IIIEE Theses 2017:8

Extended Producer Responsibility for Solar Photovoltaic panels

Practices and challenges for end-of-life management in Germany, Italy and Switzerland

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Thesis for the fulfilment of the
Master of Science in Environmental Sciences, Policy & Management (MESPOM)
jointly operated by Lund University – University of Manchester -
University of the Aegean – Central European University

Lund, Sweden, June 2017

LUND UNIVERSITY

iiiee
THE INTERNATIONAL INSTITUTE FOR INDUSTRIAL ENVIRONMENTAL ECONOMICS

Erasmus Mundus Masters Course in Environmental Sciences, Policy and Management

MESPOM

This thesis is submitted in fulfilment of the Master of Science degree awarded as a result of successful completion of the Erasmus Mundus Masters course in Environmental Sciences, Policy and Management (MESPOM) jointly operated by the University of the Aegean (Greece), Central European University (Hungary), Lund University (Sweden) and the University of Manchester (United Kingdom).

Published in 2016 by IIIEE, Lund University, P.O. Box 196, S-221 00 LUND, Sweden,
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ISSN 1401-9191

Acknowledgements

For my grandfather, a titan amongst men and a friend to all.

I would to thank my supervisor Jessika, for the support she has provided throughout this research. Your patience and guidance from the very start when I decided upon my topic to the point of final revisions has helped me stay on track and keep moving forward.

Thank you to Mr. Andreas Wade from First Solar for finding time to respond to my numerous emails and providing helpful suggestions for improving the quality of my thesis. Your inputs and suggestions throughout this research project have been extremely valuable to my work. Thank you also to Serena Sgarioto from RELIGHT srl for making so much time to respond to every question and email I sent. Thank you also to all the people who offered their time for interviews. Your inputs and help are much appreciated.

Thank you to my classmates for being a part of these fabulous two years of my life, through every up and down that came along the way and making this one of the most memorable journey of my life. Thank you also to all the teachers and staff at the IIIEE, CEU and the University of the Aegean, thank you for making these two years one of the most challenging yet enlightening and fun years of my life.

Thank you also to my family for always being there for me. Mom and Dad, thank you for supporting me in everything I do. Thank you for your patience, motivation, strength and love.

Sunanda Mehta,
June 2017

Abstract

As the capacity of solar photovoltaic (PV) panels installed around the world increases every year, so does the concern regarding their proper end-of-life management given the hazardous nature of this waste. European Member States such as Germany, Italy and Spain, being amongst the earliest adopters of this technology, have already started seeing end-of-life PV modules coming into the waste streams. In order to address the concerns regarding their proper handling, PV has been added as a separate waste category in the recast WEEE Directive (2012/19/EU) and falls under the increasingly ambitious targets set by the Directive for all the Member States. This thesis will evaluate the EPR systems in three case countries – Germany, Italy and Switzerland with a focus on policy transpositions, adaptation of the existing to include this new waste stream and the overall performance of each system in achieving its intended outcomes. Different Member States have transposed the new Directive in different ways into their national legislations and this brings up the question of how each systems is performing. By using complementary analytical methods combined with the intervention theory and a general performance framework, this thesis will evaluate each of the systems based on the three main goals of EPR: Improved Waste Management practices, Closed Material Loop and Eco-Design. The findings highlight where the systems have succeeded and where they face challenges. Recommendations are made on the basis of these findings that can be used to enhance the system performances.

Keywords: Extended Producer Responsibility, Individual Producer Responsibility, WEEE Directive, photovoltaic waste, Germany, Italy, Switzerland, policy evaluation, intervention theory

Executive Summary

In a bid to transition to a clean and sustainable future, renewable-based energy solutions are being increasingly favored over conventional sources worldwide. The deployment of solar photovoltaic (PV) across the world has grown at an unprecedented rate and is expected to reach 4500 GW globally by 2050. But along with deployment of solar PV panels also comes the issue of end-of-life management when the panels reach their end of their useful life span (~25 years). PV panels contain hazardous substances such as cadmium and lead and improper disposal of these panels can lead to potential environmental and human harm. Additionally, PV panels also contain rare materials, the recovery of which is very important to ensure their sustainable in the future. Because of these factors, management of PV waste becomes an interesting yet complex process.

The European Union introduced its very first pan-EU legislation for waste electrical and electronic (WEEE) management in 2002, with the passing of the WEEE Directive (2002/96/EC). It was based on the Extended Producer Responsibility (EPR) principle and held the producers responsible for management of waste EEE products. This Directive was revised in 2012 to include PV as a separate category, in anticipation of this looming issue (recast WEEE Directive 2012/19/EU).

