CIRCULAR ECONOMY DRIVERS AND ROLE OF PRODUCER RESPONSIBILITY IN THE FINNISH SOLAR PANEL SECTOR – STAKEHOLDER PERCEPTIONS

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ABSTRACT

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Abstract

Following the ambition of the Paris Agreement, the European Union and its Member States have taken action to tackle climate change. Actions have been implemented in a variety of ways, including long term strategies, policy tools and regulation as well as financial instruments that are further adopted in the Member States, including Finland. In the energy industry, all eyes are on renewable energy. Following the rising adoption of new capacity, certain challenges have been identified. Concerning solar panels, the challenges are related to the use of scarce materials, and the lack of recyclability and circularity in the current value chain. This master's thesis investigates market actor perceptions of the success of extended producer responsibility regulation in the solar panel retail market in Finland through the lens of circular economy. The study was conducted as a qualitative study by interviewing nine domestic stakeholders. The stakeholders were selected based on their role and presence on the Finnish solar panel market at different stages of solar panel's lifetime. Representatives from supervisory and regulatory authorities, a governmental organisation, producer collectives, service providers and producers, and academia participated in the interviews. The study found that although regulation is a guiding force in the background, producer responsibility is not the dominating factor influencing operators' circularity efforts, even though it was deemed to support the general transition to circular economy. Other factors were identified more important including the power dynamics and interaction between the actors, consumer awareness and engagement in environmental and sustainability topics, the business potential of circular opportunities together with technology improvements, system level efficiency, and general adoption of the concept of circular economy and related phenomena.

Key words
Circular economy, solar panel industry, photovoltaics, producer responsibility, electrical and electronic waste, sustainable policy

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Tiivistelmä

Pariisin ilmastosopimuksen hengessä Euroopan unionin jäsenmaat, Suomi mukaan lukien, ovat sitoutuneet hillitsemään ilmaston muutosta. Käytössä olevien keinojen kirjo on laaja sisältäen pitkän aikavälin strategioita ja suunnitelmia sekä sääntely- ja rahoitusinstrumentteja, joita toteutetaan edelleen jäsenmaissa. Energia-alalla etsitään ratkaisuja muun muassa uusiutuvasta energiasta. Kasvava käyttöönotto tuo mukanaan kuitenkin haasteita, ja aurinkoenergian kohdalla nämä haasteet liittyvät harvinaisten materiaalien käyttöön, kierrätettävyyteen ja uudelleenkäyttömahdollisuuksiin. Tämä pro gradu -tutkielma käsittelee kotimaisten markkinatoimijoiden näkemyksiä tuottajavastuusääntelystä ja kiertotalouden ajureista koskien aurinkopaneelien elinkaarta. Laadullinen tutkimus toteutettiin sidosryhmähaastatteluina, joihin osallistui yhdeksän alan toimijaa. He edustivat eri sidosryhmiä ja näkemyksiä kerättiin valvonta- ja sääntelyviranomaisilta, tuottajayhteisöiltä, valtion kestävän kehityksen asiantuntijaorganisaatiolta, palveluntarjoajilta ja tuottajilta, sekä alan tutkijalta. Tutkimuksen löydöksenä voidaan todeta, että tuottajavastuusääntely vaikuttaa vahvasti alan taustalla ja toteutuu hyvin elektroniikkajätteen loppukäsittelyssä. On kuitenkin huomattavaa, että tuottajavastuulla ei koettu olevan suurta painoarvoa tuotteen elinkaaren muissa vaiheissa. Erityisesti tuotteen suunnittelun ja käytönaikaisissa vaiheissa nähtiin olevan edellytyksiä edistää kiertotalouden mukaista toimintaa. Kiertotalouden ajureiksi tutkimus tunnisti toimijoiden välisen voimadynamiikan ja vuorovaikutuksen, kuluttajien lisääntyneen tietoisuuden ja vihkiytymisen ympäristö- ja vastuullisuusaiheisiin, toimivat tuki- ja seurantajärjestelmät ennakoitavan sääntelyn tukena, järjestelmätason tehostamisen ja kehittämisen mahdollisuudet, kiertotalouden tuomat kaupalliset mahdollisuudet, sekä kiertotalouden ja sitä tukevien toimintatapojen yleisen hyväksynnän.

Asiasanat
Kiertotalous, tuottajavastuu, aurinkosähkö, sähkö- ja elektroniikkalaiteromu, kestävä sääntely

Säilytyspaikka
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LIST OF ABBREVIATIONS

EC	European Commission
EEA	European Energy Agency
EPR	extended producer responsibility
EC	European Commission
EU	European Union
GW	gigawatt
ICT	information and communication technology
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
NGO	non-governmental organisation
OECD	The Organisation for Economic Co-operation and Development
PV	photovoltaic
SME	small and medium-sized company
UNFCCC	United Nations Framework Convention on Climate Change
WEEE	Directive on the waste electrical and electronic equipment

1 INTRODUCTION

1.1 Background

There is a sense of urgency and prominence in the contemporary discussion on climate change. The general public and policymakers have been increasingly introduced and engaged in the concept and more and more the means to mitigate the harmful environmental impacts of societies are in the pipeline. The Intergovernmental Panel on Climate Change (IPCC) has concretised the goals to limit global warming to 1.5°C from pre-industrial levels (Rogelj et al., 2018). In efforts to reach this goal, an increase in the use of renewable energy technologies to replace fossil fuel-based primary energy production is a key factor. There has already been significant development in the use of solar power. Between years 2011 and 2020, the global solar capacity grew nearly ten-fold from 73 GW to 716 GW, and in Europe nearly three-fold from 55 GW to 163 GW (International Renewable Energy Agency, 2021). Simultaneously, the global weighted average of the total installed cost has decreased to a quarter of the price over the same period (International Renewable Energy Agency & World Trade Organization, 2021). Notably, when looking at global primary energy consumption, solar represents only 1% of the energy mix that includes electricity, transport and heat. In terms of only the electricity mix, solar has a share of nearly 3% (Our World in Data, 2021). In the European context, European Union launched the Clean energy for all Europeans package in 2019 with an ambitious target of 32% for renewable energy generation in the EU's energy mix by 2030 (European Commission, 2021). Solar power and photovoltaic (PV) panels are expected to contribute towards the goal as well as the EU's commitments for the Paris Agreement.

Circular economy is connected to tackling resource and raw material scarcity. Notably, 90% of solar panels' composition can be recycled, and according to EU law, recycling is mandatory (SolarPower Europe, 2019). However, currently, there is no financially significant business case in the end-of-life management of PV technology due to the small scale of solar panel use and disposal (Sica et al., 2018). The expected lifetime of a solar panel varies from 15 to 25 to 30 years depending on the used photovoltaic panel type and the conditions of use (Majewski et al., 2021). Thus, as the magnitude of use increases, so does the magnitude of photovoltaic waste in the next 10 to 30 years. According to the International Renewable Energy Agency (IRENA), global waste of end-of-life PV panels is expected to grow from 43,500 tonnes in 2016 up to 1.7 or even 8 million tonnes by 2030 (2016).

To tackle resource scarcity and enable sustainable growth – to the extent that sustainable growth is possible – the EU has laid out an agenda European Green Deal to which the Circular Economy Action Plan contributes (Communication COM/2020/98, 2020). Waste and recycling fall under the action plan covering photovoltaic panels together with other electrical and electronic waste.

Notably, the Directive 2012/19/EU of the European Parliament and of the Council on waste electrical and electronic equipment (WEEE) provides guidelines for the treatment of electrical devices of different sizes. The preceding Directive entered into force in 2002 and has been amended since in various ways to cover more aspects in terms of, for example, processes and reporting (Latunussa et al., 2016) while the WEEE specific regulation came to force in 2003 (European Commission, n.d.e). The WEEE applies the "polluter pays" principle by the Organisation for Economic Co-operation and Development (OECD) to a certain extent through the extended producer responsibility (EPR) principle (Ylä-Mella et al., 2014b). Since 1994, EPR has been on the OECD work programme (Organisation for Economic Co-operation and Development, 2004). EPR is a policy approach for environmental protection where the producer's responsibility for consumer goods is extended until the end of the lifecycle instead of the point of sale (Organisation for Economic Co-operation and Development, 2004). In addition to the extended producer obligations, the EU's waste management policy also nominates a waste stream hierarchy and assigns a priority order for treatment methods (Bourguignon, 2015). However, the actual implementation of the WEEE Directive varies across the EU Member States as the Directive allows room for interpretation and adjustment in the national legislation (Hestin et al., 2016). Currently, the recycling rates are not fully corresponding to EU targets (WEEE Forum, 2021).

Since 2019, the EU-wide recovery target for household WEEE has been 65%. The target is calculated based on the average amount of electrical and electronic equipment placed on the market three years prior (Centre for Economic Development, Transport and the Environment, 2021). In the same year, in Finland, the registered recovery rate was 57.9%. Notably, the annual average amount of recovered electrical and electronic equipment is 13.3 kg per capita, which represents the top tier on the European scale. The electrical and electronic devices are further divided into ten categories, and each category has its individual recovery, recycling, and reuse targets that the producers are expected to comply with. In 2018, the recycling rate of WEEE was 39% in Europe (European Environmental Agency, 2021). EEA is making use of the Eurostat data and has calculated the WEEE recycling rate by multiplying the collection rate with the reuse and recycling rate.

The current methods of recycling PV panels depend on the type of the panel (Masoumian et al., 2015). However, they are largely based on crushing the modules and then separating the different material crumbs through either mechanical or chemical treatment (Masoumian et al., 2015; Sica et al., 2018; Majewsky et al., 2021; Solar Waste, n.d.). Until now, the quantities of PV technologies being recycled have been relatively low internationally and as the process does not scale up, there have not been financial incentives for the producers to invent more advanced recycling methods or ways to reuse the materials. However, depending on the source, a more significant amount of installed PV capacity is expected to reach its end-of-life within 5 to 15 years (Masoumian et al., 2015; Sica et al., 2018; International Renewable Energy Agency & World Trade Organization, 2021; Majewsky et al., 2021). This creates a need and also a driver for creating

new, economically viable services and more intelligent processes to support circular economy and tackle resource scarcity (Vakkuri, n.d.). As said, it is technically possible to recycle PV panels at a high rate suggesting that the issue is not so much technology but incentivisation (Sica et al., 2018).

Another area of interest that the OECD engaged in 1994 was waste minimisation (2000). The Waste Minimisation Programme defined the components of waste minimisation as strict avoidance and prevention, reduction at source, product reuse, recycling, and if appropriate, energy recovery. In the context of waste minimisation, waste prevention includes by definition the three first ones (avoidance, reduction, and reuse). During the OECD-driven project and international collaboration, it has been noted that waste diversity and exponentially increasing amount of waste pose challenges for management and treatment processes. Thus, waste prevention is playing a key role and promisingly, has been widely accepted as a method for managing the detrimental challenges related to environmental and social impacts of waste. To support the motivation to minimise waste, in addition to the environmental benefits, also the economic and financial benefits are recognised. For example, cost management through efficiency and reduced investments in waste treatment are factors that influence strategic business governance (Organisation for Economic Co-operation and Development, 2000).

It has been noted that the technological advancements and development enable more intelligent opportunities also for sorting as the information and communication technology (ICT), material, bio, and nanotechnologies become more sophisticated (Järvinen, 2006). On the other hand, new types of waste can simultaneously be more resource-demanding to recycle or prepare for reuse, and especially ICT produce electronic waste in large quantities. Notably, waste treatment processes face new challenges as state-of-the-art electronic equipment is expected to require more advanced end-of-life treatment and handling. More expectations are placed on the equipment, processes, logistics, and storage solutions. Even if market factors, such as material pricing, supply and demand might support monetisation and further application of waste, the directives or regulations might act as a barrier to implementation. As an example, Järvinen argues that the strict interpretation of the term waste potentially prevents re-utilisation opportunities (2006).

1.2 Aim and structure of the thesis

In this thesis, the aim is to study the perceptions of the PV market operators and stakeholders of circular economy and producer responsibility, and the coupling of the two. The thesis studies how the WEEE Directive supports not only the producers' but also other relevant market actors' ambitions to generate product and service offerings around circular economy opportunities in relation to PVs. The goal is to understand the drivers and barriers of the EPR, and what needs to be changed in order to better adopt a circular approach to PV lifecycle and

accommodate more effective PV end-of-life management methods. The geographical focus of the study is Finland. The research aims at answering the following questions:

Q1: How effective is the current WEEE Directive 2012/19/EU in terms of guiding circular economy of PV panels in Finland?
Q2: How does the regulation on producer responsibility direct the operation of PV producers?
Q3: What are the key factors driving circular economy in the Finnish PV market?

Following the introductory chapter to the topic and thesis, the literature review and theoretical background is constructed around three focus areas. The second chapter describes the PV market and used technologies, gives context in terms of the regulatory and policy environment in the EU and in Finland, and discusses key aspects of circular economy. The third chapter, Data and methodology, outlines the chosen method and data management process. Going into the fourth chapter, which reveals the results of the stakeholder interviews, the contents provide a ladder into the Discussions and analysis of the implications of the findings. To finish off, the sixth chapter summarises the outcomes in the Conclusions and is topped off with a list of used references.

2 THEORETICAL FRAMEWORK

According to Bloomberg and Volpe (2012), literature review allows an opportunity to put the research problem into context. The idea of a literature review is to collect, analyse and synthesise the findings of earlier research and identify gaps in the knowledge. The prevailing knowledge can also be contradicting or marked by conflicts, meaning that the research needs to consider possible restrictions in the current knowledge. In a way, a literature review allows authors to join academic dialogue on a topic that is related to their research problem. Additionally, the quality and depth of the literature review can act as an indicator of the quality of the new research; a thorough investigation of prior findings prevents duplication and gives grounds for advanced research that is based on the latest and most relevant knowledge (Bloomberg et al., 2012).

This chapter is divided into three main focus areas. Firstly, it will look into PV markets and how the renewable energy technologies have developed over time, especially in the EU. The second sub-chapter will give an overview of the European and Finnish regulatory contexts to understand how the legislation on WEEE relates to the surrounding policy environments of different scales. The third sub-chapter will discuss some of the popular theories of circular economy presented in the literature.

2.1 Photovoltaic market and technologies in EU

The demand for solar energy is being ramped up in the EU and the market is ever evolving due to its continuously lowering costs, adoptability, and use case potential (SolarPower Europe, 2020). However, there are only a limited number of PV technologies that have been adopted for wide-scale use, while there are also piloting solutions in the pipeline (Fraunhofer ISE, 2022; Taylor & Jäger-Waldau, 2020). To paint a picture of the challenges related to material scarcity and political vulnerability, we will briefly scratch the surface of the used PV technologies before looking into previous research on PV markets.

2.1.1 State of technical development

There are three main types of photovoltaic technologies used in PV panels. In 2020, the leading solution in the global market with a market share of 95% was crystalline silicon wafer-based (c-Si) technology (Fraunhofer ISE, 2022). The silicon-based technologies can be divided further into mono-crystalline and multi-crystalline, out of which mono-crystalline technology is more popular with its 85% market share. It is slightly more efficient with 27% lab efficiency compared to 24% for multi-crystalline.

The other type of PV technology available is thin-film technology, where the device consists of very thin layers (Taylor & Jäger-Waldau, 2020). The

recorded maximum lab efficiency of thin film solar cells varies between 23% and 21% depending on the main material. Although thin-film modules are found to hold benefits such as low manufacturing costs and low CO_2 impact, their popularity peaked in 2008–2009 and has been decreasing since (Fraunhofer ISE, 2022). Many of the challenges are related to the need for scarce metalloids and elements from the EU critical materials list (Taylor & Jäger-Waldau, 2020). Interestingly, due to development in research with alternative combination compounds and so-called tandem structures with higher economic and eco-efficiency, the thin films are expected to gain more ground.

