoiding supply disruptions of battery materials, particularly when the recovered metals from spent batteries are reintroduced into the battery supply chain (closed-loop recycling) (BCC 2022). Recycling of end-of-life batteries includes collection and pre-treatment (which can include sorting, discharging, and dismantling of the battery packs/modules), followed by different recovery processes. Currently, pyrometallurgical and hydrometallurgical processes and their combinations are implemented at the commercial scale to recycle materials from lithium-ion batteries. (Velázquez-Martínez et al. 2019)

Agri-food

As mentioned in section 1.1.1 and described more thoroughly in section 2.1.3, circularity in agri-food value chain is different from the textile and battery value chains. Nevertheless, new technological innovations have developed the resource efficiency also within the agri-food chain e.g., Global Navigation Satellite System (GNSS) enabling precision agriculture, LED lights enabling vertical farming, and affordable renewable energy enabling cell agriculture.

In precision agriculture, spatial measurements on crop growth are connected to the data about the use of fertilizers, pesticides, or irrigation, which enables significant savings in the use of these inputs in agriculture. The technology leap enabling precision agriculture was the development of Global Navigation Satellite System (GNSS). Combined with on-line measurements, internet of things (IoT) and machine learning, precision agriculture is under continuous development and is also called as smart farming (Villa-Henriksen et al. 2020). Drones, robots and satellite images are used for identifying crop growth and diseases using computer vision techniques. The data obtained are processed and analyzed using machine learning algorithms to make farming practice more controlled and optimized (Sharma et al. 2020).

In vertical farming crops are grown indoors, in multiple layers on top of each other under artificial light. The enabler for the whole concept was the development of LED lights providing an energy efficient and adjustable lighting system (Singh et al. 2015). However, the production method remains energy intensive due to intensive light need (Kobayashi et al. 2022). The main advantages of vertical farming are smaller land requirements (many layers), and that cultivation is not dependent on weather conditions. Vertical farming also provides a way to produce fresh locally grown food to the growing population in cities with minimized logistical costs.

Cellular agriculture refers to cultivating food ingredients as a cell culture in a bioreactor. The product can be the whole cell biomass as with single cell protein or a part of it as with applications to produce synthetic milk or egg white (Nyyssölä et al. 2022). The main benefit of cellular agriculture is that food can be produced without fields. According to FAO's estimates, 60% more food is required by 2050 while only 2% more agricultural land is available, which would equal ultimately to 40% of total land area (Rischer et al. 2020, Alexandratos & Bruinsma 2012). Cellular agriculture could provide a solution for this sustainability crisis. However, the technology is very energy intensive and can be compared to power-to-X technologies. Therefore, it relies strongly on the promises of affordable and available green electricity.

1.2.3. Economic

Existing regulations and guidelines at the EU and national level create a framework for companies to promote circular economy and material efficiency through economic means such as subsidies, taxation, and interest rates. Increased prices of raw materials and direct access problems are another immediate reason pushing companies into the direction of more efficient management of materials. However, aiming towards the cascade principle, i.e. most value-added use of side-streams, does not automatically mean cost-savings. Although biomass raw materials will be an increasingly competed resource in the future, its more accurate utilization involves both processing and logistics costs. First and foremost, the endeavour towards green energy and the recent war in Ukraine have resulted in rapidly increasing costs of traffic fuels and thus logistics, which emphasizes the need to find cost-efficient logistical solutions. The easiest starting point is provided by local cooperation, but feasible solutions can also be found by combining distributed and centralized processing.

A long-term viewpoint of valuing the economic benefits of circular economy is its ability to maintain natural capital. Until today, the welfare of a country has been measured mainly with gross domestic product (GDP), which measures only the changes in produced capital. There are, however, three different types of capital: human capital, produced capital, and natural capital (Figure 1). Dasgupta (2021) summarized in his review, that globally between 1992 and 2014 produced capital per person doubled, human capital per person increased by about 13%, but the stock of natural capital per person declined by nearly 40%. Thus, what we have interpreted as economic success may have been a down payment for future failure.

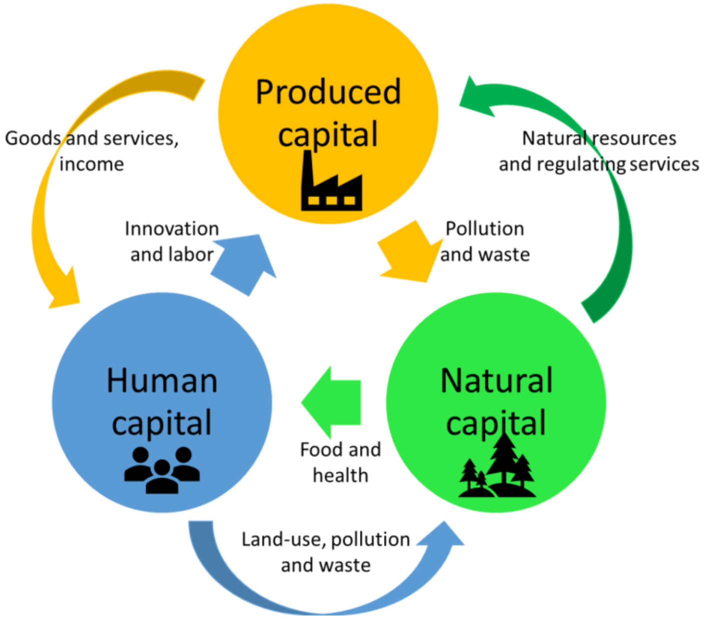

Figure 1. Interactions between the capitals (modified after Dasgupta 2021).

It is estimated that half of the world's GDP is moderately or highly dependent on nature and its services and thus exposed to risks from nature loss (World Economic Forum 2020). Especially industries doing business within construction, agriculture, and food, are very much dependent both on natural resources and ecosystem services. These industries rely on either the direct extraction of natural resources or the provision of ecosystem services such as healthy soils, clean water, pollination, and a stable climate. Therefore, not only due to the existing regulations but also to sustain their business in the future, companies should aim to resource efficiency and follow circular economy principles.

Circular economy is expected to entail financial benefits to individual enterprises as a result of retention or increase of competitiveness and resilience (e.g. McKinsey 2017) enabled by reduced supply dependence and avoidance of high and volatile prices. Sustainable supply chain and end-of life management, lower input prices and minimized environmental penalties and waste generation result in the reduction of the costs particularly in manufacturing sector (Kumar et al. 2019).

1.2.4. Political and regulatory

For the past decade, transformation towards a more circular economy has been set as a top policy priority both in the EU and in Finland (Wilts & O'Brien 2019, Kautto et al. 2021). The European Commission adopted the first Circular Economy programme in 2014. It was soon replaced by a 'more ambitious' package entitled 'Closing the loop – An EU action plan for the circular economy' (EC 2015), and in 2020 the Commission published 'A new Circular Economy Action Plan for a cleaner and more competitive Europe' (EC 2020a). While the 2015 package had the renewal of waste legislation at its core, the 2020 CE Action Plan presents a new beginning for sustainable product policies proposing more than 30 policy measures. In the promotion of circular economy, EU Trade policy (EC 2021) has an important role. This policy aims to support "the recovery and fundamental transformation of the EU economy in line with its green and digital objectives" and environmental sustainability. The implementation of circular economy practices is expected to increase the resilience, self-sufficiency and competitiveness within EU and nationally, and consequently, also strengthen the EU's economy which is the core objective of Trade policy.

In Finland, the Government has recently approved an ambitious CE vision, according to which 'a carbon-neutral circular economy is the foundation of our successful economy' by 2035 (Finnish Government 2021). The Finnish government has set the following objectives[7]:

- The consumption of non-renewable natural resources will decrease, and the sustainable use of renewable natural resources may increase to the extent that the total consumption of primary raw materials in Finland in 2035 will not exceed what it was in 2015. The natural resources used to manufacture exported products are not covered by the objective.
- The profitability of resources will double by 2035 from what it was in 2015.
- The circular economy rate of materials will double by 2035. (Finnish Government 2021)

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[7] Similar kind of quantitative objectives have been set by several other countries such as the Netherlands, Germany, and Japan.

The policy makers in Finland and in the EU thus widely share the aim of circularity transformation. The value of the global market supporting circular economy has been estimated in hundreds of billions of euros. Circular economy, together with technological progress, is seen to provide Europe an opportunity to improve resource productivity by up to three per cent per year and an increase of GDP by around 0.5 per cent by 2030. Also in Finland, strengthening of the circular economy market is likely to have a significant positive impact on the economy in the long term. However, far less clear what the means of such a systemic transformation towards circularity are (Finnish Government 2021, EC 2015, EC 2020a, Gregson et al. 2015, Lazarevic et al. 2022). So far, numerous policy instruments have been adopted to promote more sustainable resource use, including areas of waste, product and chemicals policy. However, these are often scattered, weak and disproportionately divided along economic sectors. Though reducing the use of natural resources and extending product lifetimes have been top aims of the circular economy programmes, existing measures are mostly targeted at recycling side streams and waste into new raw materials. (Kautto & Lazarevic 2020).