This thesis focuses on the transposition of the new Directive into the national legislations in Germany and Italy, PV related legislation in Switzerland, performance of the waste management systems in each and identification of challenges in the adaptation of existing systems to incorporate this new category of waste.

Research questions and design:

The objective of this thesis is to evaluate the three systems, identify where the systems have succeeded, where the challenge areas are and make recommendations based on these findings. The research is guided by the following research questions:

Research Question: How does each case system work?

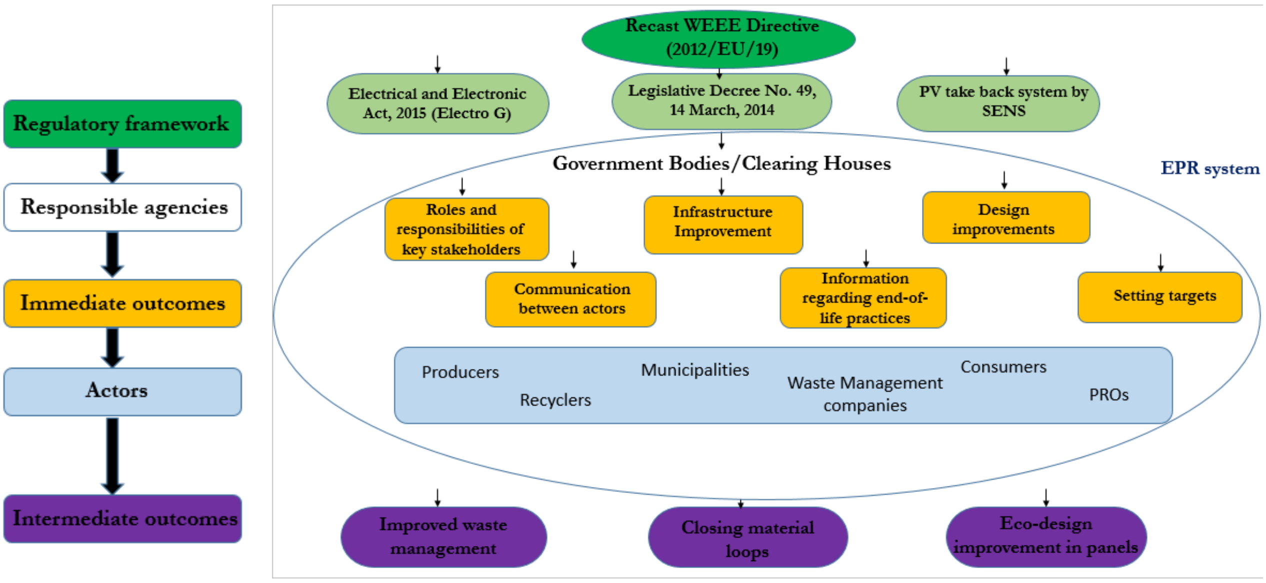
- *What are the national laws transposed by Germany, Italy and Switzerland for solar photovoltaic waste management from the recast WEEE Directive 2012/19/EU?*
- *Who are the main stakeholders involved and what are their responsibilities?*
- *What are the EPR practices that were motivated by these policies in each case country?*

Research question: How have these systems performed so far?

- *How have the systems performed in setting up infrastructure and meeting targets?*
- *How have the systems performed in relation to the goals of EPR?*
- *What are the challenges to the adoption of these practices?*
- *Are there instances of IPR practices within the systems?*
- *What (if any) are the gaps (concerning the EPR goals) in the existing policies (at the EU level) for photovoltaic waste based on these findings?*

The thesis performs a policy evaluation using Vedung's (1997) intervention theory which evaluate the actual outcomes of a policy intervention with its predicted, theoretically reconstructed outcomes. The policies under consideration are the recast Directive, the Italian transposition, the German transposition and the PV related legislation in Switzerland (ORDEE, 1998).

The figure below provides a detailed lay out of the policy intervention for the three systems. Along with the Murphy framework (Murphy et al. 2012; framework for providing an objective, statistical overview of system performance), the intervention theory is used for evaluating the three system.



The methods used for research and analysis include – literature review, quantitative data collection and observation, and stakeholder interviews. Data collected via these methods is then assessed based on the evaluation framework to identify where the challenges are in the systems.