The EU Raw Materials Initiative lists the critical materials that are being used in the European industries, and in PV production the relevant ones are gallium, indium and silicon metal (Communication, COM/2929/474, 2020). Curiously, silicon oxide in itself is not scarce. It is sourced from China and due to this dependence on Chinese PV production silicone metal appears on the listing (Taylor & Jäger-Waldau, 2020). In terms of circularity and processing, the manner of assembly and layering impact durability as well as the ease of re-treatment (Taylor & Jäger-Waldau, 2020).

2.1.2 Previous research

There is an abundance of research on photovoltaics and recycling as well as published scientific articles examining the opportunities in the field. For example, both the industry organisations as well as academic researchers have studied the financial aspects of end-of-life treatment of PV modules and the competitiveness in Finland (i.e., Ahola, 2019; Cucchiella et al., 2015; Walther et al., 2010; International Renewable Energy Agency & World Trade Organization, 2021; Masoumian et al., 2015). Bressanelli et al. (2020) conducted a literature review on circular economy in the WEEE industry on 115 papers. Based on their findings, there are multiple studies conducted in the field. However, certain research gaps remain. They identified four key areas for further observation. Firstly, the occurred research has mostly been static simulations and quantitative in nature. The authors highlighted the need for more empirical theory-testing and more practical implementation. Secondly, the approach is rather top-down than bottom-up although there are strong signals that there is a willingness to implement circular economy business strategies without regulatory intervention. Thus, it would be required to find the leverage and drivers for bottom-up circular economy strategies apart from regulatory carrot and stick. Thirdly, the existing research is lacking a holistic view to the life cycle and actors, especially in the design and manufacturing stage. This would allow the distribution of the main burden from the end-of-life solution management more even across the value chain. Lastly, Bressanelli et al. (2020) concluded that in terms of the 4R's – Reduce, Reuse, Remanufacture, and Recycle – the two middle ones should be studied in more detail to capture the higher potential of circularity.

In terms of WEEE and end-of-life management in the Finnish context, there are for example publications by Ylä-Mella and corresponding teams in addition to her Doctoral dissertation (Ylä-Mella, 2015; Ylä-Mella et al., 2014ab, 2015).

Notably, the articles discuss the small domestic EE appliances and mobile phones and thus cover a very different area from the PV panels. Additionally, the approach was focused on consumer behaviour and engagement instead of the producer responsibility. Their findings, however, are encouraging. They found that Finnish and Nordic people, in general, are rather well educated in terms of environmental issues. This supports the recycling process of domestic appliances and has allowed Finland to reach the WEEE recycling targets set by the EU. However, the process flow has not reached its full potential or efficiency. As an example, one hindrance in the handling process is the long distances and transportation needs from the collection point to the recycling centre. Additionally, in connection to the recycling of mobile phones, they found that there was a tendency for them to not be taken for collection (Ylä-Mella et al., 2015). The reasons listed were such as uncertainty about where to take the device or how to get rid of it. Thus, although the citizen engagement level in WEEE end-of-life management is promising, there is still room for improvement through increasing education and awareness and communicating the retailers' take-back obligations.

In terms of the application of EPR and driving recycling economy, a study with a selection of Finnish WEEE stakeholders was conducted by Danska (2012). She found that the different stakeholder companies had varied perceptions about the definition of EPR policy. Naturally, the legislation and EU regulations guide effectively the operations, but the strategic decisions are made based on the resource-productivity rate. Although the purpose of the EPR is to influence the early stages of the product's life cycle and product design, the producers place more importance on the efficiency measures in terms of materials, energy, and costs. These aspects have more weight on the product design and simultaneously limit the negative environmental impact. A curious viewpoint that was raised in interviews was related to the EPR and free market dynamics. The EPR was created when products had a negative recycling value. Due to an increase in raw material prices and a shift in the general mindset, there is a market for waste. Since the producers have the responsibility, thus, the priority to collect waste directly from the end-users, the practice distorts the dynamics and prevents free competition. The shift in the demand side and market pull is a significant factor in the discussion on waste management. Additionally, a provocative example was given by comparing an electrical device to a leased car. Once the end-user is getting rid of their electronic device, that they paid a market price upon purchase and now has value as so-called waste, should they be expected to give it up for free under the EPR, or should the producers rather compensate them for the treatable raw material that they provide. Notably, not all components in a disposed electrical device are valuable but are nevertheless waste that must be properly treated, which limits the profitability of the waste treatment. On the other hand, a study by Aminoff et al. (2021) criticises the recycling policies for placing too much weight on the recycling rate and inflating it instead of focusing on recovering critical raw materials.

Cole et al. (2017) stated that to create a suitable environment for re-usable consumer devices, many conditions need to fall in place. The main obstacles identified in the UK were related to reverse logistics, quality and safety proofing of

repaired equipment, and building consumer confidence in second-use products (Cole et al., 2019). The research noted operations and decisions made that were effective in the short term but did not serve the purposes for reuse and upcycling. Thus, while the organisations adapt to the minimum legal requirements, there can be rebound effects of different kinds. The findings also included the limited amount of products being disposed of that limits more ambitious research and development, the lack of potential economic profits and the strong public emphasis on recycling instead of reuse. Results from a Danish study had similar findings to the UK one (Overgaard Zacho et al., 2018) as the full potential of reuse of electrical and electronic equipment was not realised nor were any precautions towards it embedded in the process. On the other hand, the quality of the equipment was often found too poor to allow refurbishing. The need for a common quality standard was raised, although for non-commercial actors the process might add too much bureaucratic burden. Additionally, concerns were addressed towards the producer's brand watering down in case of reuse and refurbishing.

A common factor for the above-mentioned studies is that terminology is at times lacking clear-cut definitions and differentiation between similar terms. Firstly, the term "waste" is seen as misleading and its definition a limiting factor towards reuse and circular culture. Additionally, for example, device, apparatus, tool, and equipment are used as interchangeable terms in the WEEE Directive, which is challenging especially from a supervisory point of view (Danska, 2012).

2.2 Regulatory context in EU and Finland

While the main law from which the Finnish Government Decree 519/2014 on electrical and electronic equipment waste is derived is the WEEE Directive, in the following chapters provide an overview of the regulatory context in which the Decree is implemented. As a general benchmark to all climate action is considered to be the Paris Agreement. The Paris Agreement is an international treaty under the United Nations Framework Convention on Climate Change (UNFCCC), that is signed by 196 Parties that represent different nations (United Nations Framework Convention on Climate Change, n.d.). The Paris Agreement is widely referred to also in the EU and Finnish climate strategies and policies in order to fulfil their nationally determined contributions (United Nations Framework Convention on Climate Change, n.d.). Table 1 summarises the international and national policy elements that serve the most proximate regulatory framework for the producer responsibility scheme in Finland.

TABLE 1 Summary of the international and national regulatory framework

Ruling body	Policy type	Policy title	Main contents	Date of implementation
		International		
Signed by 196 Parties to the UNFCCC (2021)	International treaty on climate change	Paris Agreement	Backbone for the EU and its Member States' climate strategies	2016, revisited every five years
European Commission	Priority strategy 2019–2024	European Green Deal	Roadmap towards socially and environmentally sustainable economic growth	2019, targets set up 2030 and 2050
European Commission	EU Law	EU WEEE Directive 2012/19/EU	Term definitions and rules for WEEE treatment in EU	2012, transposed into national laws 2014
European Commission	Action Plan	New Circular Economy Action Plan	Driving circularity, priority on resource-intensive industries. Main regulatory outcomes: Ecodesign Directive, Energy Label Directive, Green Public Procurement regulation, Waste Framework Directive	2020 (First version 2015-2020)

Ruling body	Policy type	Policy title	Main contents	Date of implementation
		National		
The Finnish Government	Programme	Sustainable Growth Programme	Promote sustainable growth within the areas of welfare, employment, equality, digital competence	2021
Ministry of Environment	Regulation	The Waste Act 646/2011	Umbrella law for waste-related decrees	2011
Ministry of Environment, compliance supervised by the Centre for Economic Development, Transport and the Environment for Pirkanmaa	Regulation	The Government Decree 519/2014 on WEEE	Describes means to decrease the harmfulness of WEEE, and the EPR scheme related to WEEE	2014

The WEEE Directive falls under the Circular Economy Action Plan by the European Commission and is closely connected to the topics of circular economy, chemicals and restriction of hazardous substances in electrical and electronic equipment, and waste and recycling (European Commission, n.d.c). In general, the action plans are building blocks toward the EU strategies. In particular, the Circular Economy Action Plan is part of the EU Priorities strategy called the European Green Deal (European Commission, n.d.b).

2.2.1 Sustainability policies by the European Commission

The EU WEEE Directive falls under the scope of the European Commission's priority strategy called A European Green Deal (European Commission, n.d.c). The Green Deal was presented in December 2019 to make Europe the first climate-

neutral continent by 2050. The core idea was to create a roadmap to support the European economy and make the economic growth sustainable in both environmental and societal terms. In December 2015, the first Circular Economy Action Plan was adopted and in March 2020 – following the adoption of the European Green Deal, a new Circular economy Action Plan saw the light of day (European Commission, n.d.b). As per the title, the action plan aims at driving the EU economy towards circularity through a variety of actions. It is focusing on the resource-intensive industries with high circularity potential, including electronics and ICT.

The topic of circular economy is overarching and connected to multiple topics on the EU agenda. The most relevant issues in connection to this thesis are the Sustainable Products and Ecodesign topics, and the related regulation (European Commission, n.d.a). Under the supervision of the European Commission, the European Product Bureau has been conducting preparatory research on sustainable product policy instruments and the necessary measures to harmonise the rules for environmental sustainability (European Product Bureau, n.d.). The main instrument of the framework is the Ecodesign Directive, and the legal framework additionally includes Energy Label, Ecolabel and Green Public Procurement instruments. The measures aim to harmonise technical standards, especially within the EU, but also with the main non-EU partner markets. The Ecodesign and the Energy Label Directives are focused on reducing the environmental impact throughout the life cycle, and EU Ecolabel Regulation No 66/2010 is a framework for voluntary impact reduction during production and consumption (European Product Bureau, n.d.; Regulation 66/2010/EC, 2010). Green Public Procurement, on the other hand, focuses on the environmental impact management in the public procurement and criteria selection (European Product Bureau, n.d.). One of the included product groups is dedicated to solar photovoltaics; the related study group is assessing the feasibility of Ecodesign, Energy Label, Ecolabel and Green Public Procurement instruments for solar photovoltaics modules, inverters, and systems. The research by European Product Bureau consists of both stakeholder consultation and technical assessment. The stakeholder and expert consultations are aiming to capture the views across the product group and supply chain, referring to manufacturers, suppliers, distributors, installers, investors, public authorities, testing bodies, consumer organisations, academia, NGOs, and Member State representatives (European Product Bureau, n.d.).

Notably, on March 30, 2022, the European Commission published a proposal for the regulation to set ecodesign requirements for sustainable products. One feature introduced in the proposal was a digital product passport. The digital passport is expected to provide information about products' environmental sustainability. With its help, it is possible to estimate the recyclability and repair opportunities and assess the lifecycle impacts while increasing consumer awareness and monitoring by the authorities (European Commission, 2022). Additionally, in relation to the composition of electrical and electronic devices, the EU oversees and regulates the use of hazardous elements in the products in order to limit the harm to the environment and public health as per the Directive 2011/65/EU (2011) on the restriction of the use of certain hazardous substances

in electrical and electronic equipment. Although in principle all products that have an electrical or electronic component fall under the restriction of hazardous substances, there is a list of items that are excluded from the regulation. Professionally installed and fixed structures of photovoltaic panels fall under the list of exceptions (Directorate-General for Environment, n.d.). Thus, the legislation is not an applicable area of study in this thesis.

When looking towards the end-of-life of a product, under the waste and recycling topic, the main objectives revolve around improving the waste management system, stimulating innovation in recycling, and limiting landfilling. Further, the Waste Framework Directive lays down basic concepts related to waste management as well as gives definitions on, for example, waste, recycling and recovery (European Commission, n.d.d). The Directive refers to the waste hierarchy where waste prevention is the most preferred option, followed by preparing for reuse, then recycling, recovery, and disposal being the least favoured action, as visualised in Figure 1 (European Commission, n.d.d).

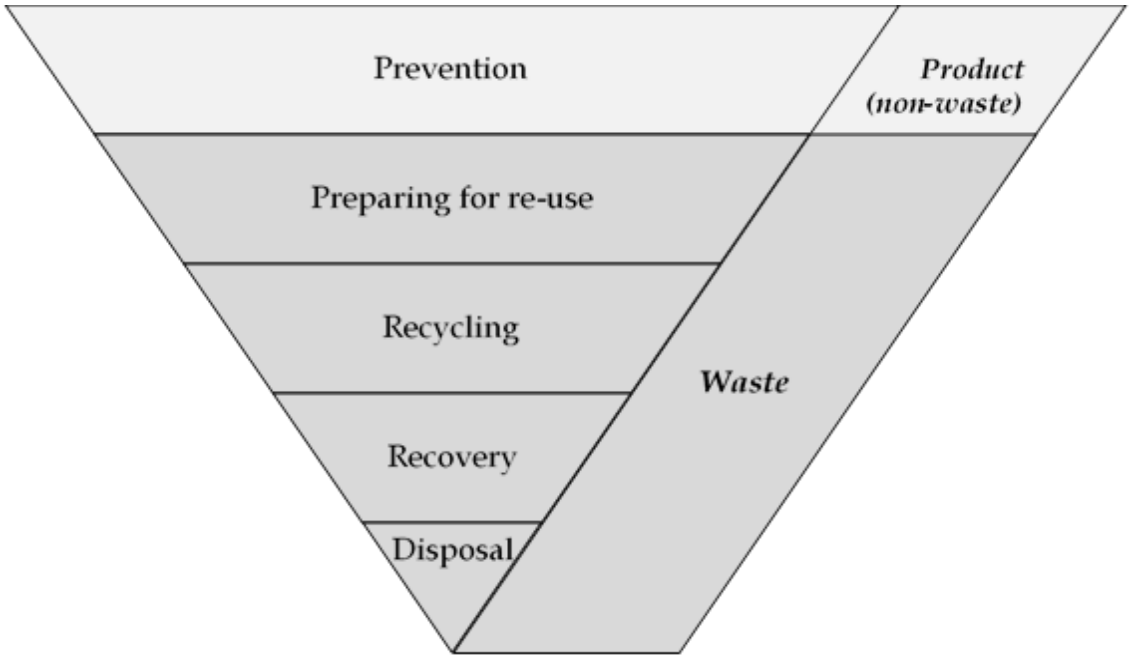

FIGURE 1 Waste hierarchy as described in the waste framework directive

Additionally, the periodical waste-related targets are outlined by the Directive as is the guidance for the calculation and measurements. To highlight two key definitions, the Directive defines by-products as "a substance or object, resulting from a production process, the primary aim of which is not the production of that item." It also encloses the criteria for the end-of-waste in Articles 6(1) and 6(2) stating that certain specified waste is no longer waste when it has undergone a recovery operation – this includes recycling – and complies with specific criteria as per follows [Directive 2008/98/EC, 2008, Article 6(1)]:

- *the substance or object is commonly used for specific purposes*
- *there is an existing market or demand for the substance or object*
- *the use is lawful (substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products)*
- *the use will not lead to overall adverse environmental or human health impacts.*

The Directive 2012/19/EU of the European Parliament and the Council on waste electrical and electronic equipment (WEEE) regulates the treatment of electrical devices of different sizes at all stages of their lifecycle. The Directive is a recast of the previous version of the Directive 2002/96/EC amending for example the scope, waste calculation methods and product range (Directive 2002/96/EC, 2002; Directive 2012/19/EU, 2012; Latunussa et al., 2016). The regulation on WEEE specifically first came to force on 27 January 2003 (European Commission, n.d.e). In August 2012, the producer responsibility was extended to photovoltaics and the recycling of PV panels. This means that WEEE Directive expects producers to finance the collection and environmentally sound recycling of the PVs that have reached their end-of-life. In the Directive, producer refers to anyone aiming to provide the PV panels in the EU market area, regardless of the manufacturing country (European Commission, n.d.e.; Majewsky et al., 2021). The WEEE is thus applying the OECD's "polluter pays" principle to a certain extent (Ylä-Mella et al., 2014b). The priority order of the treatment methods for waste minimisation assigned by the EU's waste management policy is very much aligned with the components identified by the OECD (Bourguignon, 2015; Organisation for Economic Co-operation and Development 2000). First and foremost, the producers are expected to prevent waste. Secondly, there is preparing for reuse, after that recycling and energy recovery, and only lastly disposal, which is the least preferred option (Bourguignon, 2015). The execution of the WEEE Directive varies across the EU Member States as the actual takebacks are implemented under the national regulations. Currently, the recycling rates are not fully corresponding to the EU targets (WEEE Forum, 2021).