To answer the sustainability challenges of textiles, the EU is seeking ways to create more sustainable practises in the industry, also supporting circular economy. The European Commission has set an EU Strategy for Sustainable and Circular Textiles, with a vision that states:

"By 2030 textile products placed on the EU market are long-lived and recyclable, to a great extent made of recycled fibres, free of hazardous substances and produced in respect of social rights and the environment. Consumers benefit longer from high quality affordable textiles, fast fashion is out of fashion, and economically profitable re-use and repair services are widely available. In a competitive, resilient and innovative textiles sector, producers take responsibility for their products along the value chain, including when they become waste. The circular textiles ecosystem is thriving, driven by sufficient capacities for innovative fibre-to-fibre recycling, while the incineration and landfilling of textiles is reduced to the minimum." (EC 2022a)

The strategy introduces for example mandatory ecodesign requirements, banning the destruction of unsold products, tackling the microplastics pollution, information requirements and a DPP to enhance communication between actors in the value chains, setting a minimum criterion for environmental claims of textiles, extension of producer responsibility and boosting reuse and recycling of textile waste (EC 2022a). The strategy sets pressure for textile companies and fashion brands to actively seek more sustainable operation and business models. In addition, the mandatory separate collection of textile waste should be started in all EU member states by the year 2025 (Directive (EU) 2018/851, article 10).

The European Commission (EC 2020b) has proposed a new Batteries Regulation which aims to modernize the EU's legislative framework for batteries being an integral part of the European Green Deal and the first initiative of the European Commission on the Circular Economy Action Plan. This proposal builds upon the existing Battery Directive 2006/66/EC and will replace it. The revised Battery Directive aims to ensure that batteries placed in the EU market are sustainable and safe throughout their entire life cycle by establishing mandatory requirements for batteries. These requirements include e.g. restrictions on hazardous substance use, mandatory recycled content targets, performance and durability parameters, and end-of-life management requirements and carbon footprint declaration.

In the core of the European Green Deal, the Farm to Fork strategy (EC 2020c) addresses the challenges of sustainable food systems and recognizes the links between healthy people, healthy societies and a healthy planet. Even though the EU's transition to sustainability in food production has started in many areas, food systems remain one of the key drivers of climate change and environmental degradation. Therefore, there is an urgent need to reduce the dependency on pesticides and antimicrobials, reduce excess fertilization, increase organic farming, improve animal welfare, and reverse biodiversity loss.

In terms of sustainability of food systems, circular bioeconomy is a largely untapped potential for farmers and their co-operatives. Advanced bio-refineries producing biofertilizers, protein feed, bioenergy and biochemicals offer opportunities for the transition to a climate-neutral European economy and creation of jobs in primary production. For the reduction of methane emissions from livestock, biogas can be produced from agricultural wastes, like manure, in anaerobic digesters. Farms also have the potential to produce biogas from other sources of waste and residues, such as from the food and beverage industry, sewage, wastewater, and municipal waste.

Another major issue in achieving better sustainability in food systems is tackling food loss and waste. Reduction of food waste brings savings both to the operators in food chain and consumers. Moreover, the recovery and redistribution of surplus food that would otherwise be wasted has an important social dimension.

1.2.5. Social and informational

The emerging circular solutions are expected to increase the competitiveness of the national and European industry and create more jobs. According to the estimate of the Club of Rome, full adoption of a circular economy would create more than 75,000 jobs in Finland (Wijkman & Skånberg 2016). Hence increased employment can be seen as one of the drivers to circular economy. However, at the same time, some economic sectors, such as mining of ores and manufacture of basic iron and steel, have been shown to experience significant employment losses (ILO 2018). On the other hand, the measures that enable the transition, i.e., material efficiency, waste recycling and reuse, industrial ecology, energy efficiency, renewable energy, and green procurement, result in positive net benefits in job creation as being relatively labour-intensive (Echeverría et al. 2020).

There are many social factors that can affect the behaviour of companies and consumers. Nowadays many enterprises acknowledge the importance of positive company image that can be attained by social responsibility through the operations (e.g. Galbreath 2010). Here, the compliance with circular economy principles can be one of the key elements that generally has positive environmental consequences due to reduction of waste and use of virgin natural resources. In addition, circular economy is expected to entail other benefits to enterprises such as, retention or increase of competitiveness that brings about financial gain, and resilience (e.g. McKinsey 2017).

Consumers play a key role in the value chain of many products, e.g., textiles and food. Several social factors affect human consumption habits. Human beings generally have a strong need for communality and therefore, social and cultural norms and collective behaviour have been identified as important factors affecting their purchasing and consumption habits (e.g. Melnyk et al. 2022) as well as their waste recycling activity (Thomas and Sharp 2013). Environmental product labels can be an effective means to direct the consumer purchasing behaviour to desired direction since several studies show that most consumers would prioritize products that have an ecolabel (Moser 2015, Liu et al. 2017).

Platforms, and other information sharing and management systems, are largely based on open collaboration and communication and have been identified as important drivers to companies' circular economy measures (Uusitalo et al. 2020).

1.3. Barriers to circular economy

Corvellec et al. (2022) brought up practical difficulties to circular economy when connecting waste streams to production and substituting primary raw materials with secondary raw materials. In the global market, products are manufactured, purchased, disposed, and recycled in different geographic locations. Efficient recycling would thus lead to vast transfers of resources across the globe. Also, substantial amounts of consumed materials are stocked in homes, companies, and infrastructures. And even when received for recycling, the yield in recycling processes is never 100% and the wearing down of materials sets limitations in material properties.

The complexity and interrelationships prevailing in the environment can create a barrier to the implementation of circular economy. It has been acknowledged that circularity does not always result in environmental sustainability, however it increases supply security. Circular solutions can result in shifting the environmental problems since its implementation can cause for example, emissions arising from transports and processing of wastes, increased water footprint, loss of habitat (increased use forests as renewable resources). Hence, it is important to adopt a holistic, system wide approach in the environmental assessments of circular product systems. Currently such assessments are difficult to carry out due to the lack information on the actual absorptive capacity of the planet and resource intensity of service-based economy, among others (Velenturf & Purnell 2021). Moreover, the design of circular, sustainable value chains requires data on the expected life cycle impacts within the chain. Usually not all required data is available, or it might be in an unsuitable form. The competitive positioning of companies creates a barrier to opening data if there is no clear benefit from this action.

The lack of information on products' environmental footprint contributes to the consumers' attitudes and hence, their behavior. For example, the absence of labelling information has been identified as a barrier for purchasing organic food (Aitken et al. 2020). On the other hand, some studies show that emotions rather than rational information are more important contributors as regards to decisions on purchasing (e.g. Koenig-Lewis et al. 2014). Currently, the number of different environmental labels and certificates totals 456 in 199 countries and 25 industry sectors.[8] The vast number of different markings can in fact reduce their credibility and consequently, create a barrier to consumers' desirable purchasing behavior.

Concerning the food value chain, the use of plastics in food packaging has traditionally been justified by the longer shelf life (e.g. Shrivastava et al. 2022). Hence, the objective of reducing the use of single-use plastics in food packaging would conflict the objective of reducing food

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[8] https://www.ecolabelindex.com/, as of December 2022

loss. However, another recent study shows that single-use plastics packaging increases food waste (WRAP 2022).

Particularly in the sparsely populated areas in Finland, long transport distances and fragmentation of operations create a barrier to the implementation of circular systems. These together with low volumes can also make sort separation of recyclables unprofitable as well as environmentally unfavourable. Moreover, regarding agri-food value chains, it is worth recognizing that primary production and food processing is mainly focused on certain areas while consumption focuses on densely populated urban areas. Hence, the need of nutrients and generation of nutrient rich wastes do not meet spatially, meaning that implementation of recycling requires increased transportation which leads to increased environmental footprint. Yet, import of food items from outside Finland adds on this problem.

The implementation of circular economy can be aggravated by some institutional and regulatory barriers. The lack of a consistent regulatory framework is frequently mentioned as a significant barrier and different regulations can be obstructing (e.g. Hart et al. 2019). For example, strict environmental criteria for waste to be recycled can prevent its utilization.

The policies that support the production of biofuels and bioenergy from organic waste effectively prevent the development of and investment to other circularity-based solutions (Keegan et al. 2013). These policies may also aim at developing rural areas by supporting agriculture through the generation of alternative revenue streams. According to Valve et al. (2020), in the agri-food value chain, the transition to the circular nutrient economy still calls for policy measures that restrict inefficient nutrient use, generate demand for recycled fertilizers, and support biomass processing.