Key findings:

Based on the analysis of the data collected, the following findings were made regarding the systems:

- While infrastructure is present for PV collection, specialized PV waste recycling is still lacking.
- Communication between upstream and downstream actors is lacking and in most cases non-existent.
- PV waste related data is reported as part of WEEE.
- Interest in investing in specialized PV recycling solutions is lacking due to several reasons such as low incoming waste volumes and economic infeasibility.
- This is also reflected in interest in investment in Design improvement of the panels as most producers are part of collective schemes and do not foresee sufficient gains from such investments.

Conclusion:

Proper end-of-life management of waste PV panels is a priority from both reduced environmental impacts point of view (leaching of harmful materials into the surrounding, decrease in environmental impacts from use of recycled materials and recovery of critical resources) and an economic angle (valuable material recovery).There are still, however, challenges to fully optimize this systems, from the point of view of meeting EPR goals and scaling up systems to meet future demands.

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Abbreviations

B2B – Business-to-Business

B2C – Business-to-Consumer E-waste – electrical and electronic waste

EEE - Electrical and Electronic Equipment

EPR – Extended Producer Responsibility

EU- European Union

IPR – Individual Producer Responsibility

PoM – Put on Market PRO – Producer Responsibility Organization

WEEE – Waste Electrical and Electronic Equipment

1 Introduction

1.1 Background and Significance

Moving away from conventional forms of energy and global dependency on fossil fuels (coal, oil, etc.) to more renewable based energy solutions such as solar energy is a proven way to reduce the emissions of greenhouse gases and mitigate climate change (Masson et *al*., 2014; Elliott, 2000). The deployment of solar photovoltaic (PV) panels has increased at unprecedented rates since its adoption in the early 2000 (UNEP, 2016). According to The International Renewable Energy Agency (IRENA) the total capacity of solar PV will reach 4,500 GW by 2050, up from 222 GW in 2015. Such a dramatic increase in PV volumes will present significant end-of-life management issues if proper processes and policies are not implemented on time (IRENA, 2015). Given the average life span of 30 years of a PV module, vast amounts of PV waste streams will start accumulating globally around the 2030s. Earlier adopters of the PV technology such as the European countries of Germany, Italy and Spain could start generating significant waste volumes even sooner.

In anticipation of this looming issue, PV waste was added to the EU legislation on e-waste management, i.e. the Waste Electrical and Electronic Equipment (WEEE) Directive (Directive on waste electrical and electronic equipment) in its latest recast in 2012 (PV was included under the existing 'Category 4: Consumer Equipment and Photovoltaic panels'; for the transitional period of August, 2012 till August, 2018 and 'Category 4: Large Equipment' starting 15th August, 2018, WEEE Directive 2012/EU/19). The legislation was introduced in 2002 and was the very first EU-level legal framework for e-waste management in the Member States. As per the Directive, the producers are responsible for the take back and the end-of-life management of their respective products. The main objectives of the WEEE Directive are to prevent waste EEE (and associated potential hazardous components) from being disposed in landfills, and to encourage resource efficiency through reuse and recycling of EEE, as well as to minimize the environmental impact of waste EEE at end-of-life by improving the environmental performance of end-of-life operators. At the core of the WEEE is the 'Extended Produced Responsibility' (EPR) principle which requires all producers who wish to place products on the European market to be financially responsible for their entire life cycle management, irrespective of where their manufacturing sites are located (EU Commission, 2014). Since the 13th of August, 2012 the revised WEEE Directive 2012/19/EU provides a PV- specific EPR legislation that covers the collection, transportation and treatment of PV. Producers join a third party, such as Producer Responsibility Organizations (PROs) that take on these responsibilities and manage the discarded products of a similar kind (otherwise termed as 'Collective Producer Responsibility'). PROs such as PV Cycle have established fully operational collection and recycling schemes for waste PV panels along with its pan-Europe members and has managed to achieve recycling rates of as much as 96% (PV Cycle, 2016). There are also instances of producers' setting up their own take – back systems for their particular brand of products. In this way, the producers are physically responsible for managing the end-of-life impacts of their own products. Such a system is an example of an 'Individual Producer Responsibility' (IPR) system (Rossem, 2008; Dempsey et *al*., 2010). An example of such a system is the system set up American firm First Solar, which is funded and managed by First Solar. (The concepts of collective and individual EPR systems will be further explained in the 'Literature Review' chapter).