From the consumer perspective, the Directive allows them to return the small-scale electronic devices to any shop selling similar products without the need to make a new purchase. On the other hand, some regulatory hurdles were set up to limit the purchase of electronic equipment from non-EU countries (European Commission, n.d.e; Bourguignon, 2015). There are many policies and regulations that direct product development and environmental impact management at the different phases of the product life cycle. However, the study is limited within the scope of the above-mentioned policy schemes.

2.2.2 Finnish policy environment

The Finnish Government has laid out a Sustainable Growth Programme that was published in March 2021 (Valtioneuvosto, 2021). The programme falls under the governance of the Paris Climate Agreement, the EU Green Deal as well as the

carbon-neutrality targets on both the EU and national levels. Thus, the programme is cross-sectoral and identifies a range of points of importance in society (welfare, employment, equality, digital competence). The programme is funded by the Next Generation EU recovery package which is a one-off recovery instrument by the EU. As indicated by the title, the programme is aimed to promote growth and it considers the three principal areas of sustainability: environmental, social and economic aspects while following the targets of the Government Programme. The Sustainable Growth Programme consists of four pillars (Valtioneuvosto, 2021, p. 5):

> *1) A green transition will support structural adjustment of the economy and underpin a carbon-neutral welfare society*
> *2) Digitalisation and a digital economy will strengthen productivity and make services available to all*
> *3) Raising the employment rate and skill levels will accelerate sustainable growth*
> *4) Access to health and social services will be improved and their cost-effectiveness enhanced entails the framework of the energy system.*

Out of the four, the first pillar Green Transition entails the framework of the energy system and describes measures for emissions reductions in the national electricity production. Additionally, circular economy and carbon neutrality are highlighted. The programme demonstrates the ambition coming from the political and state administration level. Thus, it should be expected that the ambition translates into support measures and circularity schemes to assist in the corporate transition.

The Waste Act 646/2011 (amendments up to 528/2014 included) aims at preventing the harm and hazard to both humans and the environment deriving from waste and waste management and limiting the quantity and harmfulness of waste. In addition, the Act is a tool to promote a sustainable product and process design and effective end-of-life treatment. The waste act also acknowledges the polluter pays principle. By definition, "waste means any substance or object which the holder discards, intends to discard, or is required to discard" (Waste Act 646/2011, 2012, p. 3). As per the Act, reuse of a product is meant when the product or a component can be used again for its originally assigned purpose, and preparation for reuse covers the process by which the product can be reused such as checking, cleaning and repairing. Additionally, there is a difference in what is categorised as waste and what is a by-product. A substance or object is a by-product and not considered waste when it is produced as a side-product and can be put in use nearly directly "as is" and fulfils relevant product requirements. By definition, "waste producer means anyone whose activities produce waste or anyone who carries out pre-processing, mixing or other operations resulting in a change in the nature or composition of such waste" (Waste Act 646/2011, 2012, p. 4).

The Waste Act also influences the producer obligations in different sectors. The producers of electrical and electronic equipment are required to provide a financial guarantee to the supervising authority Centre for Economic

Development, Transport and the Environment for Pirkanmaa to demonstrate their ability to cover the costs of reception, transport, and other waste management as well as to manage the educative responsibilities related distribution of information and promoting the reuse of domestic devices sold by them (Centre for Economic Development, Transport and the Environment, n.d.; Waste Act 646/2011, 2012). Notably, the producer collectives are designated to take over the implementation of the listed producer responsibility tasks. In Finland, five producer collectives are operating in the field of electrical appliances (Centre for Economic Development, Transport and the Environment, n.d.). Out of the five, there is one – ERP Finland – that has listed the PV panels in its service portfolio. In addition to the three collectives that recover a range of electrical equipment, there are dedicated ones for ICT and lighting waste (Centre for Economic Development, Transport and the Environment, n.d.).

The European Commission's Recast WEEE Directive was transposed to Finland, and the Government Decree 519/2014 on electric and electronical equipment waste came into force on July 15, 2014, pursuant to the Waste Act 646/2011 and Environmental Protection Act 86/2000, currently known as Environmental Protection Act 527/2014. The Decree provides for measures that decrease the amount of waste deriving from electric and electronical equipment and limits its harmfulness. Additionally, it aims at driving the preparation for reuse, recycling and other utilisation potential while improving the quality of treatment. It states that the product design should not include methods that purposefully prevent recycling, repairing or updating of the device. In the design and production phase, it is necessary to ensure for example that the battery or energy storage can be easily removed by a non-professional user (Government Decree 519/2014, 2014).

In addition, the Government Decree 519/2014 on electric and electronical equipment waste dominates the design of the payments that are due by the producers. In principle, the payments are proportional to the amount of electric and electronical equipment that the producer places in the domestic market and coordinated by the producer collective that the producer is a member of. Additionally, the total payables by a producer collective must cover the costs derived from completing the assigned EPR duties. The payment structure strategy must encourage developing products that are recyclable and repairable and support the production of long-lasting products. Additionally, there should be an incentive for the use of recycled material within the framework defined by the Decree. Notably, the producers have the responsibility to inform the users about end-of-life treatment and recycling opportunities. Solar panels are counted as part of the large appliance's category (Government Decree 519/2014, 2014).

By definition, producer responsibility is "an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle" (Organisation for Economic Co-operation and Development., n.d., Extended Producer Responsibility section). Within European Union and Finland, the EPR applies to companies that place batteries, cars, packages, paper, paper products, tyres or electronic or electrical equipment on the market in a professional manner (Centre for Economic Development,

Transport and the Environment, n.d.). As producers of electronic and electrical equipment are viewed as actors whose business is producing or importing electronic devices or selling those products under the operator's own brand. There can be only one responsible operator for a specific device, however, a brand can have several producers (Centre for Economic Development, Transport and the Environment, 2017). In December 2021, the Waste Act was amended to include also producers who are established outside of Finland, but distance sell directly to the consumer in Finland (Centre for Economic Development, Transport and the Environment, n.d.). Vice versa, the direct distance selling companies located in Finland are part of the EPR scheme in their target country. In these cases, the producer needs to appoint an authorised representative to fulfil the assigned obligations and responsibilities (Centre for Economic Development, Transport and the Environment, n.d.). There is no transition time for the amendment in Finland, but the European Commission's WEEE Directive allows it until 5 January 2023 (Centre for Economic Development, Transport and the Environment, n.d.; Directive 2012/19/EU, 2012). Another modification was related to the producer collectives. By the end of the year 2021, every producer had to join a producer collective or establish one with other producers (Centre for Economic Development, Transport and the Environment, 2017). The collectives need to consist strictly of producers, other operators are not allowed. The EPR supervised by the Center for Economic Development, Transport and the Environment for Pirkanmaa is applied only in continental Finland as Åland acts as an independent jurisdiction area also in this matter (Centre for Economic Development, Transport and the Environment, 2017).

The EPR can be observed through three main nominators: Firstly, operative, or physical responsibility for the product's end-of-life management, secondly the informative responsibility to disseminate information about the environmental impacts and recycling opportunities, and thirdly the financial responsibility for all the assigned tasks. The operative responsibility and financial obligations can be externalised to treatment facilities and through producer collectives. However, the informative obligation can be viewed as an individual responsibility as the producers are expected to provide records of the dissemination activities to the supervising authority (Centre for Economic Development, Transport and the Environment, 2017).

As said, the basis for most of the environmental and waste regulations that are in place in Finland is deriving from the guidelines and directives set by the European Commission (European Commission, n.d.e). Additionally, international agreements guide national policy making. Once the regulations and agreements are ratified, there are little to no opportunities to change them in a short period of time. The most effective period for influencing the future regulation is during the revision and commenting period. Individual companies often have only limited opportunities to partake in the regulatory process at the EU level. The organisations might not have the expertise, time, or financial resources to participate in the dialogue. To enable especially the small and medium-sized companies (SMEs) but also other, large companies' viewpoints to be heard, different interest groups and industry networks have been formed

(Teknologiateollisuus, 2021b). In Finland, the producers of electronic devices fall under The Technology Industries of Finland which represents Finnish technology companies. The interest group has five main sectors that it focuses on: electronic and electrical industry, machinery and metal product industry, metal refining, planning and consulting, and information technology (Teknologiateollisuus, 2021a).

2.3 Circular economy

As one of the key attributes of the EPR is stated to be its support for the transition to circular economy (Centre for Economic Development, Transport and the Environment, 2017). Therefore, to understand the link between the two, we will observe also the theoretical side of circular economy. The traditional "take-make-dispose" model of linear consumption is losing ground to more sustainable approaches (Ellen MacArthur Foundation, 2013).

2.3.1 Elements towards circular economy

Circular economy is a concept to disrupt the status quo of a product's lifetime, and it has gained attraction in the academic world as well as among policymakers since the 1970s (European Commission, n.d.e.; Geissdoerfer, 2017). Circular economy is based on the idea that the lifetime of a material and resources does not end as a product reaches the status of being waste or by-product. Rather, the material flow is a loop (Geissdoerfer, 2017). Ellen MacArthur Foundation has been credited for its definition of circular economy "an industrial economy that is restorative or regenerative by intention and design" (2013, p. 14). The existing open production model is not efficient from the point of view of raw material use, although many of the developed processes and thus end-products are cost-effective (Urbinati et al., 2017). On the other hand, when considering the lifetime of raw material from an economic point of view, it would make sense to exploit its value to the fullest after investing resources to extract and process it into a refined product (Korhonen et al., 2018). However, very commonly the established business models are based on the concept of the linear flow of raw materials and energy between environment and human use. As Korhonen et al. refer, the environmental system is being "run down" (2018, p. 38) as the planetary boundaries are being pushed for the sake of upkeeping the constantly growing supply of products, and emissions and waste are returned to nature in return. Notably, the potency and efficiency of industrial processes are fine-tuned but simultaneously they generate several individual and accumulating sources of waste and emissions (Urbinati et al., 2017). Naturally, the consumption model is not only applicable to industrial activities but embedded in the general mindset of the public and the operational design of the society (Broman & Robèrt, 2017).

There is research discussing the key elements that contribute toward enabling circular material flow in industrial production. Notably, there are points of

consideration across the value chain. Starting with the product design, it is noted that to enable circularity, the raw material choices are meaningful (Broman & Robèrt, 2017), and consideration should be placed on the use of toxic materials that cannot be reused or that will prevent reuse (Ellen MacArthur Foundation, 2013). Additionally, as the process to prepare for reuse or disassemble a product should be made as effective and less resource demanding as possible, the design should support that aim. Additionally, standardisation and "modularisation of components" is proposed as a strategy (Ellen MacArthur Foundation, 2013). Urbinati et al. (2017) propose a categorisation for the different product design practices to assist in the strategy formation, such as design for recycling, design for remanufacturing and reuse, design for disassembly and design for the environment. In relation to the producer responsibility and take back management (Bocken et al., 2016), there is a need for cost and resource-effective collection and treatment systems and thus developing the value proposition in reverse cycle (Ellen MacArthur Foundation, 2013).

To enable circular economy, it is necessary to understand the implications to the business environment as well as identify the relevant action points. Sustainable business models are expected to address the triple bottom line approach as well as integrate multiple stakeholder interests into their decision-making criteria (Ellen MacArthur Foundation, 2013). For example, Bocken et al. (2014) describe the archetypes for sustainable business models. They identified the applicable grouping of features that enable value creation from sustainability. The three main groupings can be divided into technological, social, and organisational business innovation. The archetypes under the technological group are maximising material and energy efficiency; creating value from "waste"; and substituting with renewables and natural processes. In the social grouping are delivering functionality rather than ownership; adopting a stewardship role; and encouraging sufficiency. The third grouping, organisational, consists of re-purposing the business for society/environment; and developing scale-up solutions. Each archetype is related to circular economy in different degrees. However, creating value from so-called waste directly reflects the principles of circularity and closed-loop material flow. Additionally, the producer responsibility and take-back policies are closely connected to this archetype. At the core of the archetype is the idea of eliminating waste as a by-product and rather turning the waste streams into a value-adding input. The archetype is loosely applying biomimicry as in the natural processes there is no actual waste in the environment as the output products are further utilised by other flora and fauna (Bocken et al., 2014). The ambition to convert waste to a valuable input requires having a user with a need for such a stream. Thus, circularity requires the creation of new partnerships and generating industrial symbiosis between different operators and even industries (Broman & Robèrt, 2017).

Along the same lines as the earlier study, Bocken et al. (2016) offer a categorisation of circular business model strategies to slow or close resource loops. The proposed slowing down strategies include access and performance models that are based on the idea of the customer not needing to own the physical product. Extending product value refers to producers taking back a product and

refurbishing it for further use and the classic long-life model is based on careful repair and durability planning. Notably, the reuse and second-life products are attaining more attractive value propositions but there are still challenges in the mindset of the public and inbuilt resistance to recycled electricity products (Ylä-Mella, 2015, Cole et al., 2017). Also, encouraging sufficiency includes extensive repair planning but extends to upgradability, warrantees and supporting non-consumerism (Bocken et al., 2016). In terms of the innovative business models, also Ellen MacArthur Foundation refers to sharing or leasing-based offerings instead of ownership-based (2013).

Business model strategies for closing the resource loop consist of extending resource value through developing new uses for the to-be waste, and the industrial symbiosis concept that directs residual outputs to another process as an input. The input can be used for an internal process or provided to an external actor that operates in geographical proximity. The approach adopted by the EC Circular Economy Action Plan (Communication COM/2020/98, 2020) and for example Ellen MacArthur Foundation (2013) highlights that slowing down the rhythm of linear cradle-to-grave product lifetime is not the goal of circular economy but rather feeding the "industrial metabolism" with materials and resources in a way that they provide high-quality input over and over again. However, towards that goal, the factors to assist in system-level integration need to be identified and market actor interaction and supported. Potential tools for such would be relevant education and training and creating opportunities as well as infrastructure for industrial symbiosis (Ellen MacArthur Foundation, 2013).