Legislation governing the environment is fragmented both horizontally (between sectors) and vertically (between levels of government). The necessary mechanisms for coordination have also been lacking (e.g. van Asselt 2012). Fragmented regulation creates conflicts over potentially overlapping jurisdictions and incompatible rules (Medvedieva et al. 2018). These may lead to inequality in authorization and permit processes as well as conflicting norms, standards and decisions that are not accordant with the circular economy principle.

Moreover, lack of incentives, has been identified as one significant barrier to circular economy (e.g. Hart et al. 2019, Uusitalo et al. 2020). Design (of processes, products, services) has been acknowledged to have a major contribution to the total, over the lifetime extending environmental footprint of the final outcome (EC 2020a). However, so far the mechanisms directing companies towards sustainable, circular solutions have been mainly voluntary, such as ecodesign and Design for the Environment (DfE) guidance. Furthermore, while these voluntary instruments stress recyclability and minimization of waste, so far they do not specifically consider the use of secondary raw materials. It is worth noting that EU is planning to establish mandatory ecodesign requirements for textiles (see also chapter 1.2.4).

Search for the solutions to implement circular economy seems to be still rather technology driven. While economic factors are also considered, it can be difficult to predict the social factors that may hinder the practical adoption of the new circular solutions. Poor public acceptance of circular products and services is one of such barriers, which should be identified in the very early stage of planning.

While the circular economy concept dates back to several decades, the potential cumulation of hazardous substances along with its implementation has been acknowledged only recently. Currently, the allowable levels of contaminants in waste are typically regulated in relation to its mass rather than its content of valuable resources, meaning that the regulations focus on reducing the release of hazardous substances rather than promoting resource circulation (Johansson & Krook 2021). At the same time, the global market makes it difficult to manage the contaminants in the whole value chain. For example, even though the most harmful chemicals in textiles are restricted at the EU level, some of these, e.g. dyes and flame retardants, can still be found in textile waste due to continuing use in other countries (e.g. China, India, Bangladesh, Indonesia), which are the main manufacturers of fabrics and garments (e.g. Freire et al. 2019, Gulati et al. 2022). Any harmful substances that might pose unacceptable risks to humans or the environment need to be managed properly in circular systems. This requires technology, incurs costs, and can generate hazardous waste, which needs to be further treated safely. The fact that fabrics used in garments are very often blends creates an additional problem since, the separation of different fibres for recycling generally requires the use of solvents, which can be harmful.

1.4. Structuring circular economy through R-strategies

Circular strategies, also known as R-strategies, take a step forward from the waste hierarchy. While the waste hierarchy aims to increase the use of wastes and side-streams in the best possible way (through prevention, re-use, recycling, recovery, and disposal as the ultimately final option), circular economy starts already at the design phase by designing products so that waste and pollution are eliminated, and products and materials are circulated at their highest value.

R-strategies can be classified under three approaches (Figure 2):

- smarter product use and manufacture (R0 Refuse, R1 Rethink, R2 Reduce),
- life extension strategies (R3 Reuse, R4 Repair, R5 Refurbish, R6 Remanufacture, R7 Repurpose)
- creative material application (R8 Recycle, R9 Recover)

The environmental benefits of R-strategies vary among the different approaches (Horn et al. 2023, Potting et al. 2017). Often, the highest degree of circularity, lowest use of resources and caused emissions comes through refusing to purchase new products and smarter product use and manufacture, while life extension strategies are considered the second-best option, and creative material application the last option. The gained environmental benefits are, however, always case specific depending on the use of raw materials and energy, the complexity of product design, recycling technologies, and the presence and accumulation of hazardous materials, among other things. Therefore, also the selection of the R-strategy resulting in lowest environmental impact should be based on analytical work e.g. by using life cycle assessment (LCA). The concurrent use of several R-strategies during a product’s life cycle (e.g. using recycled materials, implementing efficient production technologies and reuse models, after which the product can still be repurposed) is able to accumulate environmental benefits even further.

In this report, the suitability and benefits of the various R-strategies, as well as examples of these, are given for the textile, battery, and agri-food value chains.

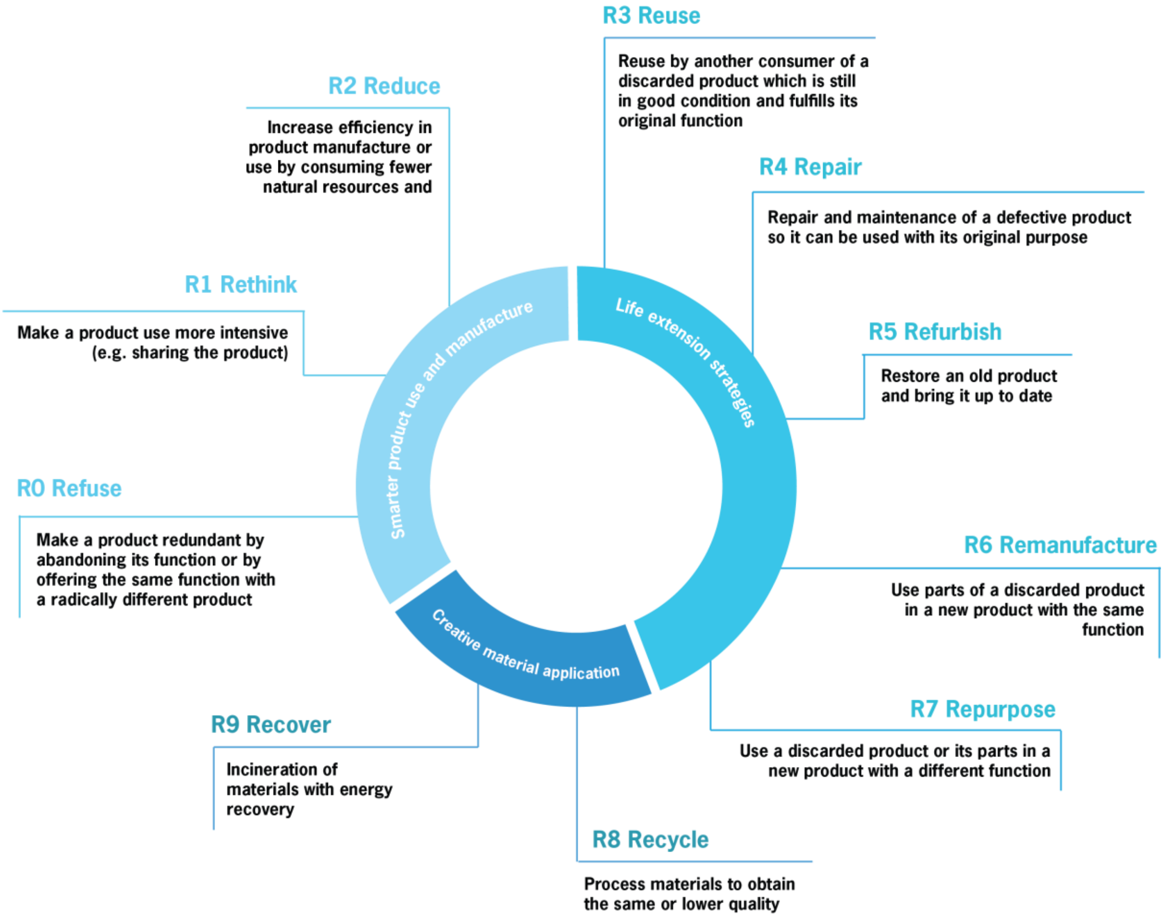

Figure 2. R-strategies offer a framework to design circular materials, products, business models and value chains. (Kivikytö-Reponen et al. 2022, modified after Potting et al. 2017).

2. Applying R-strategies for chosen value chains

2.1. Value chain descriptions

2.1.1. Textile value chain

The textile value chains are complex and scattered in different parts of the world, including different stages and actors. The currently dominant value chain is based on a linear supply chain, focusing on efficiency and volume to serve the growing demand for garments. In their current form, the global textile value chains are unsustainable, due to enormous production volumes, short life cycles and the large amounts of textile waste (Mellick et al. 2021). Generally, the stages of a linear textile value chain include the following phases: obtaining and processing raw materials (e.g. bast, leaf, seed, synthetic, animal fibres); fibre spinning; design; manufacturing of fabrics and garments; distribution; retail; use; and end of life (incineration/landfill or recycling) (Karthik & Gopalakrishnan 2014). It has been estimated, that only about 1% of end-of-life textiles are recycled back into new fibres (Ellen MacArthur Foundation 2017).

The circular value chain of the textile industry, which has been in the focus of much research and development during the recent years, has been suggested to offer a more sustainable alternative. It highlights closing the loop by minimizing the amount of textile material going to waste (incineration/landfill) and emphasises intensifying the use phase (increasing the use times and repairs, while reducing over-washing and tumble drying), circular design, and sustainable manufacturing from recycled materials (Figure 3).