A major concern with PV waste is that solar panels contain a wide variety of hazardous substances in them such as – lead, cadmium, etc. which if poorly handled can cause significant harm to the environment, including humans (Veleva & Sethi, 2004). Once these materials find their way into the ecosystem, they persist and accumulate over long periods of time, causing air pollution, soil and ground water contamination (Halluite et *al*., 2005). Such toxic materials can pose severe risk to the human health if they should find their way into the food chain, such as respiratory illness, neuropsychiatric problems, comas and in some cases can even be fatal (Halluite et *al*., 2005)

Another cause of worry due to improper handling is where the waste might end up if it is not accounted for. Large quantities of highly toxic wastes move across boundaries, often from developed to developing nations where they are improperly treated and disposed, causing severe risk to the local environment and human health due to poor management practices and awareness (Widmer et *al*., 2005). And finally, PV panels also contain small quantities of rare and valuable material such as silver, indium, etc. which are being lost when they can be recycled and reused instead (Goosey, 2004).

It is required of each EU Member State to transpose the recast WEEE Directive into their own national laws. Germany and Italy are amongst the front runners when it comes to having adopted and implemented national regulations for systems for separate PV management. Switzerland has the oldest national e-waste system in the world, having established one in 1994 (SWICO recycling; elaborated in the following sections) (Fredholm, 2008). Each case has its unique way of transposing and implementing the Directive (or including PV in the existing legislation in the case of Switzerland) into its national context which is evident from the differing system manifestations in each country. The practices from these cases can serve as learnings for other countries poised to implement their own systems in the near future. Infrastructural changes, organizational changes or even design changes at the upstream level of the product that were prompted by the legislation in the three countries can provide useful insights into successful practices, possible challenges faced at the time of adoption and drivers that can influence the performance of the system.

1.2 Problem Definition

PV waste is a specialised waste category that poses unique end-of-life management problems that are unlike those observed in other e-waste streams. Solar panels contain toxic heavy metals which, if improperly handled, can leach into the surrounding soil, severely damaging the surrounding environment (BioIntelligence, 2011). In addition to this, they also contain rare and extremely valuable elements (eg. Tellurim, used in thin-film technology, which makes up – 0.0000001% of the Earth's crust) (Jones, 2013). Preserving these elements is vital to improving the overall sustainability and resource efficiency of PV panel production, especially given their finite nature. Efficient end-of-life management practices play an integral role in not only reducing the environmental impacts that take place from improper handling of panels, but can also impact the entire life cycle of the panel, from sustainable material consumption at the time of production to improved resource recovery during disposal, which is the ultimate goal of EPR and the WEEE Directive (Milojkovic and Litovski, 2005). In light of the increasing global levels of current and future installed PV and, consequently, the expected vast volumes of waste that has already started flowing in, it is necessary to study how the early adopters have adapted their existing e-waste management systems to effectively handle this specialized waste. Amongst these countries are Germany and Italy that have been treating PV waste for several years, with some cases of commercial scale success as well.

Academic literature has looked at the economic feasibility of recycling PV modules (Choi & Fthenakis, 2010), the growing problem of PV waste (IRENA, 2016; Bilimoria & Defrenne, 2013) and describing the various management approaches adopted by economies around the world (IRENA, 2016). Further, since recycling and end-of-life management for PV waste are still considered costly and redundant given the small quantities of volumes currently coming back to the producers, most literature focuses on methods for efficient recycling of panels that are either in their pilot stages or have not been commercialised on a large scale as yet (Besiou and Van Wassenholm, 2015; McDonald, 2010; MoE, 2012; Stolz and Frischknecht, 2016)

Literature on EPR practices for end-of-life management for solar PV waste in particular, and in the EU, is scant. Practices in Germany, Italy and Switzerland are mostly mentioned as part of grey literature in academic material, with a focus on Life-Cycle Assessment (LCA) of solar panels or when discussing trends in current waste handling practices (Stolz, 2016; Besiou and Van Wassenhove, 2015; ITRPV, 2016). Given the recentness of introducing PV as a separate waste stream in the revised WEEE Directive in 2012, most literature concentrates on challenges associated with the WEEE obligations (Bilimoria & Defrenne, 2013).

This thesis aims to contribute to the existing literature and perform a thorough analyses of the national regulations, EPR related practices and performance of the waste management systems that have been implemented in Germany, Italy and Switzerland. Studying the uniqueness and novelty of the three systems, their differing waste management practices and the challenges faced during effective implementation of policies by the three cases will be useful for all stakeholders along the value chain to understand what are the successes and failures of these systems. Using the intervention theory frameworks by Tojo, 2004 for EPR programmes for environmental policy (further adopted from Richter, 2016 and Pellegrino, 2016) and a comparative recycling system framework (Murphy et al., 2012, introduced and evaluated in the succeeding sections) this thesis will perform a systematic review of the literature present on systems for PV waste handling, collection and recycling and the adoption of the recast WEEE Directive into the national legislations, to identify what are the practices that are employed by Germany, Italy and Switzerland that have placed these countries amongst the front runners of PV waste handling. Additional sources of information will also include relevant stakeholder interviews and quantitative data analysis.