2.3.2 Identified hurdles and challenges in circular economy

As often in disrupting business models, multiple hurdles need to be addressed when it comes to implementing circular economy in practice (Panchal et al., 2021). Korhonen (2018) and Marsillac (2021), for example, have studied the challenges related to adopting circular economy approaches and noted that the hurdles have multi-fold features. The challenges are related to thermodynamics, process and material management, social and cultural aspects, system boundary limits and definition, governance and product life cycle management, and cross-organisational and sectoral flow management (Korhonen, 2018). In terms of limitations in the process, it is notable that the cyclical systems require resources as well and produce waste and emissions as per the laws of physics even if there were ambitions toward a closed-loop system (Korhonen, 2018). Additionally, it is noted that the problems – and responsibilities can be shifted along the product lifecycle depending on the definition of system boundaries. In terms of social and cultural definitions, again the definition and use of the term waste are underlined. It is a socially and culturally constructed concept that has a strong impact on the attitudes and handling, and thus influences the eagerness to assess its further use cases (Korhonen, 2018). The long lifetime of a product – notably the case of PVs – is highlighted. PVs are constructed and designed tens of years before their end-of-life and recovery for treatment (Masoumian et al., 2015). Due to this, the PVs reaching their end-of-life are not necessarily applicable to the state-of-the-art

reuse principles (Marsillac, 2021) – especially noting the rapid technological development that is ongoing in the PV solutions (Taylor & Jäger-Waldau, 2020). Moreover, throughout the long lifetime, the product has avoided multiple regulatory or design development steps in a way that would facilitate effective redesign or disassembly at the end of the lifetime (Marsillac, 2021; Panchal et al., 2021).

Tsanakas et al. (2020) studied the end-of-life management of the PV installations and the potential value creation of circular approach. According to their findings, there will be a need for solving the challenges related to reverse logistics globally and upkeeping the quality and value of materials throughout the recovery process. Additionally, they highlight the importance of process management; for the treatment processes to be financially appealing, it needs to be scalable and optimised. A key variable towards this is a sufficient amount of treatable mass, in this case referring to retired PV waste. Notably, having enough mass is not enough to ensure an effective circular process. The material needs to be kept in adequate quality for processing or reuse – here the careful design of logistics and storing network comes into play in addition to the pure product design.

3 DATA AND METHODOLOGY

After defining the research problem and creating grounds for the research in the form of a literature review, the next step is to create a research design. The related decisions consist of the type of research to be conducted; should it be theoretical or empirical, experimental or not, quantitative or qualitative (Bloomberg & Volpe, 2012). This research is an empirical qualitative study on the relationship between the concept of circular economy and regulated producer responsibility in Finland.

3.1 Research design in theory

This section will describe the theoretical background of the qualitative research and how it was implemented in this thesis process.

3.1.1 Qualitative research and related theory

It has been said that qualitative and quantitative research have their own distinct cultures (Mahoney & Goertz, 2006; Lichtman, 2017). Qualitative research revolves around discoveries from the collected data and generating theories based on the information whereas quantitative research uses the data and measurements to examine relationships and properties of the studied issue (Hair et al., 2015). The differences in the two approaches are many-fold, as are their distinct weighting and focus on research design (Mahoney & Goertz, 2006; Lichtman, 2017). At its extreme, the selection divides researchers into two groups and it has been implied that there is only little movement from one method to another (Lichtman, 2017). Notably, the importance of utilising both statistical and case-based methods has been acknowledged as well as the benefits of a mix of both (Mahoney & Goertz, 2006).

To start with, qualitative research is a study of social phenomena and interactions that cannot be measured in a laboratory or hygienic setting (Lichtman, 2017). Hair et al. (2015) additionally state that the qualitative approach is suited for research problems that are not fully or even partly covered in previous studies. An unquantifiable nature of a research problem directs the study method towards a qualitative one, the approach inherently presents inductive thinking as the process moves from specific to general (Hair et al., 2015).

In terms of research goals and questions being asked, qualitative research is interested in causes-of-effects and especially the why's and what's of human behaviour (Lichtman, 2017). This means that qualitative research looks at individual cases and what are the causes for those instead of observing the average effect of selected variables. This is also visible in the preferred sample or study size. Mahoney and Goertz (2006) present an example of qualitative research on social revolution where only three country cases were used to describe the

impacts. This feeds into the concepts of causation; the qualitative approach aims at identifying common causalities for a limited number of cases.

In qualitative research, the emphasis is placed on the case selection (Mahoney et al., 2006). The observations are derived case by case, and thus a careful definition of the scope and focus is required (Lichtman, 2017). Through specific criteria for the case selection, it is possible to identify the so-called positive cases that exhibit the favoured outcomes. The importance of the details and unique features of the cases are highlighted and considered during qualitative examination. Hence, qualitative research considers it crucial to understand the individual and unique drivers and features of each case in order to draw conclusions (Lichtman, 2017). When studying exceptional outcomes, the sample size is unavoidably and by definition small in contrast to outcomes or conditions that are not considered extraordinary – a common phenomenon is rarely extraordinary. Notably, the observational and interpretative nature of the research setting leads to results that are more often thematically or narratively presented in the form of pictures and verbal description rather than as statistical analysis or numerical tables (Hair et al., 2015).

The roots of the grounded theory approach date back to the 1960s and the book "The Discovery of Grounded Theory" by Glaser and Strauss (Eriksson & Kovalainen, 2008). By stating that qualitative research is grounded, one refers to an approach where the conclusions and results are derived from the information that is collected during the study rather than emerging from existing knowledge or theories (Hair et al., 2015). The distinct feature of grounded theory methodology that sets it apart from other qualitative methods is that its iterative process between data collection and analysis is dominated by a structural process that has a somewhat strict pre-established form (Eriksson & Kovalainen, 2008). As a rule of thumb, regardless of the study field or subject, grounded theory research should result in a new theory proposition.

Three distinct types of scientific reasoning that can be utilised in the critical examination are deduction, induction and abduction (Mantere & Ketokivi, 2013). In short, deduction refers to reasoning where a conclusion on a particular case is drawn from a general, and an example of deductive reasoning would be theory-testing research. Induction thereafter refers to a generalisation based on a particular case. Often inductive reasoning is linked with qualitative reasoning, and the grounded theory lays out the basis for inductive reasoning. However, the two are the basic forms of reasoning whereas abduction is a combination of the two accepting an amount of uncertainty and is rather a best-estimated guess that is reached based on facts or evidence. Although in this thesis the inductive reasoning is highlighted, the aim is to apply abductive logic in order to develop a more thorough and comprehensive analysis. Through the selected number of interviews, the aim is to identify elements that create hurdles in the implementation of circular elements in the photovoltaic market and describe – based on the evidence – the factors that steer the sector development towards circular economy.

This thesis adopts a qualitative approach by carefully choosing the interviewed stakeholders and forming a perception of the circular opportunities in

the PV market and building a bottom-up scenario identifying the enablers of favourable and functioning environment for circularity.

3.1.2 Data collection methods in qualitative research

Hair et al. (2015) divide the methods of qualitative data collection into two groups: interviews and observations. Interviews entail in-depth interviews, focus groups, case studies and projective techniques, and observations can be either done by human, electronic or mechanical means. Starting with interviews, they can be designed in various ways and given different degrees of structure and formality, and the number of people present can vary according to the needs of the research question. Silverman (2001) discusses the typology of interview studies that uses a grouping of positivist, emotionalist and constructionist approaches. The category is nominated by the nature of the research question. If the study is interested in facts; changes, processes, operations, consequences, or so forth, the interview questions are formed to gather concrete information and are so-called "what" questions (Eriksson & Kovalainen, 2008). This type of data collection is called the positivist approach, or alternatively naturalist or realist approach. Emotionalist, or subjectivist, interviews aim to explore people's experiences of the said processes or changes, and the questions are built to understand how they perceived or felt in the situations. The third type, the constructionist approach, differs from the previous two by asking "how" questions and focusing on the interactions between the interview parties. As often in research, the distinction is not necessarily clear cut and research can make use of more than one type of interview questions (Eriksson & Kovalainen, 2008).

In terms of interview structure, depending on the needs of the study, it can be structured, semi-structured, or unstructured, guided or open, formal or informal, and so forth (Eriksson & Kovalainen, 2008; Hair et al., 2015). Interviews that are conducted using the positivist approach are typically structured and have a well-prepared script that it follows, notably, the questions are open-ended and require a descriptive response from the interviewee (Eriksson & Kovalainen, 2008). The structured format enables systematic synthesis and comparison of the results. Although, on the other hand, it restricts the flow of the discussion and poor planning might result in low-quality responses (Hair et al., 2015). Guided and semi-structured interviews cater for the needs of both "what" and "how" questions (Eriksson & Kovalainen, 2008). The pre-selected themes and core discussion points provide guidelines for the discussion while still leaving room for more informal and dialogic conversation (Hair et al., 2015). However, the analysis of the results is more burdensome than in structured interviews since the interviewees are allowed to reply in a more diverse and varied manner (Hair et al., 2015). At the other end of the spectrum are the unstructured interviews that represent of a discussion than an interview (Eriksson & Kovalainen, 2008; Hair et al., 2015). This approach aims at exploring the topic in an as diverse and broad manner as the interviewees wish allowing the discussion to take any direction possible and focusing on understanding the phenomena strictly from the person's subjective point of view (Hair et al., 2015). Often unexpected insights emerge from

the interviews and thus provide grounds for generating new research questions and study areas (Eriksson & Kovalainen, 2008). Depth interviews represent as unstructured interview type as they are free flowing discussions, and often on sensitive topics (Hair et al., 2015).

This research has adopted the positivist approach in order to capture the current status of the system and understand the dynamic between the regulatory framework and potentially other drivers that impact the commercial strategies. Notably, as there is not so much research on the circular opportunities in the PV lifecycle system in Finland, an informal dialogue might allow for more unexpected insights to come to light. However, the biggest disadvantages of unstructured interviews would have been related to the amount of work required in the analysis stage. On the other hand, in terms of the structured and semi-structured interviews, more effort is placed on the preparation stage to avoid bias and poorly targeted questions. Therefore, a semi-structured interview plan was generated to direct the conversation but still leave room for distinct answers. Elements of the observational approach will be utilised in the form of document review and content analysis of the interview transcriptions.

3.1.3 Coding of qualitative data

Qualitative data is challenging to analyse (Bryman & Bell, 2007). For this, coding is used in qualitative analysis to simplify the mass of information and identify patterns and meaningful attributes from the data (Hair et al., 2015). The process of coding was described by Miles and Huberman (1994, as cited in Hair et al., 2015). Their simplified process contains data collection, data reduction, data display, and drawing conclusions. The coding process is iterative, meaning that during the analysis, it is necessary to re-visit the raw data multiple times to narrow down the significant aspects. Additionally, the process requires repetition between data collection and analysis. Bryman and Bell (2007), as well as Corbin and Strauss (1990) discuss coding as an activity in a practical and detailed manner. In the following, we will briefly introduce the relevant terminology as in Bryman & Bell (2007). In practice, concepts are the founding element of the analysis and "building blocks" of grounded theory as described by Corbin and Strauss (1990, p. 425). They are identified from the interview transcriptions as repetitive discussion points or incidents with proven relevance in the study area. It is necessary for the researcher to generalise and find a common term for the occurrences that can be described by the interviewees in a variety of ways. Concepts can be grouped under categories. While there can be numerous concepts, the number of categories is relatively low. However, not all concepts will be part of a category. Categories have properties to describe them and specify the characteristics of each. Hypotheses on the other hand are generated to anticipate the dynamics between the concepts. In the end, categories are connected to act as a basis for the resulting theory. Two types of theory were described by Bryman & Bell (2007): substantive theory and formal theory. Substantive theory refers to a certain instance whereas formal theory is more general and can cater to more than one substantive instance.

The grounded theory is subject to some criticism. The main criticism related to the lack of objectivity due to increased awareness and research; how can the researchers ensure that they examine the concepts without bias and avoid seeking traces of evidence towards pre-existing knowledge (Bulmer, 1979 as cited in Bryman & Bell, 2007). Other, rather practical factors that might distort the iterative and objective study are time constraints and availability of resources in the context of laboursome transcribing and potential external expectations placed by funding bodies (Bryman & Bell, 2007). Bryman and Bell also discuss the challenges brought around by the vague use and definition of concepts and categories in the literature that can be found confusing. Additionally, there is a concern if many grounded theory studies indeed result in a theory as it by definition should.

3.2 Research design in practice

The actual thesis research took place during the first half of the year 2022. As described above, it was preceded by careful research on the theoretical and practical background to ensure the relevance and suitability to the thesis topic. The coupling of theoretical and practical aspects of the research design are described step by step in Figure 2. After defining the research question and conducting a careful theoretical review, the actual data collection took place in the form of the interviews. Based on the materials from the interviews, data analysis prompted a thematic grouping of the main findings that are summarised in full in FIGURE 3. The following chapters will discuss in more detail the practical implementation of the research from starting the process, to conducting the interviews and to results analysis and coding.

3.2.1 Path from the start to interviews

The qualitative data collection process was started in February 2022 by making the first contact with identified potential interviewees. The main contact method was via email. In total, 23 people were contacted resulting in nine interviews from eight different organisations. The participants were provided with information about the interview style, purpose and goal prior to the interviews. In addition to ensuring their awareness of the context of the study, the aim was to confirm that the contacted person would be the best-suited person from the organisation to attend. On a few occasions, the interview invitation was forwarded to a better fitting colleague, which served the purpose well. Additionally, the participants received the official documents such as the privacy statement and information about the study, and all participants agreed to the terms – it was confirmed separately that there were no objections for recording the interviews and including the name of the participant and their represented organisation in the final thesis. All interviews were conducted remotely through Zoom teleconference and recorded to facilitate transcribing.

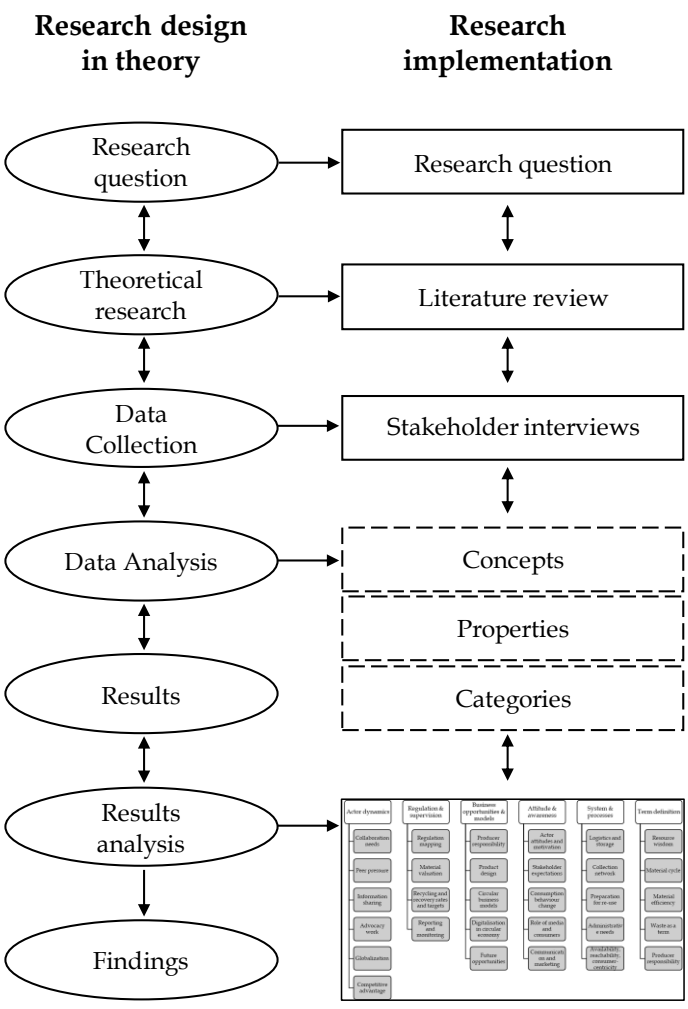

FIGURE 2 Coupling of the research design in theory and in practice

The interviews were conducted as semi-structured and were rather informal in style. Although the main question pattern was set (see Appendix 1 for the template questions), the participants were encouraged to discuss any topics in further detail and often the initial question points stirred up follow-up inquiries and discussions. As expected, depending on the expertise of the interviewee, some topics were discussed in more depth while other answers were only scratching the surface. The interviews had varying lengths between 30 minutes to over an hour, the most common duration was approximately 45 minutes. As per the data management guidelines by the University of Jyväskylä (2021), the materials were stored on

the U-drive and handled with care so that only the author had access to private and personal information.