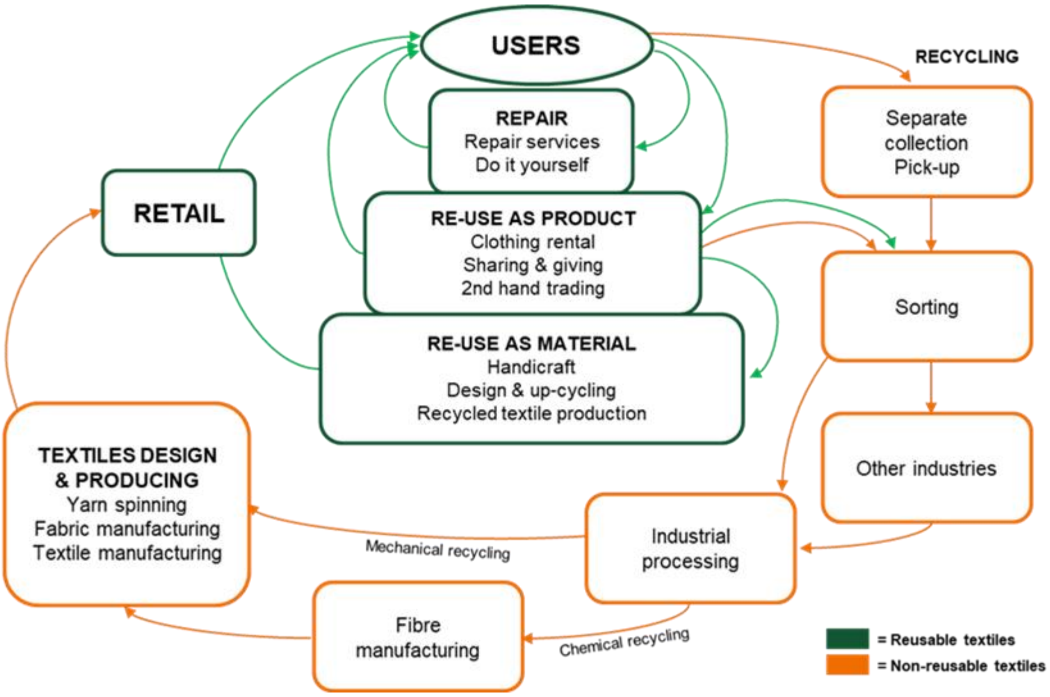

Figure 3. Circular textile ecosystem (modified after Fontell & Heikkilä 2017).

The R-strategies introduced by Potting et al. (2017) are at the core of the circular textile ecosystem and can be seen to add value to all life cycle stages; also generating new business models (Coscieme et al. 2022). Particularly the R-strategies related to circular design, service-based models, sharing, re-use and recycling are applicable in the textile industry (Heikkilä et al. 2021). How the R-strategies are implemented in the context of textiles are presented with examples in chapter 2.2.

2.1.2. Battery value chain

The current battery value chain in Finland is on the development phase, and therefore it is particularly important to pay attention to circularity of this stage (Figure 4). Raw material producers are in the beginning of the value chain, including mines that provide battery mineral ores (nickel, cobalt, copper, lithium, graphite) and processing plants that produce mineral concentrates. Concentrates are further processed into battery chemicals such as nickel sulphate, cobalt sulphate, and lithium hydroxide. These metal salts are the main ingredients in precursor cathode-active materials (pCAM) that are further processed into cathode-active materials (CAM). Then battery cells are produced from cathode and anode materials, electrolytes, and separators. These cells are then assembled by manufacturers into battery packs and integrated into battery management systems. The batteries find their first life in various solutions such as consumer electronics, electric vehicles and as part of energy storage solutions. As the battery product has served its purpose, it may be suitable for a 2nd life application in other solutions, even with decreased performance expectations. In the end of the value chain, used batteries are collected, sorted, and dismantled, and recycled. Depending on the components and their usability, they may be circulated to manufacture of the same product or used for other purposes.

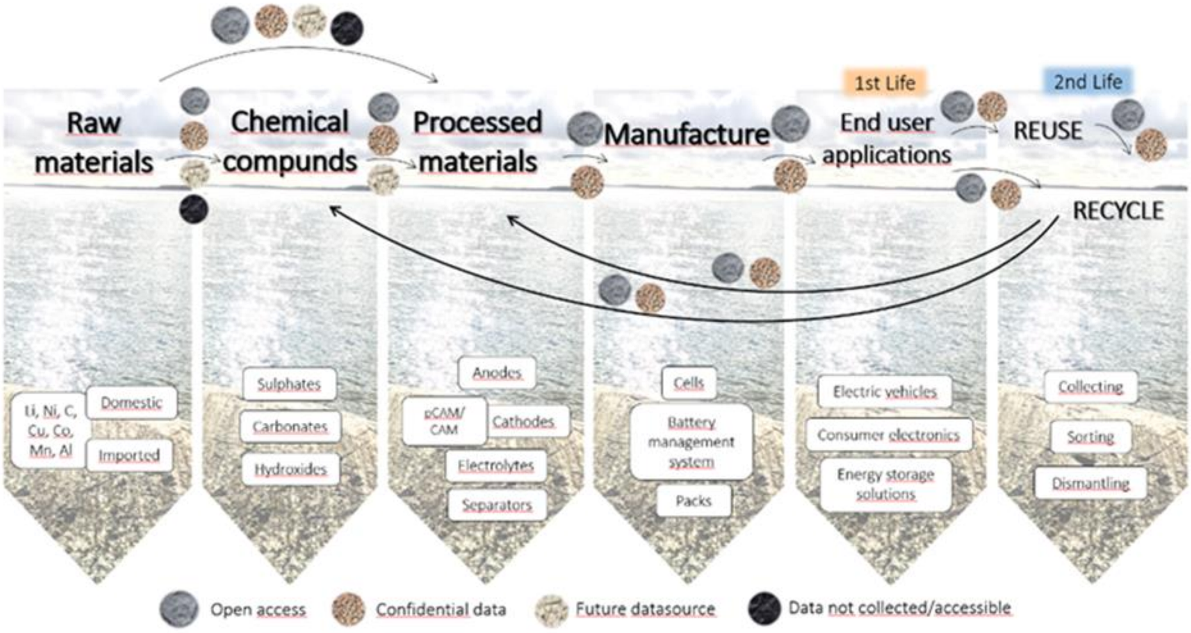

Figure 4. The developing battery value chain in Finland (modified after Kauppila et al 2022).

Applying the R-strategies to the battery value chain, it is possible to optimize material use and circulation and simultaneously the environmental impact of battery production can be reduced. R-strategies are examples of reducing waste in the raw material production, supporting product unification, and sharing, and encouraging the use of recycled materials in manufacturing. R's that apply especially well to the current needs also consider reuse and repair, resulting in prolonging the life of batteries, and generating the information about the state of health of batteries.

2.1.3. Agri-food value chain

Agri-food value chain is not only one value chain, but more like subsequent steps within the food-system (Figure 5). Soil regeneration refers to maintaining the soil structure and fertility by restoring the soil organic matter and nutrient content as well as controlling the acidity through lime application. Agriculture refers to primary production providing end products such as meat, cereals, legumes, vegetables, and fruits. These are then further processed to various food products (food industry), and transported to shops, restaurants, and households (retail, consumption). Finally, food- and biowaste is collected, and treated by composting or used in biogas production. Some biowaste is even incinerated as part of the municipal mixed waste.

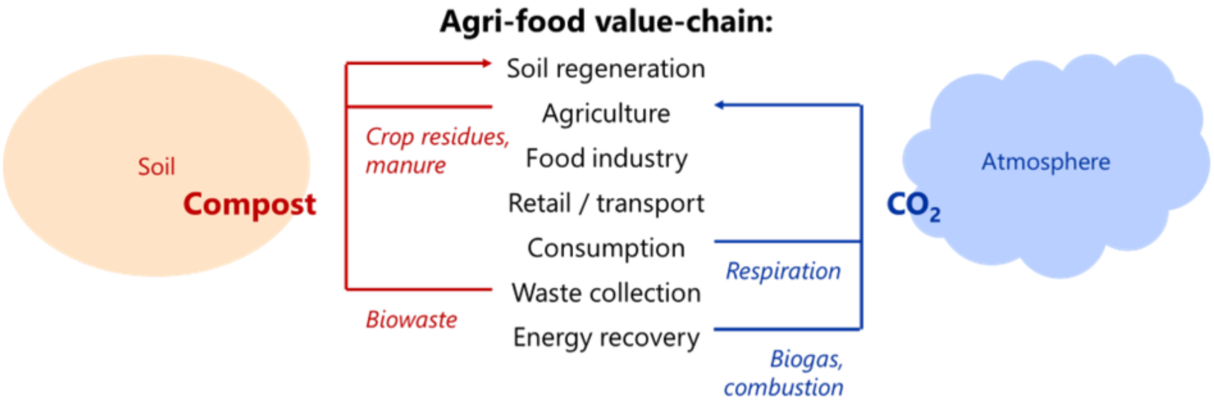

Figure 5. Simplified description of the subsequent steps within the food system modelling an agri-food value chain.