In addition to these outcomes, this thesis will also explore the case of First Solar as a study on practical IPR cases and compare its operation to that of the collective EPR systems of the other cases to evaluate performance. The purpose of this inclusion is to provide a holistic overview of the EPR system adoptions and make relevant recommendations based on the variety of learnings from these systems.With the help of this knowledge, policy makers, manufacturers and other stakeholders will be able to gauge what actions can possibly lead to better handling of this specialized stream of e-waste. They will be able to use this information to frame better policies and practices in their own countries and promote recycling of PV amongst the various upstream and downstream stakeholders.

1.3 Research Questions

Research Question: How does each case system work?

- What are the national laws transposed by Germany, Italy and Switzerland for solar photovoltaic waste management from the recast WEEE Directive 2012/19/EU?
- Who are the main stakeholders involved and what are their responsibilities?
- What are the EPR practices that were motivated by these policies in each case country?

Research question: How have these systems performed so far?

- How have the systems performed in setting up infrastructure and meeting targets?
- How have the systems performed in relation to the goals of EPR?
- What are the challenges to the adoption of these practices?
- Are there instances of IPR practices within the systems? If yes, how does the system work and how has it performed so far?
- What (if any) are the potential gaps concerning the EPR goals in the case systems for photovoltaic waste based on these findings?

1.4 Scope and Limitations

The focus of this thesis is the PV waste management systems in Germany, Italy and Switzerland. This excludes the systems for other e-waste management and their performance. Since the recast WEEE Directive has only been introduced in 2012, most of the corresponding improved PV recycling technologies are still either in the research pilot stages and have not been commercialized. This poses a limitation in understanding the actual performance of the policies and a lot of the information during conducting a literature review had to be drawn from the common PV recycling practices where it is treated along with the other e-waste. Without readily available recycling solutions, a lot of the producers and recyclers that were interviewed for this thesis preferred to store the waste PV modules that they received till a either a sizeable quantity was amassed to be sent to appropriate recyclers in other regions or till commercially scaled, economically feasible recycling technologies are a commonality. Another challenge, identified during the course of the research was readily available and consistent primary data for specifically PV waste. To overcome this, the author chose to use suitable proxies (scenario development, projections, etc.) in some cases; in others, where a cross Member State review of performance was required and appropriate data was unavailable, the author chose to use dated (2014) figures as proxies to stand in for current system performance.

The time scope for the legislations consulted for the paper have been kept from 2002 (when the first WEEE Directive 2002/96/EC was introduced) till 2016 to draw upon historical as well as current assessment of the WEEE management systems in the three cases. The focus of this thesis is simply to evaluate the effectiveness and – of the three systems in meeting the three EPR goals of – Improved Waste Management practices, Closing material loops and Eco-Design. Each of these goals will be assessed based on certain outcomes following the transposition of the new WEEE Directive into the national legislation, or in the case of Switzerland, on the basis on self-initiated actions for managing PV waste.

As it will be difficult to obtain economic data, due to confidentiality and competitive reasons, the author felt it best to narrow the scope of the thesis to more accessible data which is that of material flows and legislative motivations in the system. Lastly, geographically the thesis has been narrowed down to assess only three cases, i.e. Germany, Italy and Switzerland, as the systems in each country are very diverse, have some quantitative data available as, being amongst the earliest transposers of the WEEE Directive, the existing EPR systems were modified to include to PV a few years ago and have been seeing end-of-life modules trickling back for some time now.

1.5 Structure of Paper

The succeeding Chapter 2 provides a background to the WEEE Directive, the three case countries and First Solar. Chapter 3 summaries the finds of the Literature Review and introduces the two frameworks (Intervention theory for policy evaluation and the Murphy framework for an overview of the system performance). Chapter 4 introduces the Research Design for the thesis and the Methodology used for data collection and analyses. Chapter 5 summarises the findings from the data collected from research methods and, based on these findings, identifies wherein the challenges lie in the system. And finally Chapter 6 provides recommendations based on the findings and the concluding remarks.