3.2.2 Interviewed stakeholders and their role in the market

Although the Finnish solar panel market does not operate in an economic bubble, for simplification, the interviews are limited to include domestic actors and exclude international trade and foreign operators. The interview participants are part of the life cycle of solar panels and contributors to circular economy. The interviewed individuals and their organisations are listed by the stakeholder type in Table 2.

TABLE 2 List of the interview participants and organisations by the stakeholder type

Stakeholder type	Organisation	Expert
Authority	Centre for Economic Development, Transport and the Environment for Pirkanmaa	Satu Ala-Könni Senior inspector, EPR matters
Authority	Energy Authority, Energy efficiency & Ecological design	Juha Toivainen Chief Specialist
Consumer organisation	Motiva	Ilkka Hippinen Chief Specialist
Producer collective	Elker ry, WEEE	Sini Jääskeläinen Specialist
Producer collective	Elker ry, WEEE	Elina Tanskanen Specialist
Producer collective	SER-tuottajayhteisö SERTY	Arto Puumalainen Executive manager
Research and academia	University of Oulu, Faculty of Technology, Water, Energy and Environmental Engineering research unit	Jenni Ylä-Mella Post-doctoral researcher
Service provider	Helen Oy	Minna Junnikkala Head of Solar & Wind Energy
Service provider	Solnet Green Energy Oy	Antti Lehmuskoski Sales Manager

Notably, although the participants view the market through the lens of their organisation's role and interests, the comments do not necessarily represent the official position or policy of their represented organisation. The comments are rather personal views and opinions stemming from their general professional experience.

Energy Authority operates under the Ministry of Economic Affairs and Employment and supervises the electricity and gas market in Finland (Energy Authority, 2021). Following the Clean Energy Package adopted by the EU in 2019, the expert organisation was given new tasks in relation to promoting renewable energy and energy efficiency initiatives (Energy Authority, 2021). The authority to oversee the management and end-of-life treatment of WEEE is the Centre for Economic Development, Transport and the Environment for Pirkanmaa (n.d.). The Centres for Economic Development, Transport and the Environment of different regional areas fall under the Ministry of Economic Affairs and Employment in addition to following the guidance and goals of other ministries and governmental bodies (Centre for Economic Development, Transport and the Environment, n.d.). Each regional branch is dedicated to monitoring, collecting information and analysing the prospective of their region's business, environment, infrastructure, and employment opportunities. They also grant funding to various projects and initiatives as well as impose policies, such as the waste treatment regulation and the producer responsibility. As a link between the producers and waste treatment facilities, there are producer collectives to assist and oversee the rights of producers. For the management of electrical and electronic equipment waste, national and international producer collectives offer as a service to take over the EPR related obligations on behalf of the individual producer (Centre for Economic Development, Transport and the Environment, n.d.). In Finland those are namely SER-tuottajayhteisö ry SERTY; European Recycling Platform ERP Finland ry; and service company Elker Ltd which is an umbrella organisation for three distinct producer collectives: SELT Association, ICT Producer Co-operative, and FLIP Association. Out of them, Elker and SERTY took part in this study. While Elker was founded in 2004 by the three producer collectives, it also belongs to a European joint venture network. Thus, it is well connected to other EU markets as well as Norway and Switzerland (Elker, n.d.). SERTY (n.d.) on the other hand has operated in the field of WEEE since 2000. Solnet Finland Ltd (n.d.) is a Finnish solar electricity provider. It operates mainly within the business-to-business market by designing and installing solar panels on customers' own property as well as providing PPA solutions and solar electricity as a service. Although Solnet is one of the largest providers in Finland with a 4.3-million-euro turnover, it is still a modest actor on the global scale (A. Lehmuskoski, personal communications, March 17, 2022). Helen Ltd is a Finnish incumbent utility providing district heating and cooling in Helsinki and selling electricity nationwide to domestic and industrial customers (Helen Ltd., n.d.). It is among the market leaders in Finland together with Fortum and Väre and has been vocal about its research and development activities. The company aims to be a pioneer in renewable offering and a significant action point in their strategy is to replace coal in their production by 2029 (Helen Ltd., n.d.). Based on their annual report, in 2021, the

company's electricity production mix consisted of natural gas (30%), coal (25%), nuclear power (27%), and renewables (18%), namely hydro, solar, and wind. In terms of academic viewpoint, the University of Oulu and Jenni Ylä-Mella were invited. Ylä-Mella is a post-doctoral researcher from the department of water, energy and environmental engineering and has authored articles related to topics on waste management, recycling, resource management, environmental awareness, and management of WEEE in the Finnish consumer market (University of Oulu, n.d.).

3.2.3 Coding of the interview material

The coding of the material was conducted as an iterative process and the results were refined with each round of revision. The process was conducted in a very manual manner. Digital copies of the original interview transcriptions were created and stored together with other materials on the University of Jyväskylä's U-drive. The stakeholder identifier codes were created by an online random sampling tool to avoid human bias in the numbering or ordering. In terms of coding, the paragraphs and the pieces of text that had special significance or contained topics that were discussed repetitively were highlighted. As a method for the highlights were yellow highlight colour and an accompanying comment box that summarised the main message of that specific text snippet. From the interview-specific Word documents, the information was combined into an Excel sheet. In the first stage, the Excel sheet contained dedicated columns for the stakeholder identifier code, the original piece of interview text and the summarising description. As a next step, it was necessary to zoom out of the detailed cases and define the describing terminology. There were three rounds of revision and rephrasing during which the descriptive terms were rendered and topics grouped under a set of main titles. After the second round of revision, the original transcriptions were visited once more to examine if by chance any key issues were neglected during the initial selection. Although the Excel sheet contained close to 500 rows of selected material from the interviews, the most comfortable method to do the grouping was to use the filtering tool of an Excel sheet and manually pick the synonymous descriptions instead of researching for a dedicated qualitative coding program. In the end, six main themes, so-called categories, were nominated. The categories are:

- Actor dynamics
- Regulation and supervision
- Business opportunities and models
- General attitude and awareness
- System and process
- Term definition

The six main categories consist of concepts. The key concepts that feed into the Actor dynamics category were such as information exchange, domestic and

horizontal collaboration, international collaboration and global markets, rights, responsibilities and obligations, division of responsibilities and tasks, internal and external supervision and peer pressure, market share and following dominant position, lobbying efforts and advocate roles. The category of Business opportunities consisted of the barriers and drivers to monetisation; opportunities brought by service-based offerings, technology advancements, corporate investment strategies, the enabling features of megatrends and changes in consumption patterns, digitalisation, benchmarking to other industries, energy market as well as societal development. The general attitude and awareness category expanded, but the concepts are tightly knitted together. The main properties of this category are related to the significant shift in people's awareness of climate change and engagement in mitigation activities on several levels. The concepts also included both the positive change but also the notion of needing to improve the dissemination of information about not only circular themes but also the practical side of the consumer waste management system. The system and processes category, on the other hand, focused to gather the concepts that describe the functionality of the waste management system, the challenges in the network and logistics, process management and identified pitfalls, and the lengthy supplier chains. Regulation and supervision grouped together concepts related to policy notions and regulatory environment at local, domestic and international or EU level and both obligatory as well as voluntary agreements. Other concepts were related to ecodesign and modularisation, sustainable product features, recycling and circularity targets, reporting and related tools. The category of term definition took a step back to describe the way that the stakeholders define and perceive the relevant concepts – namely circular economy, producer responsibility, and waste.

4 RESULTS

Based on the iterative coding process, six main categories were nominated (Figure 3). They were Actor dynamics, Regulation and supervision, Business opportunities and models, General attitude and awareness, System and process and Term definition. In the following sub-sections, each category and their properties are described in more detail outlining the dynamics between the concepts, while also drawing connections between the categories. The citations integrated to the results discussions are derived from the interview transcriptions and are loosely translated from Finnish to English by the author.

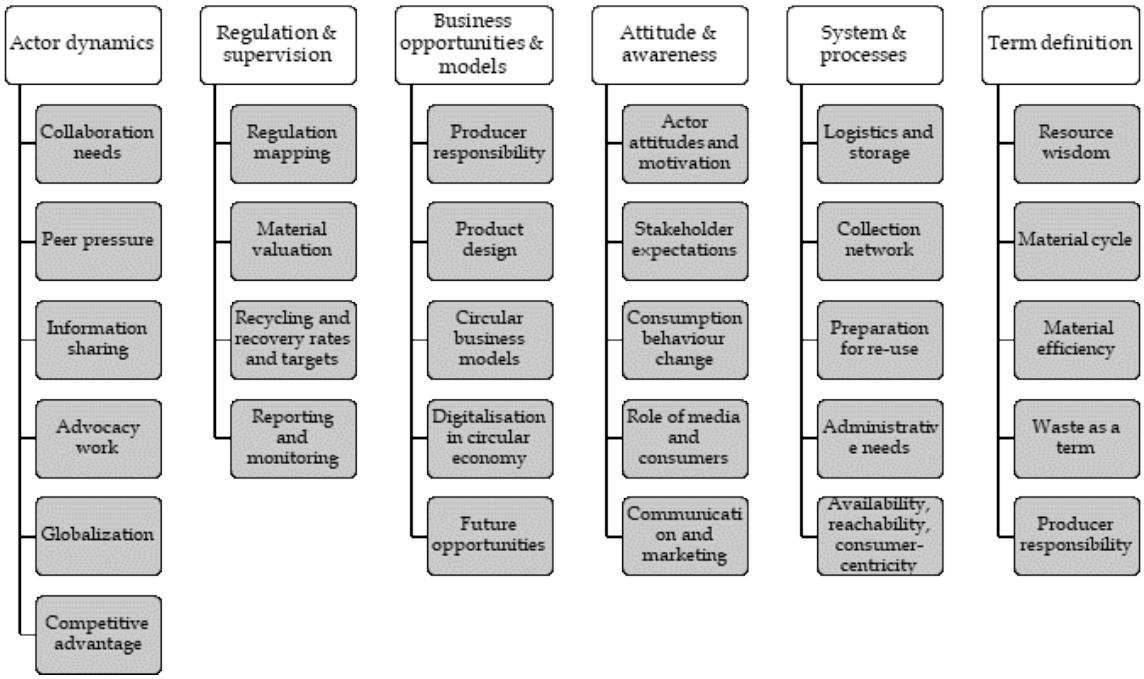

FIGURE 3 Categories and their main properties

4.1 Actor dynamics

The main properties of actor dynamics are collaboration requirements, peer pressure, information sharing, advocacy work, impacts of globalization and competitive advantage as summarised in Figure 4.

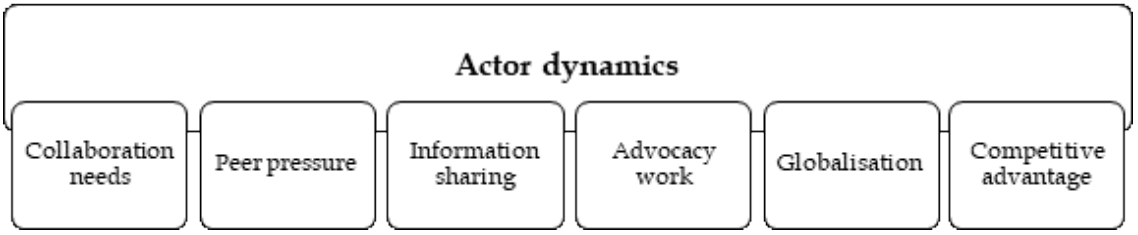

FIGURE 4 The main properties of category "actor dynamics"

In the interviews, the division of roles and responsibility was described as follows:

> What can be seen on the [waste management] operator's end is that when there are new requirements on how devices should be recycled, or recycling criteria, or what devices need to be taken to the recycling operator, the responsibility to come up with a solution and deal with it falls on the lap of the recycling operator. (Stakeholder 5)

In terms of actor dynamics, there were especially two sub-themes that were highlighted. In terms of domestic actor dynamics, the stakeholders noted that it would be beneficial in various ways to have collaboration between the different actor types. This includes transparency and information exchange. It was said that a hurdle in enabling industrial symbiosis and resource circularity is a sort of jealousy of information. The companies prefer not to disclose information on their processes or materials presumably in the fear of revealing company secrets or giving up competitive advantage. Another angle to not highlighting the amount or type of by-products was assumed to be related to the potential brand damage. If the public was made aware of the generated waste, it could paint a picture of polluting company activity. Being connected to the general atmosphere and attitudes, the potential of circularity is missed here. Instead of assuming that waste is definitely a negative thing, it could be perceived as an opportunity for finding an alternative use for the by-product and providing a valuable material for another type of production process. The shift in producer awareness and engagement in environmental topics was summarised as follows:

> Over the past seven or so years there has been a change in the producer's awareness of the producer responsibility, and in general, the level of knowledge on the corporate environmental responsibility has increased. On average, the companies are more open to the idea of environmentally sustainable behaviour. (Stakeholder 5)

The interaction between the domestic producers has also encouraged the actors to join a producer collective. There were several instances mentioned where peer pressure of sorts had worked as the main driver to engage in a collective, as per

the quotation above. Similarly, the power of customers was demonstrated when the producers expressed that the reason for joining a collective was due to a client inquiryaboutn their collective membership. This type of general movement was seen to be a positive sign and beneficial for the whole sector.

While there is an atmosphere of "if they don't, why would I" as well as "well, if they do, I should too" (Stakeholder 8), openness and transparency of information are at times lacking between the actors. This was said to be a challenge from a variety of perspectives. Firstly, monitoring and having a general overview of the market is challenging if the sales and recovery rates are not publicly displayed. More importantly from the circular point of view, the secrecy of used materials and processes makes it challenging to identify opportunities for collaboration or material trade as described in one of the interviews:

> It is similar to what we have noticed when working on the industrial symbiosis initiatives, it is quite challenging to persuade organisations to join as it is not evident to them what are the concrete benefits or financial benefits to investing time and resources in such projects. We have also noticed that companies are quite jealous of their information. Circular economy requires that one needs to be transparent in terms of information, for example, if a company produces waste by-flow, no one will come up with a solution on how to make use of it unless they know such by-flow is available. (Stakeholder 9)

There are projects and consortiums of a variety of sorts and sizes bringing the actors together. There are national level initiatives, EU-wide and global, the funding and coordination can be governmental and from the ministry level or by the local or international interest organisations, research organisation-led or informal collective of near competitors.