The material cannot be recycled in the same way in the agri-food value chain, as it is recycled in textile or battery value chain. The carbon is circulating mainly through atmospheric route (CO_2) after being consumed, used for biogas production, or burned for energy. Part of the carbon is left in the compost or digestate from the biogas process and circulating back to the soil in the form of soil amendment (Figure 5).

Other compounds circulating within the food-system are nutrients. Similarly to carbon, also nitrogen is mainly circulating through atmospheric route (N2) and partly bound to compost or digestate. Phosphorus (P) is either circulating in the food-system bound to manure, compost or digestate, or it can be leached out from soil to water system where it is finally sedimented in the bottom of lakes and the Baltic Sea, but before that causing eutrophication.

Finally, even packaging materials are involved in the food system and play a key role in delivery and protecting food from spoilage and thus minimizing food loss and food waste.

2.2. R-strategies in value chains and business models

Reviewing the textile, battery, and agri-food value chains through the R-strategies can be used to map the strengths and weaknesses and to perceive which parts have already been assessed and which parts require more attention.

2.2.1. R-strategies in the textile value chain

R0 Refuse

Refusing to buy unnecessary products, minimizing collections and rethinking the form of fashion

Depending on the actor at hand, the refuse strategy can be implemented on various levels. For instance, the consumer may refuse to buy unnecessary products, the brand owners may create slower fashion, i.e. fewer collections in the fashion industry and focus on timeless design, in which case the need and supply for textile products is reduced (see e.g. Sasta). The form of products may also be digital, instead of physical, by creating exclusive virtual garments to trade and wear in the metaverse, as a way of expressing oneself. These digital collections do not require manufacturing of physical products (Muller et al. 2022) (see e.g. Fabricant).

R1 Rethink

Sharing, buying textiles-as-a-service and increasing modularity in textile products

To make product use more efficient, textile products may be shared, leased or rented (see e.g. Mudjeans and clothing libraries, such as Vaatepuu). Textile-as-a-service models are also used in the workwear sector, where the ownership of textiles remains with the provider, who takes care of the maintenance and recycling of used textiles (see e.g. Touchpoint, Lindström, Image Wear, Fristads). Textile products can also be created with multi-functional design, where one garment can be transferred to various different forms (see e.g. Vietto).

R2 Reduce

Efficiency in production and use: digitalization, zero-waste targets, recycled and bio-based content, user efficiency improvements

To reduce resource use during the entire life cycle of a textile, both production and use phases can be considered. As for production phases, processes can be optimized via digital tools, but also other lean manufacturing methods, and bio-based materials may be applied (see e.g. Spinnova, Ioncell). Also utilizing production side streams in clothing manufacturing creates efficiency in material use (see e.g. Purewaste). In addition, it is important to consider material losses during manufacturing and losses of unsold products at retail or online shops (e.g. returned products). Also, the reduction of resource consumption during use may be improved by reducing unnecessary washing and drying and

	increasing energy, chemical and water efficiency during washing and drying.
R3 Re-use	**Reuse, 2nd hand retail and platforms** Reuse of used, but intact textiles by other consumers may be increased by handing over textiles directly from one consumer to another, by donating clothes to charity, or by reselling them. Handing over clothing occurs often through unofficial and unstructured routes within families or friends. For donating clothes there are several platforms (see e.g. Kierrätyskeskus/Reuse Center, Fida secondhand). As for resale, there are options for direct resale either online[9] or via flea markets[10], in addition to businesses purchasing and selling used clothes[11]. Recently, clothing brands have also created their own 2nd hand online stores (see e.g. Marimekko Pre-loved).
R4 Repair	**Clothing repair services and platforms, DIY kits** The repair of defective textile products enables longer use times of clothing. Depending on the textile or garment type, there are different parts of the product that may break down, such as zippers, buttons, seams, or the textile material, all of which require different type of repairing. There are various repair sewing shops that offer repair services for clothing. In some cases, also clothing brands repair broken products either free-of-charge or for a certain fee (depending on the age of the product, see e.g. Sasta or Patagonia). There are also DIY kits available for purchase to support effortless repair (e.g., Fabpatch), as well as NGOs dedicated to educating the public in matters of home economics (e.g., Martha Organisation).
R5 Refurbish	**Refashioning of clothing** One of the typical reasons for consumers to discard old textiles, mainly garments, is due to being outdated, out of fashion, wrong size or simply bored with certain features of the product. In these cases, refashioning these items by dying, resewing, refitting or adding new materials of feature to the product, may increase the use phase. In many cases, repair sewing shops offer refashioning services alongside traditional repair services (see e.g. Ompelimo Caava). Sometimes also second-hand shops (e.g. Kierrätyskeskus/Reuse Center Plan B) offer refurbishing of the old products.

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[9] https://www.tori.fi/

[10] https://www.kirpputorihaku.com/

[11] https://emmystore.com

R6 Remanufacture **Utilizing existing fabrics for new textile products**

Remanufactured fashion is defined as fashion clothing that is constructed by using reclaimed fabrics, which can either be post-industrial or post-consumer waste, or a combination of both (Dissanayake & Sinha 2015). These can cover e.g. patchwork, dying or reusing the textile material in a disassembled manner to produce new textile products (e.g. Globe Hope, Pure Waste).

R7 Repurpose **Using discarded products or parts for new products**

There are two ways how to implement these in textile products; either using non-textile product, such as plastic bottles, as raw materials for textile products, or using a discarded textile item in a different function, for example recycled textile fibres in building insulation, rags or carpet padding. Excess textile material from e.g. manufacturing of upholstery can also be used for creating new textile products (see e.g. Lovia). The main idea is that the purpose of the product or material is changed.

R8 Recycle **Textile waste recycling for new textile fibres**

Discarded textiles, i.e. textiles that cannot be utilized in the above described ways can be directed to recycling via the separate collection of textiles (mandatory in the EU from the year 2025). The textiles are sorted and can be processed for example via mechanical, thermo-mechanical and chemical recycling processes (see e.g. Rester, Lounais-Suomen Jätehuolto, Infinited Fiber Company). The input for the process can be for example pre-consumer waste (e.g. side streams of production) or post-consumer waste (end-of-life textiles of consumers). The purpose is to process the materials so, that they can further be utilized in different applications. The less different fibre types there are included in the product or material to be recycled, the easier the recycling is. Textile waste recycled for fibres can be utilized in clothing, or in lower grade products, such as composites.

R9 Recover **Incineration**

Incinerating the textile materials and recovering them for energy is the least favorable option from a value retention perspective. Incinerating municipal solid waste may substitute for fossil energy, but as for any incineration process, causes emissions and loses the value of the material for good. According to Dahlbo et al. (2021), approximately 60% of all end-of-life textiles in Finland were recovered as energy through incineration in 2019.

2.2.2. R-strategies in the battery value chain

R0 Refuse **Virgin mineral raw materials and mine waste**

Recycled raw material components have been suggested to be used instead of virgin raw materials. Depletion and unsustainability of virgin raw materials are acknowledged issues, therefore, the sole use of them should be avoided and other alternatives developed. Alternatives include e.g., replacing current metal-based cathode materials with salt (Broadbit 2022) or plastic based components as well as anode and electrolyte substitutions with biobased materials. Graphite can be substituted with lignin-based materials (Stora Enso 2022).

Zero residue targets are aiming to find useful purposes for all the materials excavated during the mining of battery minerals.

R1 Rethink **Traceability and collective use of rechargeable batteries**

Unification of charger and battery types are a growing trend which enables multiuse of products instead of individual purchases. Leasing of batteries as well as swapping points are integrating into everyday life (Gogoro 2022, Tier 2022). Responsible production and use of raw materials is controlled with battery passports that enable tracing of the origins in a digital form. Traceability can be extended all the way to recycling.

R2 Reduce **Recycled raw materials and effective production**

Reduction of new materials is achieved by increased recovery and recycling of metals and other raw materials. Battery legislation is working on targets for minimum recycled contents in the active materials.

Production costs are reduced with concentrated production facilities and gigafactory models are increasing (EnergyVaasa 2022).

R3 Re-use **2nd life applications and conversions**

Batteries that have served their designated time can be used further for other purposes. There is a market for 2nd life products e.g., as energy storage solutions from electric car batteries (Cactos 2022). Used batteries can be converted into battery packs which extend their life span. 2nd life applications are increasing and even 3rd life applications have been discussed (Kravee 2023).

Legislation has set targets for collection rates including portable batteries (70%) and spent batteries from EV's (100%) by 2030.