> Depending on the different components, there are multiple options for the panels. We make use of the producers in the Tier 1 category, referring to the biggest, spearhead ones. Then again, when you go down the supply chain, you always end up to the origins – it's all roads lead to Rome type of a situation. (Stakeholder 2)

As the quotation above indicates, globalisation and the challenges related to it were brought up in several instances. It was noted that Finland is a small market on a global scale, and even the most significant players in the Finnish markets are very small globally. Thus, opportunities to have a say in the international market are limited. For example, there are some opportunities to vote through the wallet and change technology or component providers. However, notably, as it was said along the lines of the famous saying, "all roads lead to China". The message was, that although a producer could change their supplier for sustainability reasons, the components or their raw materials are still sourced from China. The role of interest groups was highlighted as they are able to amplify the message of smaller actors. For example, in connection to the mistreatment of Uyghurs in China and

the potential connection to the sourcing of crystalline silicon for the PVs, the European interest group SolarPower Europe took a stand on behalf of their member companies to be against the use of Uyghurs during the sourcing process. Notably, the sourcing chains are long in the electronic equipment industry where the different components and raw materials are provided by different producers and assembled at various stages of the production chain by other actors. The electrical equipment that reaches the Finnish market has already visited the working stations of various companies and countries. Another aspect of globalisation is related to the opportunity to influence product design. Not only is the assembly done out of the reach of Finnish actors, but also the main target market is usually other than Finland. In the case of photovoltaic panels, they are mainly designed for the sun-filled areas that have the highest potential for solar energy. There could be minor technical alternations done for the panels that are directed and imported to the Nordic circumstances to ensure optimal performance and endurance during winter months, but it is not significant. Hence, although the importance of circular-enabling product design was acknowledged, there was scepticism if there is any opportunity to influence the design process.

> All the big global data and IT companies are the leading the way with the renewable generation and realising PPAs [Power Purchase Agreements] and service agreements. Amazon, Facebook, Microsoft, they all have massive PPAs that have financed the building of new wind and solar power capacity in Europe. (Stakeholder 2)

Leading from the previous quotation, the size of the company was brought up in various instances and on different scales. It was noted that the large companies and corporations have a significant advantage due to their size compared to small and medium-sized companies. The same applied when discussing domestically measured large companies and SMEs as well as Finnish companies and global conglomerates. It was noted that circular schemes often add an administrative step to the recycling process. Thus, considering the participation in such a scheme and the increasing regulatory demands for more detailed reporting are easier for a large company to fulfil. Whereas SMEs might not have the personnel resources or opportunities to integrate such administrative tasks into their processes efficiently. Thus, it was said that large size distinctively brings competitive advantage, and the increasing regulatory demands even further diminish the margins for SMEs. The need for fair and just regulation was vocalised in multiple interviews in order to allow competition while still supporting the SMEs to carry on doing business and stay on board with sustainability. The competitive advantage of size also creates a link to the opportunities to influence the market and have a driving power towards the goals of one's interest. As summarised by the stakeholder 8, the difference in perspective and opportunities is dependent on the size of the company:

> You can really see the difference. For some, especially small actors, it is very forced [to join a producer collective] and they do it only because they

> are being told to do so, whereas others are more proactive to inquire about their responsibilities and how they could tick all the boxes. (Stakeholder 8)

4.2 Regulation and supervision

The category of regulation and supervision is characterised by the necessity of careful mapping of pieces of different regulatory areas, valuation of the (secondary) raw materials, reaching high circularity rates and meeting the set targets, and purposeful reporting and monitoring (Figure 5).

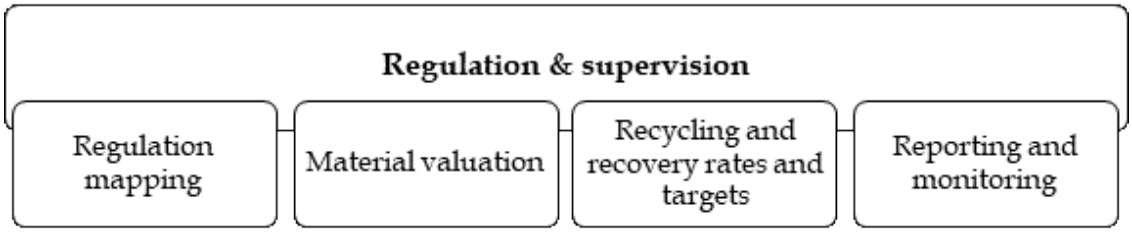

FIGURE 5 The main properties of category "regulation and supervision"

The perception of how well the initial goal of the producer responsibility has been realised was described by one of the interviewees as follows:

> The directive has been created with the goal in mind that the producer responsibility will guide towards producing more environmentally friendly devices. But in practise, the most important thing is that all waste will be recovered and end up to waste collection instead of being ditched into the nature, forests, lakes, or be incinerated, so that it would be find its way to the right place in the end. (Stakeholder 6)

Not only did the stakeholders highlight the courtesy between the different actors' speciality fields and not stepping on others' toes by intervening in their area but also the distinct areas of regulation. It was seen to be a good thing that the different types of regulations and directives have their specific focus. Thus, the regulation can be mapped and knitted together rather than having pieces of regulation that extend very widely. Concretely, what is meant by this is that for example the producer responsibility should cover the whole lifetime of the product but still the ecodesign directive has its role in specifying the expectations for the sustainable product design. Additionally, the waste regulation was perceived to be necessary on its own as it has implications for the waste management operations that are not relevant to the scope of, for example, ecodesign.

There were varying views on the necessary amount and strictness of regulation. Depending on the perspective, there were comments indicating that regulatory measures should be implemented more aggressively to drive and push

towards circularity and circular business models. On the other hand, the regulations were said to form a barrier to product development and innovation as the legislative framework could be restrictive or lag behind market-driven development. Notably, in a developing field such as photovoltaic panels, according to the interviews the authorities have realised their responsibility:

> Ecodesign and energy label decrees have been prepared for a few years now. It has taken its time as it is relatively challenging to establish the levels for minimum requirements or figure out the aspects that are the dealbreakers. For example, solar panel technology is constantly being developed so it is crucial to avoid setting too harsh limits that would exclude certain products out of the market or cut future development directions. (Stakeholder 3)

It was underlined that the upcoming regulation aims to be unrestrictive and focus on having minimum requirements in terms of efficiency, expected lifetime, and opportunities for reuse rather than placing prohibitions on the used technology for example. The goal is to ensure consumer usability through these minimum requirements without excluding or blocking potential innovation directions. The transition towards circular business models was said to require not only regulatory stick but also carrot and financial incentives:

> The reality is that it [circular economy] is rarely good business and the euros are a priority for companies. The regulation has its place, and in my opinion, it is good that we have strict and ambitious regulation. But it also has to do with how we impose them: that we advise and supervise and supervise and advise, instead of sanctioning as the first thing when something doesn't go according to the rules. (Stakeholder 6)

Through reassessing the value and valuation of waste, the circularity and reuse aspects would have more appeal. Different opportunities such as more effective pricing for the distracted raw materials or generated waste types were described. There were no strong views to oppose or support the claim on the competition distorting effect of producer responsibility. The extension of the producer responsibility regulation was welcomed due to the wider self-monitoring expectations. For the authorities' use and monitoring purposes, accurate and clear reporting was mentioned as the key factor. However, there can be seen as a connection to the increasing administrative burden for SMEs.

> [In relation to self-monitoring and increased reporting demands] even when it is a mandatory thing, the smaller actors are less enthusiastic to adopt them as it is more consuming for them. On the other hand, the increased monitoring helps to tackle the freeloaders from the sector. (Stakeholder 8)

In spring 2022, the Sustainable Products Initiative package by the EU is being developed and published bit by bit. It was expected to bring clarity and guidance to the product features' minimum requirements. These minimum requirements aim at ensuring a certain level of durability, repairability and quality for a range of products. Some of the requirements are as practical as stating that the products should be possible to repair using most common tools and spare parts that are widely used and easily available for everyone. The political state and message from the authorities have a role in encouraging companies to invest resources in the circularity and development of their services. As the business decisions are carefully calculated, the regulatory stability and consistency are needed for corporations to steer towards more uncharted business areas in support of the financial incentive, as indicated by the quote below:

> Ideally, the price of a device would be determined according to how it has been designed, if it has been designed to be repaired or to be easily prepared for reuse. (Stakeholder 3)

4.3 Business opportunities and models

As Figure 6 demonstrates, assisting features in reaping the benefits of circularity can be expected to derive from the future scope of regulatory producer responsibility, product design revamping, adoption of circular business models, and exploiting advances in, for example, technology and digital "smart" solutions.

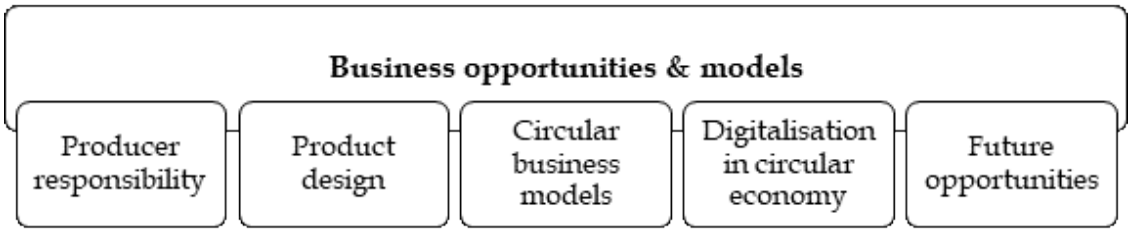

FIGURE 6 The main properties of category "business opportunities and models"

The unused potential of circularity was vocalised as follows for example:

> In our field, it is quite "old school circular economy" that we implement here, although everyone says to be presenting the top end of circularity. To me, it seems that the main business is still in gathering the material, crushing, and recycling instead of findings ways to prepare the products for reuse, how to fix them or use them as spare parts, prolonging the useable lifetime or implementing sharing economy type of solutions. (Stakeholder 7)

The importance of product design was brought up when discussing the circular opportunities of a product and solar panels. Product design is the dominating factor that determines how a product will fit into the waste hierarchy. Through the design process, it can be determined to what extent a product is repairable and if it can be easily prepared for reuse, or if recycling is the only way to proceed. Here we are taking the stand that every produced item must be at least recyclable and not end up in incineration. The opportunities of circularity and re-valuation of materials were described as a future prospective:

> I'm waiting for the day when the members of producer collectives will not pay money for the services but rather the value of the material is positive and covers the expenses of the recycling pipeline: recovery, logistics, handling. (Stakeholder 7)

There are multiple implementation opportunities for circular economy models. It was clear that each actor would have a different approach and place more importance on certain actions depending on their core business area. Although it was noted that recycling is not the only measure of circularity, it was raised the most often. It was notable that recycling and circular economy were also used as equivalent terms. Depending on the actor, the definition of circular economy was weighted either very strongly only to the end-of-life operations and recycling whereas others actively sought after other circular measures or even argued against using recycling as the defining action of the product lifetime. Other highlighted circular business models were related to service-based and deposit-based offerings, sharing economy solutions, and types of industrial symbiosis. The connection with the circular opportunities and new policy directions was drawn as follows:

> Surely more of the service and maintenance packages will be created so that the provider will be more present throughout the lifecycle – offering a certain level of effortlessness to the customer. Also, deposit systems where the customer pays a deposit and is able to return the panels to the same provider at the end of the panels' lifetime will gain popularity. The offerings with repair and reuse aspects should be partly facilitated through the sustainable product package and the increased ease of repairs – with the commonly available spare parts and tools. (Stakeholder 3)

Finnish energy utility Helen provides solar as a service for household customers in a form of rentable panels. The company has three solar panel parks in the metropolitan area of Finland from where a customer is able to have a nominated panel for a monthly fee. They are compensated for the electricity that the panel produces. It was admitted that the nominated panel offering is not created for customers who wish to minimise their electricity expenses but rather meant for people who want to support renewable energy production and increase their adoption. It can be seen rather as supporting the cause than strictly a financial decision. Regardless, according to the company themselves, the solar parks have

a high reservation rate and attract widely interest also internationally. For the deposit-based offers, there was a reference to the Finnish bottle returning system and the notion of the highly motivating impact of the financial returns. However, the lack of a functioning secondary market was acknowledged:

> We have studied it time to time but haven't noticed any [second-hand market for PVs] in Finland. (Stakeholder 1)

Additionally, regardless of the increased knowledge, the actors state that the defining variable in purchasing new equipment and electrical devices is the price. Although the electrical devices have energy labels and it is widely understood that the more energy efficient a product is, the less the expenses are during the useful life of for example a fridge, the purchase price still takes priority. Notably, in the product and offering development process, the actors have their own weighted mix of priorities that they need to consider throughout the different stages:

> The product development process starts from an identified customer need and a financial basis in order to proceed to the actual development phase. - -. Or sometimes it might be that we are waiting for a certain set of regulation, for example the energy industry legislation is something that we keep a close eye on. (Stakeholder 1)

Interestingly, digitalisation was highlighted multiple times. It was noted that digitalisation is an enabler and a driver of circularity in a variety of ways. Advances in digitalisation are assisting across the value chain to make processes more efficient. Not the least, it creates opportunities for tracking and monitoring activities during the transportation and recovery phases:

> Logistics, that's actually one of my favourite topics as it is such a central part of the operation in a country such as Finland with massive distances and remote locations. - -. We have reached a stage where we have been able to integrate digitalisation to make processes more efficient, meaning that all orders for collection, pick-ups, change of containers or bins, time management and reporting is digitalised. (Stakeholder 4)

There were examples of national and international initiatives to pilot industrial symbiosis. Under national coordination, there were regional projects for horizontal collaboration between actors to exchange resources and by-flows. This creates a linkage between this theme and the actor dynamics category. In general, the collaboration between actors was noted to be crucial in advancing the market but it concretises in the circular business models such as industrial symbiosis. While it is said that through transparent documentation and information sharing on best practices the actors could learn from one another but also it would act as a driver toward circular collaboration. In terms of digitalisation, it allows virtual business models such as refining the virtual power plant systems, providing

aggregator services, and managing energy islands or remote power production. Following digitalisation, also automation, simulation and optimisation are enabled to increase the process and system level efficiency.

The common challenges that were identified were related to the already long lifetime of PVs, low incentivisation to develop alternative business models, the low economies of scale, and the idea of sufficient raw materials being easily available for the foreseeable future. Concerning the producer responsibility and ecodesign, the fact that Finland is a small market in a globalised market dominated by the international conglomerates was underlined. The insignificant size and geographical location as a country with limited solar potential was used as an argument for why it is challenging or not worthwhile to drive change on a larger scale. Additionally, in addition to the pilot projects, there are prototypes of innovative solutions and products, which are expected to eventually demonstrate the feasibility of such offerings in the Finnish market. An example of such a prototype was mentioned during one of the interviews:

> An example is a collaboration project by Stena Recyling and Electrolux as they developed a vacuum cleaner that was fully produced from recycled material and is recyclable as a whole. These types of things are being discussed and there's hype, but they are largely prototypes out there. Still, it is encouraging to see that it is possible to do cross-actor collaboration. (Stakeholder 5)

Going forwards, it was commonly agreed that there are certain nominating trends that the market is being directed by. While the adoption rate of solar panels is steep and upward, it will not be only the (industrial) roofs that are equipped with panels that will make the difference. Similarly to wind parks, there will be increasingly large solar parks expanding on a nominated land area. On the other hand, integrated solar panels are expected to gain ground and a foothold in building and construction. Integrated solar panels refer to PV technology that is integrated to surface materials. It can be tinted window glass, the exterior wall, or roof tiles to mention a few examples. There are some limitations, or hurdles, to solve though, as an interview comment indicates:

> There is very little variance in the panels as they are similar in the size and dimensions, so it is easy to scale up. Windows on the other hand, there are a large variety of styles, shapes and sizes, same as with roofs, thus they are demanding subjects for the integrated surface panels and will pose as a challenge for the building industry. (Stakeholder 1)

While the primary market is being developed, also the secondary market is expected to take shape and be refined. Currently, the second-hand market is very limited. Although there is demand for used panels, there is no dominating marketplace for trading. Mainly the domestic demand is in the household sector, and it is met mainly by industrial panels that for different reasons come to the end of their first useful life. It can be related to the panels not reaching the maximum

promised efficiency or to malfunction issues somewhere else than the actual panel construct. These panels are then circulated back to household use through the grapevine and via informal channels. Interestingly, in connection to the unofficial secondary market of electrical and electronic devices in general, the circularity rate is not being recorded. Stakeholder 4, for example, raised the point that in order to document the development of circular economy from the root, there should be more attention paid in the reporting to recognise the number of devices being passed on peer-to-peer and on the informal markets, instead of recording only the material going through the official waste management channels.

4.4 General attitude and awareness

Attitudes and awareness play a role in reaching circularity, and the main properties defining this category are the attitudes and motivations of the actors, the expectations placed by the stakeholders, consumption patterns and behaviour change, level of media and consumer engagement, and efforts placed on internal and consumer communications as summarised in Figure 7.

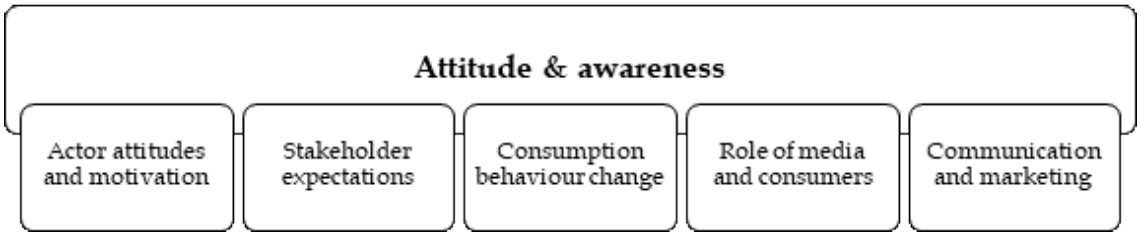

FIGURE 7 The main properties of category "general attitude and awareness"

The difference in the significance of impact between regulation and consumer engagement on the corporate environment was perceived as follows:

> 20 years ago, when the producer responsibility was adopted, I was expecting it to have more impact on the repairability and reusability of electronic equipment. It would seem that the changes are stemming from the consumer end as they have started to put more pressure on companies, instead of the companies themselves due to the regulations. I would see it so that the hike in consumer awareness is the determining factor. (Stakeholder 6)

It was noted by several actors that there is a significant shift in the consumer behaviour and expectations placed on companies. Consumer awareness has increased, and social media has provided a platform for the public to bring out their voice and it is possible to gain momentum from the grass root level.

Concerning circularity, it has been noted that the consumers are more engaged and for example, the recycling rates of different waste types, including e-waste, have increased over the past years. Additionally, the thought of generally buying second-hand products or lending is not as foreign anymore. It was uncertain what the profound reason for the increased engagement is, but it was expected to be a combination of different things such as easier access to information, communication and information work by the market players, authorities as well as non-profit and environmental organisations, and in general an increase in environmental and sustainability issues and so forth. The role of media was said to be essential in shifting public opinion as well. In addition, or as a result of the prior, the value of funding and company valuation in the eyes of shareholders is linked to the sustainability image of the company. The corporations' internal motivations for investing in solar power were estimated to be the following:

> Rarely anyone – especially in the case of corporations – acquire a solar plant purely for financial reasons, there are always carbon neutrality and sustainability targets. (Stakeholder 2)

Although the industry does not have yet much to publicise in terms of the circularity of solar panels, the external interest comes in waves. If there is a piece of news in one news outlet, many others follow and ask the players for comments or interviews. It was said that there is interest inside the market and among the end-of-life businesses, but there is close to no information to tell externally. Reasons mentioned for that were that as the market is very small, there is no incentive to develop processes and that for now, the current crushing method is quite enough – especially considering that in many non-EU markets the panels are not dealt with even to that extent.

One of the tasks listed under the producer responsibility regulation is increasing awareness and disseminating information. In Finland, there was a campaign called "I love muovi", I love plastic in English, that was perceived to have a significant impact on people's engagement in and awareness of plastic recycling. It was used as an example of a successful campaign to engage consumers, and something similar was hoped for the e-waste market as well. Many of the interviewed actors conducted research to study the motivations and attitudes of consumers towards recycling, but for a large part, the information was only for internal use and not published to the public. In general, the purchase price of a product was found to be the main motivator regardless that there is increasing information on the total cost of a product and that consumers are aware that although energy efficient product such as refrigerator costs more to purchase, the expenses of its lifetime are lower. Environmental friendliness does have a role in the buying decision, but it is not the defining factor. The difficulty of achieving behaviour change was argued when discussing the gap between attitudes and actions:

> Are we prepared to lower our standard of living? It is a relevant question and when people are being asked, they say yes. Same as when being asked

> about purchasing organic products, the answer is yes but still there's Pirkka and Rainbow [low-cost, retailer owned brands] products at home. (Stakeholder 4)

That being said, it does not mean that the work is done. Crucially, there are still especially small electrical devices laying around in people's homes that could and should be collected for processing. The Finnish phrase loosely translated as "one cannot get high quality with low price" was mentioned by stakeholder 4 when describing the purchase decisions on electrical devices. As sustainability is being connected to the evaluation of corporations and funding instruments, it is increasingly important also for the shareholders that the company has a sustainability strategy and looks into alternative business models – circular economy-based ones included.

4.5 System and processes

When focusing purely on the system and processes, it can be pieced into parts: the collection network, logistics and storage, and preparation for reuse stage. Additionally, the category caters for the discussion on the increased administrative requirements and the consumer-centricity (Figure 8).

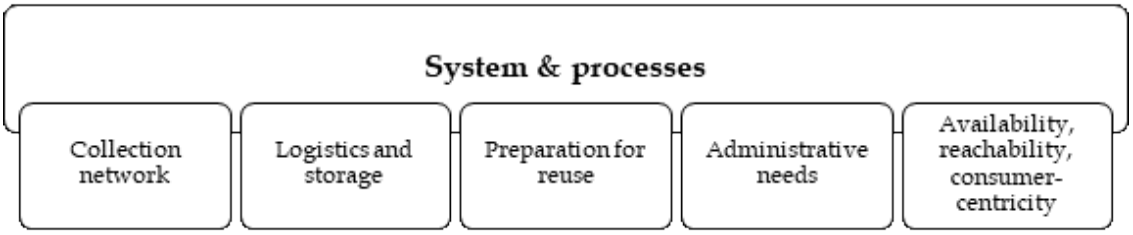

FIGURE 8 The main properties of category "system and processes"

The Finnish collection network was thanked for covering the whole country and being well maintained. However, certain challenges and improvement opportunities were identified especially when it comes to integrating the PVs into the system. In general, the fact that the current system of crushing the waste and sorting the various materials from the crunched mass is far more than is currently in place outside of Europe, it does not support the aim of preparation for reuse:

> That's a thought that I have grown very fond of – what if for once we built a system that is a functioning one and where we wouldn't just crush everything and try to separate grains of sand from each other. (Stakeholder 6)

A significant issue that was repeated in all interviews was the volume, and how it is insufficient for maintaining waste type-dedicated handling processes domestically:

> In practice, our challenge is the volume. If we are to adopt the same plans and rules that have been designed with Central European markets in mind, sure the issues derive from our distances and waste streams. - -. Regardless of the type of waste stream, it's the same. To make the system function and cater for high recycling and recovery rates – but how it would actually be realised, the expenses and environmental impacts, it's quite a puzzle. (Stakeholder 6)

In connection to the general awareness and people's tendency to stay in their comfort zone, also the collection system is a subject to a lack of engagement. It was admitted that both consumers and producers might find the collection system challenging to comprehend. Especially for consumers, the level of knowledge and awareness of the system functions could be higher. This is further related to the communication and information campaigns for which there is an identified need.

There were varying viewpoints on the producer collective system and its simplification. In general, the producer collective system was praised and found to be a rather well functioning system. Stakeholder 8 especially highlighted the dedication that the producer collectives demonstrate and their efforts to reach the producers and make sure they are aware of their responsibilities. While it is the core business for them, it has wider implications on the system level. There are ambitions from an authority perspective to simplify the actor field so that there would be only one enormous collective, a so-called one-stop shop that would cater all producers irrespective of the waste – or product – type. The stakeholders admitted that it would simplify the system from the producers' point of view if there was no need for the companies to take part in several collectives in respect to their varying product portfolios. Additionally, it was noted that it could streamline some logistic and transportation processes. However, the actors also pointed out the practical challenges that would follow such a transformation. Notably, Stakeholder 4 gave as an example that the handling and storing requirements are very different for fibre packaging and car tyres and electrical waste at the end processing phase. In general, the main challenge of dedicated processes was summarised as below:

> It is always a cost and profitability issue when we head towards ever more specific sorting, they require separate systems or developing new processes and it is always more expensive to make those changes. (Stakeholder 6)

Especially from the consumer point of view, reachability and convenience are directly linked to the rate of recycling. Admittedly, also convenience plays a role in the producer matters as the system should cater for the needs of the producers

as well even when partaking in a producer collective is mandatory. Currently, there are certain challenges related to by-flows and free riders who do not participate in the producer collective system nor report the sold equipment. To tackle the issue of freeloading, a collaboration of different actors and a free flow of information between them come to play. From the viewpoint of system functioning, having more producers onboard makes it more sustainable. While there are more member organisations, the collective has more resources and financial basis to act and carry out the set responsibilities. Although also the amount of waste needing handling increases, the shoulders are broader to take action and drive the common interests.

4.6 Term definition

When defining circular economy and producer responsibility, a set of discussion points were clearly highlighted as summarised in Figure 9. The category of term definition groups together the discussion on the literal characteristics of producer responsibility and circular economy and in more detail, resource wisdom, material cycle, and material efficiency, as well as the debate on the word waste.

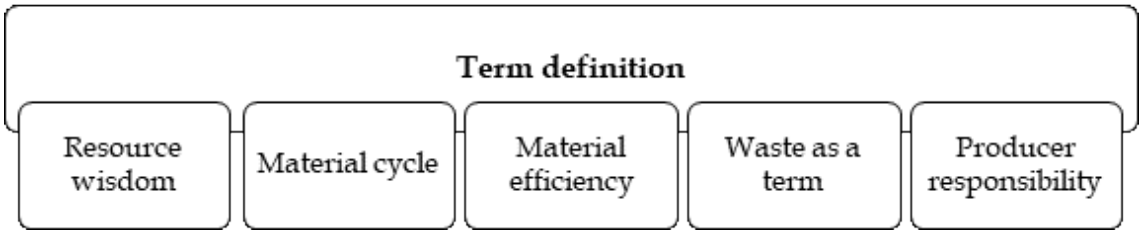

FIGURE 9 The main properties of category "term definition"

Circular economy was defined as a circular process for the materials, prolonging the product lifetime, and improving the reparability and recyclability of the given product. Resource wisdom was referred to multiple times in various forms. It was found important to decrease the share of virgin materials that are needed in production. There is a linkage to the actor dynamics and globalisation as the current level of dependency on the Chinese market and production was stated to be a motivator to develop more self-sufficient processes. In general, a significant amount of expectations is placed on circularity. However, the concept and its opportunities are not fully materialised as the real-life implementation is either still shaping or not even being considered as the economic backbone is yet missing:

> I wonder if circular economy will replace the conventional market economy someday. What if the value of products wasn't based on the monetary value of the material it consists of but that they had other value than that? (Stakeholder 7)

Going back to the ecodesign, the majority of the responsibility for circularity was placed on the product design stage. While many of the actors underlined recycling as the main circular activity, the product design was pointed out to be the main gatekeeper towards maximising circular opportunities. Interestingly, very often the textile industry was referred to as a pioneer of how circularity is penetrating the market setting. Especially the take-back initiatives and the use of recycled materials in textiles were reflected upon as an example for the solar panel industry, or WEEE more generally. In relation to the eco-modulation, the pricing of materials; virgin raw materials as well as recycled raw materials seemed to be an issue waiting to be solved. Currently, often the cost of using recycled materials is more expensive and is more resource consuming than using virgin materials. To add to that, the quality of the raw materials might vary. On top of that, also the price received from the recovered materials is not necessarily high enough to motivate recovery and recycling. The eco-modulation is expected to assist in the matter but also the market was demanded to develop mechanisms to incentivise the change. Notably, this concept development is very strongly linked to the properties of business opportunities and models category.

When it comes to adopting and accepting novel business models, the use of accurate vocabulary often is lagging. As people are adopting new terminology, they might not be aware of the specific meaning of the terms or concepts. The casual use of terms and concepts was noted by one of the interviewees:

> The goals that the producer responsibility was expected to contribute towards in terms of product design, use time, and the inner cycles and reuse and repair, are not being fulfilled as planned. Rather, when discussing producer responsibility and concepts of circular economy we refer to waste management and how it [waste] is recycled as a material. (Stakeholder 6)

Within the concept of material circularity, the term waste sparked some discussion:

> It [waste] is a regulatory term, and its definition then impacts what can be done to that material, the processing, who can receive it, and what are the required certificates or permissions for handling. (Stakeholder 9)

The concept of waste and its relevance was being pondered in a system where the product's lifetime is not linear. What is the role of waste when the material flows from cradle to cradle instead of cradle to grave, and thus, should we have such a term in the regulatory vocabulary? Waste has the burden of its existing meaning of being something that has no value or use. The negative connotation does not support the wide adoption of new use cases for waste. It was said that the definition of the term should be carefully considered in the regulatory framework, and it should be awarded a certain value. Currently, there are terms indicating to waste referred to by similar terms, thus the vocabulary should be consistent throughout the regulation and aligned across different documentation.

The level of knowledge of producer responsibility and the related regulation varied. The actors directly related to it and who work within the direct influence were naturally very aware of what producer responsibility refers to and how it concretises in business. One of the interviewees summarised the producer responsibility topic as follows:

> There are many good things [in producer responsibility]; it makes recycling [of electrical and electronic waste] free and relatively easy, and that is the starting point for the whole system to make it viable. Also, it is based on law, and it is being monitored. Although the motivations were good there is a lot to improve especially concerning circular economy and making it a reality. (Stakeholder 7)

At the other end were commercial actors that are within the scope of the regulation but are not dealing with the matter directly. Most often, the perception of what producer responsibility is was described through another sector such as packaging or small-scale electrical and electronic devices. In a conclusion, the main drivers towards circularity were summarised in one of the interviews in the following manner:

> To sum up, I'd say that the voluntary agreements, financial steering or regulation and of course marketing and communication are the main areas to pay attention to. (Stakeholder 9)

5 DISCUSSION

In general, the interviews provided a wide overview of the WEEE and solar panel market dynamics in Finland. Although originally there was a special interest to understand the impact of the regulation on circularity, it became clear that there are multiple other factors that steer the market direction varying from internal to external forces.

5.1 Findings

There were aspects that the stakeholders mainly agreed on, while other topics they had varying opinions on. As a significant and positive notion, consumer attitudes and behaviour were noted to have changed over the past years. The Finnish Energy Attitudes study has been conducted by Finnish Energy since 1983 (2021). The findings from the 2021 study show that 87% of the respondents say that the amount of solar power should be increased. Additionally, 55% said emissions reduction and climate change mitigation, and 54% increasing the share of renewable energy should be among the main 3 priorities in the political decision-making. However, 62% ranked a reasonable price of energy in the top three. This resonates with the feedback from the stakeholder interviews. Although there is a hike in awareness and interest in climate change mitigation, the price is still a key driver for the consumers. This puts pressure on the business model development but on the other hand, also can be used as a benefit. As for the industrial clients, also for consumers, the required financial investment upfront is lower in continuous payment plans compared to when buying the product one-off, or even with part payments that have interest rates included. However, if the service-based offering is built in a way that there are services included that are not benefitting the consumer nor relevant to their needs, it will act as a push factor. It was noted by various stakeholders that the circular opportunities often add an administrative burden. Imagining a scenario where the system is built to support circularity, the services should enable easy access to circular services and adoption of the circular disposal options to reach also the adoption group of laggards who are uninterested or unmotivated to take part in the circular economy.