R4 Repair	**Maintenance and optimization** Disposable batteries are superseded by rechargeable versions increasingly. New batteries are designed for longer life span through part replacement, maintenance plans and repairs. They are coupled with sensors that monitor optimal usage rates and optimized charging. Overall maintenance and appropriate use are key factors for battery R&D.
R5 Refurbish	**Remining and restoration** Developing the re-enrichment of residues and mine tailings that were enriched decades ago with insufficient methods. With current technologies these tailings can produce a yield competitive with virgin mines (Otanmäki Mine 2022). Current technologies can even extract several types of valuables while previous methods enabled mobilization of only one valuable material. Restoration of used batteries plays an important role in the ever-growing battery market.
R6 Remanufacture	**Partial reuse** As different parts included in a battery product age/wear in a different rate, viable parts can be used in the manufacture of new products. Casings and other parts not under stress/depletion can be used to host new components while battery metals and other raw materials can be collected and recycled to new components.
R7 Repurpose	**Benefitting food production and construction industry** Collected usable components can be used as raw materials for new products, e.g., nutrients from end-of-life alkali batteries in fertilizers (Tracegrow 2021). Side streams and tailings are usable as base materials for construction industry, CO_2 binding or mine fill paste. Recovered metals can be used in other products. Legislation calls for product responsibility for 2nd life batteries and has set requirements for their production.
R8 Recycle/R9 Recover	**Dismantling and material recovery** Dismantling of discarded batteries and recycling the battery parts play a significant role in the circularity of battery products. Legislation sets targets for material recovery (90% Co, Ni, Cu & 35% Li) by 2025. Also 65% of spent batteries must be recycled. Dismantling and recycling is already ongoing in the battery industry, e.g., Valmet Automotive production surplus is recycled by Fortum.

2.2.3. R-strategies in the agri-food value chain

Six R-strategies: R0 Refuse, R1 Rethink, R2 Reduce, R3 Reuse, R8 Recycle, R9 Recover, were considered more important than the others in the agri-food value chain and thus discussed below more in detail.[12]

R0 Refuse	**Refusing of defined practices**, i.e. abandoning or redirecting of certain practices, which have been recognized detrimental or destructive from the standpoint of ecological, economical, or social sustainability. Examples: Relocation of resource demanding production to resources abundant regions, e.g. when considering water consumption, redirecting water intensive agriculture away from those areas dependent on irrigation. Avoiding land use change in areas important for maintaining ecosystem services, e.g. replacing soy produced in rain forest area by domestic faba beans and other protein rich plants to feed cattle. Cellular agriculture for single cell protein production (food without fields). A future driver for cellular agriculture could be aspiration to increase forest area for GHG adsorption; in that case surplus agricultural land could be reforested. Company examples: Solar Foods[13], Onego Bio[14]. Dietary changes to intensify resource efficiency, e.g. meat is replaced by plant-based protein rich products. By using directly plant-based protein for food, the production efficiency is increased along the value chain. Avoiding overpackaging and/or replacing virgin packaging materials with recycled materials.
R1 Rethink	**Make product/resource use more intensive** Rethinking agricultural practices: vertical farming. Company examples: Evergreen Farm[15], Netled[16], Robbes Lilla Trädgård, Kerava Garden.

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[12] These six R-strategies were also discussed in a researcher workshop organized in Teams 24.10.2022. Altogether 31 researchers participated from three research institutes: Natural Resources Institute Finland (Luke), VTT Technical Research Centre of Finland, and Finnish Environment Institute (SYKE).

[13] https://solarfoods.com/

[14] https://www.onego.bio/

[15] https://www.evergreenfarm.eu/

[16] https://netled.fi/

Rethinking input needs versus nutritional quality: questioning energy intensive greenhouse production of vegetables with low nutritional content.

Rethinking quality demands: sensory evaluation what is still edible versus best before dates, acceptance of funny formed vegetables, eating broccoli stems/leaves.

Rethinking use of side-streams: how to recover side-streams with as high quality as possible for further value-added use, e.g. by source-separation and waste collection vehicles with many compartments.

R2 Reduce

Increase efficiency in product manufacturing or use by consuming fewer resources and materials.

Reducing food loss and food waste (role of digitalization and open data). Education and motivating consumers and making the price of food waste visible are potential means to reduce food waste, size and design of packaging also has a crucial role. Food loss could be reduced by proper packaging solutions and planning of purchase and logistics systems as well as open data on the consumption patterns in time. Example: Relex supply chain & retail planning platform[17], guidance for households[18], and for hotel/restaurant/catering -sector[19].

Savings in the use of fertilizers and pesticides (precision agriculture, integrated pest management), use of biopesticides and recycled fertilizers based on side-streams and waste materials instead of current mineral-based man-made fertilizers.

Savings in energy use (optimizing processing, storage and transports) and using renewable energy sources.

Reducing transport distances (favoring local food production).

Optimizing logistics (timetables, packaging systems): role of real-time digital applications.

Reduction of packaging (use of material, size of packaging) and using recycled or renewable packaging materials.

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[17] https://www.relexsolutions.com/

[18] https://www.pauliggroup.com/fi/vastuullisuus/ruokahavikkilaskuri

[19] https://projects.luke.fi/ravintolafoorumi/pajatso/

R3 Reuse	**Re-use by another consumer of discarded product which is still in good condition and fulfils its original function** Selling left-over food for new customers. Company example: ResQ App[20]. Re-using food packaging. Company example: Kamupak[21].
R4 Repair/R5 Refurbish	**Repair/Restore an old product and bring it up to date** Food is used for similar food with slight improvements, e.g. using leftovers for next day's dish.
R6 Remanufacture/R7 Repurpose	**Use discarded product or its parts in a new product with the same or a different function** Food is used as raw material for a new food product: Old bread is used to produce beer, company examples: Sinebrychoff, Teerenpeli. Brewer's spent grain is used to produce bread, company examples: Leipomo Väyrynen, Pulla-Pojat. Ripe bananas are used to produce ice-cream, company example: Suomen Jäätelö. Second class tomatoes are used to produce tomato sauce, company example: Jävla Sås Bolag. Second class apples are used to produce apple-juice, company example: Valio.
R8 Recycle	**Process materials to obtain the same (high grade) or lower (low grade) quality** In recycling the focus is material use of side-streams from agriculture or food industry. Recycling typically requires higher quality and separate collection of the specific side-stream than recover. Examples: oat hulls are used to produce xylitol (Fazer 2022), potato peels are used as feed for cows (Franco et al. 2019), side-streams from fish processing industry contain fish oils, proteins and peptides, collagen, gelatin, enzymes, chitin, and minerals (Välimaa et al. 2019), plastics from packaging material are recycled to produce new plastic through mechanical processing (Fortum 2019) or fuels through chemical processing (Neste 2022).

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[20] https://www.resq-club.com/

[21] https://www.kamupak.fi/

	Regarding recycling of food packaging materials, consumers are encouraged to return certain plastic and carton packaging materials through payment via Bower-application (HS 2023b). In Finland, money is paid from packaging used in brands such as Panda, Taffel, Felix, Grandiosa, Paulúns, Oolannin, and Riisifrutti.
R9 Recover	**Incineration of materials with energy recovery** Recover is commonly defined as incineration of materials with energy recovery. However, in food-system also nutrients can be recovered from various side-streams and wastes. The energy recovery can be done through biogas processing or combustion. Biogas plants can treat both municipal waste and agricultural side-streams e.g., wastewater sludge, biowaste, manure, and crop residues. In addition to the biogas, also nutrient rich digestate is formed in the process. Digestate can be used for fertilizing as such or after processing to recycled fertilizers. Digestate based on manure and crop residues is an excellent fertilizer, but instead many farmers do not accept wastewater sludge based fertilizers due to organic contaminants. Thus, they are mainly used in landscaping. Municipal mixed waste is treated also by combustion. Heat and electricity can be recovered from the process, but the nitrogen is lost in the atmosphere. Currently CO2 is not recovered from the combustion process, but many companies are interested in CO2 capture and use (CCU) e.g. Vantaan Energia[22].

2.3. Business examples and connections to R-strategies

2.3.1. Textile company case study

A case study (Horn et al., 2023) was carried out in collaboration with a Finnish T-shirt brand focusing on sports garments. The studied product was a polyester T-shirt, and the aim was to study the environmental consequences of implementing various R-strategies, discussed in previous chapters. For the company, this provides a valuable decision-making basis to be used when planning future strategies to embrace circular economy to the operations and value chain as it gives guidance about the magnitude and order of priority for selected options.

The selected R-strategies were: reduce (reducing washing and drying), reuse (handing over), remanufacture (collecting, reprinting), repurpose (manufacturing from repurposed PET-bottles) and recycle (recycling the T-shirt to new polyester fibre), which were compared to the linear base case, i.e. recover. The studied environmental consequences were environmental impacts based on life cycle assessment (LCA) and the environmental and health related risks, based on a risk identification study. The LCA results were normalized and weighted to reach a one-dimensional result for combined environmental impacts. The risks reduction potential,

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[22] https://www.vantaanenergia.fi/en/vantaa-energy-progressing-towards-carbon-negativity-in-2030/

on the other hand, was treated and discussed qualitatively. As a results, it was found that in comparison to the baseline option, recycling the T-shirt at the end of the life cycle was able to decrease overall environmental impacts by 8%, and using the material of repurposed PET-bottles reduced them by 9%. Remanufacturing was able to reduce impacts by 18%, which was only slightly more than reusing the T-shirts as such (18%). However, the option of reducing washing and drying was clearly the most impactful option, as it was able to decrease the impacts by 37%. By combining the different strategies, a reduction of 70% could be achieved. From the risk perspective, the baseline option contained significant risk to human health and the environment arising from the potential release of various hazardous substances particularly during raw material (oil) extraction and manufacturing phases. All R-strategies were able to reduce these risks by reducing the use of virgin raw materials. Options based on reusing the product without mechanical or chemical processing also reduced the baseline risks related to manufacturing. Reducing washing also reduced risks related to wastewater discharges or microplastics and dyes, among others.

2.3.2. Battery case study Finland

The study (Slotte et al. 2023) was carried out for batteries in electric passenger cars (xEVs) with the focus on cathode materials. Nickel (Ni) based cathode materials are currently the dominant type of materials used in lithium-ion batteries in EU. Therefore, the aim of this study was to determine the demand for Ni and the amount of Ni waste along the whole value chain as presented in chapter (2.1.2). Transition to zero emission cars (General Secretariat of the Council of the EU 2022) is going to increase the demand for raw materials used in the production of xEV batteries but the demand for primary materials can be reduced if R-strategies are applied. The effect of three different R-strategies, i.e., remanufacturing, repurposing, and recycling, on the primary material demand was studied (Slotte et al. 2023). The R-strategies were applied at the end of life of batteries in xEVs. A system dynamic model was used to describe processes involved along the value chain.

The amount of electric passenger cars in traffic use in Finland is increasing significantly from year to year and forecasts indicate that in 2030 the amount of xEVs on Finnish roads could reach 600 thousand (Ministry of Transport and Communications 2021). This prediction was used as a basis for simulations with the model. (Slotte et al. 2023) Since yearly Finnish electric passenger car fleet was used in the model the results would indicate the amount of Ni available for recycling in Finland without additional material coming from abroad. The collection rate at end-of-life (EoL) is assumed 95%.

In the scenario (Slotte et al. 2023), the number of plug-in EVs (PHEVs) in traffic use is assumed to stay at the level of year 2022 until the cars reach EoL. The rest of electric passenger cars in traffic use in this scenario consist of 66 kWh full EVs (BHEVs) with an average Ni content corresponding to NMC811. These assumptions allow to study highest demand for Ni. Even though new PHEVs may not be sold after 2035, as proposed in 'Fit for 55' package, the share of PHEVs in traffic use is expected to be higher than in this scenario. Hybrid electric vehicles (HEVs) were excluded from this study.

Based on the assumptions, to meet the predicted developments of Finnish electric passenger cars, over 30 kt Ni (cumulative from 2020) would have to come from primary raw materials by 2030 if the R-strategies are not applied. A cumulative waste generation in 2030 would be at the level of approx. 30% of this demand. If the developments of Finnish xEV fleet continue at the same rate, over 2 million units would be in traffic use in 2060. This level of increase in the xEV fleet over a 40-year span would require more than 300 kt Ni mined (cumulative) by 2060. At the same time, approx. 70% of that demand would be in waste generated along the battery value chain (note, generated wastes include tailings and 13% of Ni from mined ores is assumed to end up in tailings). The implementation of R-strategies at the end of use of batteries in xEVs reduces the demand on primary materials; in 2030 by up to 20% but already from 2040 the reduction in the demand reaches >40% for some of the strategies. The high share of repurposing (85%) instead of application of other R-strategies seem to result in the lowest reduction of demand. This is due to the time delay related to the battery lifetime in the second application (here assumed 10 years). Recycling and remanufacturing are reducing the demand for raw materials at the time the batteries reach their EoL in passenger cars. Repurposing, on the other hand, reduces the demand created by other sectors, which was not captured in this study, and delays material recycling back to the battery value chain. The application of multiple strategies, i.e., repurposing, remanufacturing, and recycling could turn out to be the most beneficial in the long-term perspective. (Slotte et al. 2023)

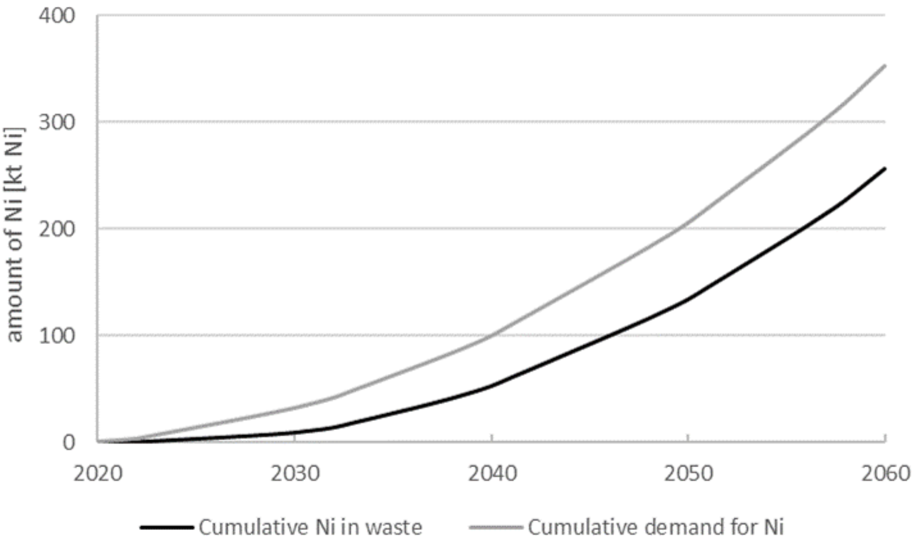

Figure 6. Cumulative demand for Ni and cumulative Ni in waste when no R-strategies are applied. (Slotte et al. 2023).

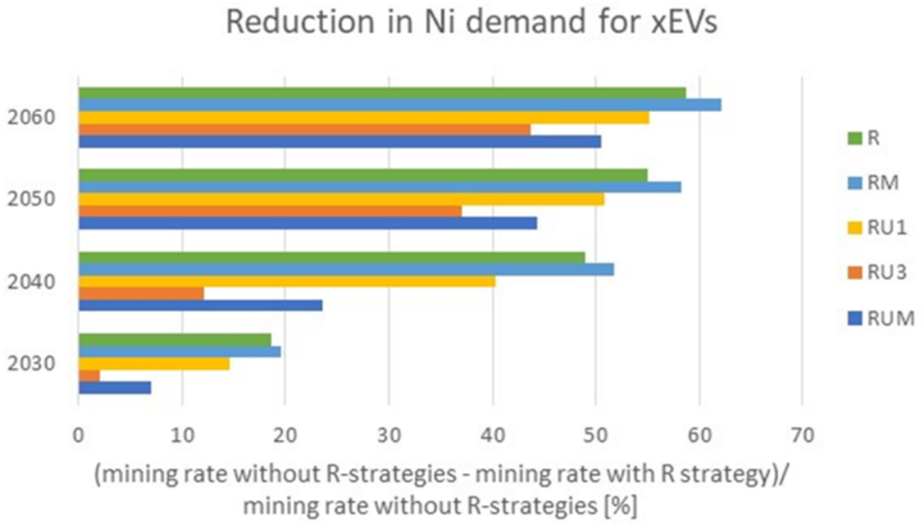

Figure 7. Reduction in demand for Ni achieved with R-strategies applied to batteries at the end of their life in xEVs (where, R – 95% recycling; RM – 75% recycling, 20% remanufacture; RU1 – 75% recycling, 20% repurpose; RU3 – 10% recycling, 85% repurpose; RUM – 10% recycling, 65% repurpose, 20% remanufacture). Note, in this results R strategies are only applied to batteries at their end of life, not to mining and manufacturing waste. (Slotte et al. 2023).

2.3.3. Oat as raw material for food and feed industry

Oat was chosen as a case study because of its economic importance in Finnish crop production and export potential based on good nutritional and health-promoting features. Additionally, the oat production and processing chain could be improved in terms of sustainability and value addition through applying cascade principle in processing residues and side streams. According to statistics for the year 2021, the cultivation area of oat in Finland was about 332 000 hectares.[23] Of the total harvest, roughly one half was straw and the other half seed yield, corresponding to ca. 1,0 million tonnes of straw and 1,1 million tonnes of seeds. Of the seed crop, ca. 300 000 tonnes (30%) were exported and 800 000 tonnes used for domestic consumption. The domestic consumption was divided into food (140 000 tonnes) and feed (660 000 tonnes) consumption. After sifting and hulling, a seed and hull residue of ca. 226 000 tonnes was extracted from the domestic share of oat seed crop.