Outside of the electrical and electronic devices, circular market-based schemes related to producer responsibility currently in use in Finland are such as deposit refund systems and advance disposal fees (Pouikli, 2020). Those can be observed in metal and plastic beverage containers where the deposit is included in the consumer price and paid back upon appropriately returning the container. A similar type of deposit-based business model was proposed for the solar panels by some market actors to emphasise the shift away from ownership-based offerings also in the consumer market. However, it is not expected to take place in the immediate future due to several practical challenges. An interesting

implementation of a renewable energy opportunity is by Helen as they rent out designated solar panels to their household customers. According to Helen's representative, the concept is internationally unique and acclaimed, however, this could not be confirmed from other sources. Nevertheless, notably, the concept is expected to attract especially consumers in urban areas or in locations where their own solar panel installations are not feasible, and who are committed to supporting and financing the transition to renewable generation without guarantee for own economic returns. The service model is rather exclusive and attracts a limited demographic. However, the success of the first three solar parks gives out promising signs of consumer movement and support. Thus, feeding off of the awareness, engagement, and increasing wealth of the middle-class, there might be an opportunity to shift the focus of the service-offering towards value-based rather than purely economies-based. Notably, the motivation mechanism would be different in the business-to-consumer and business-to-business markets. While in the consumer market the purchase decisions stem from the individual's own attitudes and needs, an industrial actor is subject to the expectations of their internal and external stakeholders and dependent on the financial implications of the decisions. Traditionally, economic sustainability has been the key driver in commercial and business activities as the main purpose of a business has been defined to generate wealth for its owners (Baumgartner & Rauter, 2017). However, increasingly the importance of environmental and social aspects is being highlighted by the internal and external stakeholders of the company. As noted in the results as well as in theory, the public pressure is being used for influencing companies' strategic decision making and management (Broman & Robèrt, 2017).

As a decisive factor in corporate incentivisation and to guide corporate investment strategies, the EU is implementing a variety of green financing tools as well as sustainability regulations as positive and negative reinforcement. One example of such a tool is eco-modulation. Eco-modulation and waste pricing schemes were mentioned several times in the interviews. Eco-modulation refers to the financial carrot and stick of ecodesign. It was noted that there are certain challenges related to this incentive scheme. In terms of literature, a review of the implementation of eco-modulation in France (Micheaux & Aggeri, 2021) found that eco-modulation on its own will not be a sufficient instrument. In practice, the governing bodies seemed to be hopeful for the upcoming changes in the pricing structure. Naturally, the process of balancing the burden between parties will be a challenging task. However, the representatives of producer collectives were unsure if the costs associated to waste regulation influences the production or product design decision made by the companies. Especially for large corporations, the expectation is that the pricing would not make a difference but rather there are other significant push and pull factors. Although the EU is laying out the assessment criteria and financial support instruments such as EU taxonomy 2021/2139 to direct investments into environmentally sustainable economic activities, the business model needs to be profitable on its own (Commission Delegated Regulation 2021/2139/EU, 2021).

Curiously, the issue of standardisation of reused panels did not appear extensively in the interviews. This could be explained by the lack of a second-life

market for PV equipment. Therefore, the issue is not a timely nor acute matter for the stakeholders. There were only some small-scale re-sale activities on occasions where a commercial customer was provided with solar panels and individuals from the company inquired about the opportunity for household installations on the side. Leftover or retired commercial PVs were then offered for these individual households. However, this type of reuse activity seemed to appear on very scarce occasions that it cannot be referred to as a secondary market. EU Directive takes the definition of reuse a step forward and adopts the definition "preparation for reuse" as part of the terminology (Directive 2012/19/EU, 2012) and guidelines of the WEEE. This is an aspect of consideration for the PV components; separating different elements and components of the panel in an advanced manner so that they could be integrated and reused elsewhere.

While the regulatory bodies – both locally, domestically, and internationally – provide the regulatory framework for the companies to operate in, the actors also have ambitions to have a say in how the market should be developing in the future. In terms of advocacy work, it had been noted by the actors that there are opportunities to influence and direct the regulation framework both on the national as well as EU levels. Notably, the EU level interest group SolarPower Europe has highlighted similar themes in their agenda to the findings in this thesis. Out of their ten workstreams (SolarPower Europe, 2020), there are seven that frequently appeared in the interviews, namely industrial strategy, sustainability, grids and connectivity, lifecycle quality, solar buildings, storage, and digitalisation. Additionally, the importance of international cooperation and corporate sourcing is aligned with the findings.

On the system level, the matter of logistics was a point of interest and importance in the interviews echoing the findings from the literature. Korhonen (2018) and Marsillac (2021), for example, noted that process and material management are common hurdles in implementing circular economy. Additionally, Cole et al. (2017) and Tsanakas et al. (2020) suggested that collection and transportation can be a potential bottleneck for wide-scale preparation for reuse. If the WEEE is not treated and stored properly during the collection phase, it makes it challenging to restore and refine the equipment for the next round of its lifecycle. Although, currently, there is no set recovery process in place for the panels due to the scale of business, the challenges that the industry is expected to face in the future will be related to the system management. As the value of (secondary) raw materials is very dependent on the quality and purity of the material, it will be key to develop a process that contributes to maintaining the products in a shape that serve the post-treatment purposes.

In terms of future development, the plastics and textile industries were mentioned as pioneer or exemplary fields to take an example from. However, it is notable that the natures of the products in the textile and plastic markets are very different from photovoltaic panels in terms of lifetime span, raw materials and reuse opportunities. That being said, especially with textiles, there are common factors in the complex and long sub-sourcing chains. It is challenging to track back the sustainability and actions taken by the sub-contractors, while still many of the products are originating from South and South-East Asian countries

that are high-risk areas. Especially China was mentioned by name as the sourcing country for the panels' raw material. The dependency on certain raw materials sourced from politically volatile areas is factored in in the EU's list of scarce materials (Taylor & Jäger-Waldau, 2020).

Digitalisation was mentioned as a key enabler in the future PV market. A concrete example of digitalisation assisting in connecting actors and providing a smooth exchange of information is the Datahub project by Finnish electricity transmission system operator Fingrid (Fingrid, n.d.). The recently launched datahub enables the exchange and access to consumption and production data as well as connecting the user points with better efficiency. This makes it possible to better utilise the features of smart meters that are installed in 99% of Finnish consumption locations (Energy Authority, 2021). This is only one example, as digitalisation can enable connectivity on several levels. A use case to utilise digitalisation would be a digital product passport system (European Commission, 2022). As digital product passport could provide information about products' environmental sustainability, recyclability and repair opportunities, the companies could use that information in their service design and in building their offerings portfolio. In the interviews, digitalisation in general was expected to facilitate more effective and resource-efficient reporting and monitoring. For the authorities and supervising bodies especially the digital product passport or similar digital label would assist in the monitoring activities as well as tackle the freeloader issue in the industry. For service providers and market players digitalisation offers opportunities for refining virtual and remote offerings while simultaneously shifting focus towards service-oriented business models such Energy-as-a-Service (Wu et al., 2021).

In principle, waste streams can be divided into two categories: material or product related streams (Bourguignon, 2015). Material-based streams consist of metal, glass, paper and cardboard, plastics, wood, rubber, textiles and bio-waste, whereas product-based are packaging, electronic waste, batteries, vehicles, and mining and construction waste. The EPR and WEEE Directive are material-based, not product-based (Bourguignon, 2015). They expect that each raw material can be recycled similarly regardless of the composition of the original product or the used method (Danska, 2012). Notably, not all electrical equipment is built the same nor are the components standardised. This means that the products by different manufacturers are not necessarily compatible in terms of the method of recycling, or even the components that are used in a certain product can require varied treatment (Bourguignon, 2015; Danska, 2012). In general, it would be cutting corners to state that circularity is singlehandedly better or more sustainable, as it is notable that circular systems as well require resources and create waste and emissions – not to mention the risk of impurities in the final products.

5.2 Reflection to research questions

To summarise the general analysis of the results and understand their implications, it is necessary to revisit the aim of the study and reflect the findings to the original research questions.

> Q1: How effective is the current WEEE Directive 2012/19/EU in terms of guiding circular economy of PV panels in Finland?

Based on the findings, it can be said that the implementation of the WEEE Directive 2012/19/EU is being enforced on the market actors even though they are not necessarily aware of the underlying regulatory forces. However, its effectiveness in relation to circular economy is questionable. Notably, it encourages recycling and end-of-life treatment of the PVs, but it does not – yet – extend to other circular services. There are varying views on the optimal strictness of the regulation that would be the most fitting as the market-driven approach is perceived as the most effective towards financial sustainability.

> Q2: How does the regulation on producer responsibility direct the operation of PV producers?

In the best-case scenario, the regulatory framework creates guidance and pushes the actors collectively towards the common goal. In the worst case, it can be as if guided by "pushing with a rope", indicating that there is no real effect in the policy. As it was stated in the interview, it is crucial that the regulations do not limit the research and development of novel technologies. It should leave space for the actors to refine their product portfolio and develop it in a new direction and away from the make-use-dispose mindset. If the policy is very restrictive, finding alternative approaches to provide products or services loses its innovativeness. Eco-modulation and redefining the pricing structure for waste to create value for waste flows is a tool towards that. It is unrealistic to expect one piece of policy to solve such a profound challenge and make the transition to circularity, thus a mapping of supporting regulations and policies is required. It is crucial to keep in mind, that the solar panels are recovered and treated some decades after they are designed and manufactured (Taylor & Jäger-Waldau, 2020). Thus, they have avoided several regulatory hoops and the technology is not the as state-of-the-art as the panels that are fresh out of the production line (Marsillac, 2021; Masoumian et al., 2015)

> Q3: What are the key factors driving circular economy in the Finnish PV market?

Strong drivers towards circularity are financial incentives, especially in the form of an economically sustainable business case, but also as financial initiatives and

schemes deriving from the EU or nationally. Secondly, the increased consumer engagement in environmental topics and empowerment in tackling climate change is perceived as significant factor in shaping the corporate conduct in general but also the service and product design. While also horizontal peer pressure is seen as an influencer in especially SMEs' engagement in sustainability actions, horizontal and vertical actor collaboration and transparent information exchange act as key enablers towards circular economy models that are largely collaborative in nature.

5.3 Limitations and future research

In terms of the identified research gaps, this thesis addresses the practical, bottom-up approach that the current research is lacking according to the literature review by Bressanelli et al. (2020). This thesis scratched the surface of studying the actor perceptions. While it was concluded that collaboration is deemed crucial in order to implement circularity in the industry, practical challenges and competitive culture hinder the smooth and transparent exchange of information. Notably, the sample size was very modest and only an indication of the direction in which the different stakeholders expect the market to develop. Additionally, the study area was wide. Limiting the focus of the study might have helped to sharpen the results and outcome of the research. On the other hand, the wide overview lays grounds for future research to dive into a dedicated category allowing more depth in the analysis. Notably, the selection of policy schemes is limited to the scope of the research and is excluding a number of other relevant pieces of policy that have indirect impact on product design and safety management, for example. While discussing the key role of economic viability of the circular business models, the thesis does not display figures or calculations to demonstrate what is the state of the current situation or which measures would have the greatest potential. Additionally, the technical feasibility of PV circularity is not within the scope of the study.

For further research, there could be opportunities to observe in more detail the design and manufacturing phase of the product lifecycle as well as seek the collaboration potential between the operators in the production and the end-of-life treatment. Developing use cases for the Reuse and Remanufacturing of the 4R's might require product-specific research in order to establish the required modifications to features and in treatment. For example, a revision of the process management and system functioning might assist in the design of a more collaborative recovery and logistics network but also seek means for more siloed handling and treatment channels. Additionally, as potential future research, dissolving the complexity of the technological supply chains and seeking means to decrease the dependency on the Chinese raw material supply would be contributing not only towards increasing the social and environmental sustainability but also potentially shifting the influencing power to the local markets – either EU or domestic research and development. Not to mention, decoupling the political

risk from achieving sustainability goals. In terms of eco-modulation, there would be space for assessing its effectiveness and understanding its impacts on market mechanisms.

6 CONCLUSIONS

In terms of circularity in the PV market, it all comes down to the economies of scale. The most significant hindering factor in adopting circular solutions for the PVs reaching end-of-life is the limited number of products disposed of. On top of that, the lifetime of solar panels is very long compared to small-scale electric devices and technological improvements are increasingly implemented as the panels improve in efficiency and durability. Thus, even though the devices would be in a good condition to be prepared for reuse, the technology in them might be outdated by the time of recovery. Although it is recognised that the process should be developed and carefully thought through, there is a limited level of ambition to realise the goal in practice. Based on the interviews, the stakeholders are engaged and driven to develop the processes and circular system, but the realities of the current situation act as an anchor. In terms of actor perception, it is generally agreed that sustainable use of materials is essential, and the devices that reach the end of their lifetime should be recovered and collected for appropriate handling. In terms of photovoltaic panels, it is noted that it would be beneficial to have the components and materials for circulation in order to avoid the use of virgin materials. However, in reality, as stated above, the long lifetime of the PVs and the current small scale of operation limits the ambitions to realise the required change towards more advanced circularity. Based on the interview results, the market actors conduct business according to the EPR policy to the extent that the regulation requires. However, it is doubtful that the producer responsibility has a significant impact on the lifecycle of a PV product apart from the recovery and recycling obligations that the operators are dedicated to. Especially in the design and use phase there are identified opportunities that are not reaped. This is notable as the importance of ecodesign is highlighted in the literature as well as in the actor interviews. Due to the long and complex supply chains, impacting the build-up and design of the product is found challenging. To add to that, sourcing of the raw materials is largely limited to specific locations and actors that are a long distance away from the Finnish market both geographically and in terms of the supply chain. Thus, the perception of not being able to actively contribute to the global context limits the motivation to place resources toward influencing the early stages of PV lifecycle. However, the presence of the producer in the product's use phase is expected to change as more service-based business models are adopted.

While the regulatory environment lays out the principles for market operators, it is notable that there are other significant factors that steer the market development. Instead of EPR and related regulation, strong drivers towards circularity stem from the power dynamics between different actors, public pressure and demands to meet the consumer expectations, technology improvements, system level efficiency, and general adoption of the concept of circular economy and related phenomena that then translate into novel business opportunities. A key feature in circular business models is collaboration and information sharing. It

has been noted that concepts such as industrial symbiosis are not feasible without active and transparent interaction between the participating actors as well as potential collaborators. Harnessing the megatrends and development in other areas the society should be integrated into the PV market development. For example, digitalisation is deemed to enable a variety of solutions for the intermittent energy generation. From a system point of view, any tailored process should be designed in a way that would suit the current scope but is prepared to cater also for the needs of the future – more significant – mass of discarded PVs.

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APPENDIX 1 Interview template structure

Below is presented the template structure of stakeholder interviews. The language of the interviews was Finnish. Thus, the contents were translated to English by the author.

Section	Question
Background information	Name
	Title
	Professional background
	Organisation name
	Organisation profile and role
Circular economy	How do you define circular economy?
	How do you see the role of regulation in promoting circular economy?
	What other factors drive circular economy?
	What aspects are the biggest challenges towards implementing circular economy?
	What kind of (business) opportunities does circular economy provide in the solar industry?
Extended producer responsibility	How do you define producer responsibility?
	In relation to the goals of circular economy, how effective are the tasks listed under the EPR regulation?
	How do you perceive effect of the obligations under the EPR in product or service design?
	How do you expect the producer responsibility to develop in the future?