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[23] The Finnish Cereal Committee VYR. https://www.vyr.fi/fin/in-english

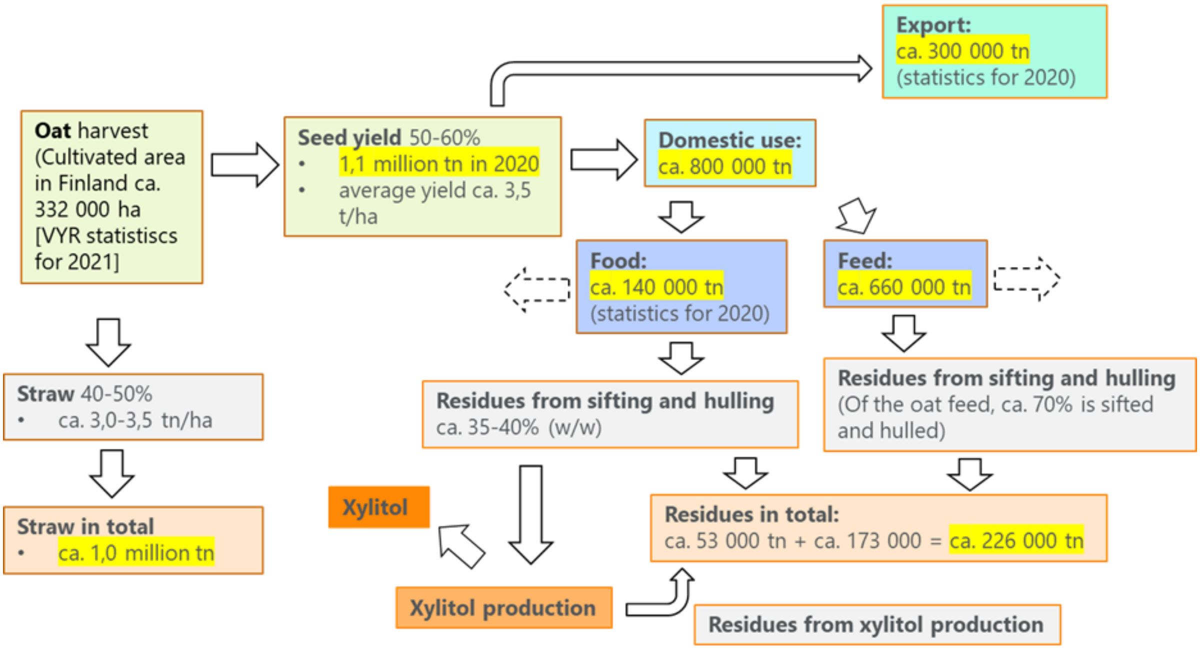

Figure 8. The oat harvest and harvest fractions in Finland.

In the oat production and processing chain, the main residues are straw (ca. 3,0–3,3 tn/ha/year) and sifting and hulling residues from the domestic share of seed crop (ca. 226 000 tn/year). Straw is mainly used as soil improvement component after chopping, as bedding material to livestock and as feedstock in thermal power plants. Used livestock bedding material goes most often to a biogas plant, where it is converted to bioenergy and recycled fertilizer. In view of the cascade principle, value addition to straw could be generated through repurpose -based utilization. Straw as a lignocellulosic material can be used as raw material for consumer board, textiles, bioplastics, and adhesives[24]. The lignocellulosic, fibrous composition of straw opens up possibilities to replace e.g. cotton or synthetic fibres in textiles with straw-based fibre. In addition to value-added use of straw, this would contribute to increased sustainability in fibre-using industries as the demand for primary or synthetic fibre could be reduced.

In addition to straw, seed and hull residues form another major residue group in oat production. These residues have been mostly used as livestock feed or feedstock in thermal power plants, but their composition opens possibilities for research and development of high-value components. Fazer Ltd has developed an innovation to produce xylitol from the side stream of Fazer Mylly, Fazer's own oat mill in Lahti. Xylitol production from oat seed hulls is a good example of side stream recycling, which has resulted in an added-value product through innovative processing of a generally low-value side stream from food industry.

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[24] https://www.ch-bioforce.com/

3. Summary

Circular economy is a model of economy for keeping materials in use and preserving their value as high as possible throughout the value chains. Finally, after the useful life, material loops will be closed, while preventing downcycling. Here, circular economy strategies, i.e. R-strategies, provide a systematic way to formulate and analyse the different aspects of the life cycles of the products and materials. They can be utilized by various stakeholders, such as different types of enterprises, small and large, governmental organizations, consumers as well as in different phases of the product life cycle starting from the product design to end-of-life processes. Degree of circularity, use of resources and caused emissions, smarter product manufacture and use can be designed and evaluated through R-strategies (R0=Refuse, R1 =Rethink, R2 =Reduce,R3 =Reuse, R4 =Repair, R5 =Refurbish, R6 =Remain, R7 = Repurpose,R8 = Recycle, R9 = Recover), All R-strategies are important to consider, though the impact on circularity and overall sustainability is likely higher in the beginning of the material value chain.

R-strategies can be applied as such in the textile and battery value chains, but also in the agri-food value chain, where some of the materials recycling is not so evident, many circular economy principles (resource efficiency, cascading use, circular design) can be applied. In short, it depends heavily on the value chain at hand, which of the R-strategies may be utilized or prioritized, and which types of special concerns need to be tackled when planning for a circular transition. In the following, we discuss some of the special aspects related to the selected value chains.

In the textile value chain, currently the most important aim is to replace fast fashion with longer product use and essentially reduce production and consumption volumes. For example, consumers' willingness to repair garments, or to buy repair services, will also affect the life cycle length. Also, the implementation of reuse-, rental- or second-hand models will make the product use more intensive and indirectly reduce demand. However, it needs to be kept in mind that in case these involve substantial transports or washing processes, they may reduce the environmental benefits. Also, reducing washing and drying of textiles during their use significantly decreases the environmental impacts, as well. Textile fibres can be circulated to some extent, but in every round, there is some wearing of the material and the quality of the recycled fibre deteriorates in comparison to virgin fibre. The recycling, including preparation phases, such as sorting usable textiles from not-usable ones, separating different types of fibres, and removing existing colors, may need processes which require the use of chemicals, water, and energy. Depending on the processed material, its contents and used technologies, the environmental load may be substantial, as well. Any harmful chemicals in end-of-life fabrics also need to be removed and managed safely.

The battery value chain is developing and expected to grow due to rapid electrification of mobility and demand for renewable energy. This means, that batteries are a vital element of the green transition, hence the supply of raw materials and recycling of metals is crucial to meet the future needs in various solutions including electric vehicles and energy storage. Battery chemistries evolve and recycling technologies need to be further developed to meet the recycling targets. For example, elements such as Li, Co, and graphite are in focus of battery value chain, and there is active research and development activities in the field of substitution, such as graphite replacing with renewable lignin-based material. Forerunners and large companies in the field, hold power in decision making, which battery solutions will be accepted by the markets.

In the agri-food value chain, food loss and food waste are clearly a low hanging fruit since even one third of all food is estimated of being wasted. What it comes to circularity in the agri-food value chain, it is best supported by increasing local food production including production inputs such as fertilizers and fuels. In a local system, side-streams from agriculture, food industry, and food consumption can be used as raw materials for production of other food products, feed, materials, chemicals, fertilizers, and fuels. In a local system, transport distances are short and do not create a barrier for efficient utilization of side-streams.

In addition to food itself, food packaging is integral part of the food system. Plastic is still the most common material used in food packaging. Environmental impacts can be decreased to certain extent by avoiding overpackaging and/or replacing virgin packaging materials with recycled materials. Some systems, based on reusable food packaging, already exist. However, it is worth noting that the feasibility of reusable packaging depends on the operational environment (e.g. logistics) and the line of business (e.g. food processing industry vs. restaurant industry). Yet food packaging has an important role, which should not be compromised, in logistics and keeping food fresh, lengthening the shelf life, and avoiding spoilage and thus generation of food loss and food waste.

Despite of the many possibilities, circularity does not always result in increased environmental or social sustainability. Circular economy processes may need energy, water, and chemicals, as well as create waste and emissions. Moreover, for some of the solutions, which require changes in consumer attitudes and behavior, may be difficult to gain public acceptance. Also, the policies are still evolving; some are lagging behind and preventing circularity, and some policy mixes are not coherent. Therefore, when circular economy strategies are taken into use, it is crucial to both assess the economic, environmental, and social impacts with a holistic, system wide approach. At the same time, consumer behavior and policy development need to be incorporated in the wider transition pathway.

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Luke
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You can find us online

luke.fi

Natural Resources Institute Finland (Luke), Latokartanonkaari 9, 00790 Helsinki, Finland