2 Background to Cases

2.1 The WEEE Directive

The WEEE Directive was first introduced in 2002 by the European Parliament and the Council of the European Union in order to address the issue of rapidly growing e-waste due to increased consumption of EEE in the EU. Its purpose was to prevent the generation of WEEE where possible and to increase the reuse, recycling and recovery of WEEE to minimize disposal (Directive 2002/96/EU). As previously mentioned, there were three main objectives of the Directive, namely: eco-design, improved waste management practices and closing of the material loops.

After the introduction of the Directive in 2002, all the EU Member states were required to transpose it into their respective national laws by the 13th of August, 2004. Each state was required to implement systems consisting of the relevant laws, regulations and various provisions which would allow the state to fulfil the requirements laid down under the Directive. The states had the flexibility to decide the nature of the transposition and system design, given that it was a Directive and not a Regulation. There were 10 categories of electronic and electrical waste mentioned under the scope of the Directive, with assigned 'recovery' and 'recycling' targets based on minimum weight. Private households were expected to fulfil a collection target of 4 kilograms per capita per year which consisted of all WEEE.

2.1.1 WEEE Directive recast 2012/19/EU

The WEEE Directive was updated in 2012, after the European Commission undertook an impact assessment of the previous Directive in 2008 to assess its performance. It was formally enforced on the 13th of August, 2012 and brought with it several changes.

According to Article 7 of the Recast Directive, *"From 2016, the minimum collection rate shall be 45% calculated on the basis of the total weight of WEEE collected […] in the given year in the Member State concerned, expressed as a percentage of the average weight of EEE placed on the market in the three preceding years […]."*

"From 2019, the minimum collection rate to be achieved annually shall be 65% of the average weight of EEE placed on the market in the three preceding years in the Member State concerned, or alternatively 85% of WEEE generated on the territory of that Member State."

Another important change brought about by the revised Directive was the change in categorisation of the WEEE. From the previous 10 categories of WEEE, which only covered household WEEE, the categories went down to 6 with included, respective targets for 'recovery', 'recycling' or 'preparation for re-use and recycling'. PV modules were introduced as a separate waste for the first time, under Category 4 'Large Equipment'. These categories and targets are presented in Table 2-1.

Table 2-1 WEEE categories under the Recast Directive and respective targets starting 15th August, 2018

Categories under the WEEE Directive Recast (starting 15th August, 2018)		**Temporary Exchange Equipment**	**Screens, monitors, equipment with surface screens > 100**	**Lamps**	**Large Equipment**	**Small Equipment**	**Small IT and telecommunication equipment**
Targets	% recovered	80	70	75	75	70	70
	% prepared for re-use of recycled	75	50	65	65	50	50

Source: Annex V, recast WEEE DIRECTIVE 2012/19/EU

The recast Directive specifies a transitional period between 13 August, 2012 and 14 August, 2018 during which time countries will adapt their systems to fulfil the new requirements while continuing to adhere to the scope of the old Directive. Producers are financially responsible for the waste management from their respective products and can chose to cover finances either individually or by joining a collective (as mentioned under Article 5.2d of the recast Directive). In case of a collective, producers cover their responsibilities via Producer Responsibility Organizations (PRO) which facilitate the collective handling of the waste (OECD, 2001). Historical waste is also required to be covered under the financial requirements (Article 12.4).

Member States are responsible for the operational responsibility and the designing of the national systems. Different states have adopted different systems for managing this responsibility, from assigning it to the municipalities (Germany) to allocating it to the producers and PROs (Sweden). Besides the operational responsibility, there is also the informative responsibility towards the recyclers and end users, which is also to be covered by the producers. These variations in adopting the Directive into their national regulations and systems has led to many diverse and unique national e-waste management systems across the EU States (Rossem, 2008).

2.2 Germany

Keeping in sync with the EU Directive, the framework for PV handling specified in the German legislation also relies on the EPR principle which was introduced for the very first time in the country in 1991, under the 'Packaging Ordinance' (Fishbein, 1996). Under this provision, the producers of every kind of packaging waste were responsible for taking back their waste, either individually of by joining a collective (Duales System Deutschland). There were several start-up and cost related problems, but the EPR concept was a success and spread to other fields.

Of the EU market, Germany was one of the earliest adopters of solar PV for residential use. By 2015, Germany had a total of 40 GW installed solar PV capacity, which supplied 6% of the total net electricity consumption in the country, the highest in the EU (IRENA, 2016). Figure 2-1 presents the evolution of PV waste in Germany since 2011 and its growth till 2018.

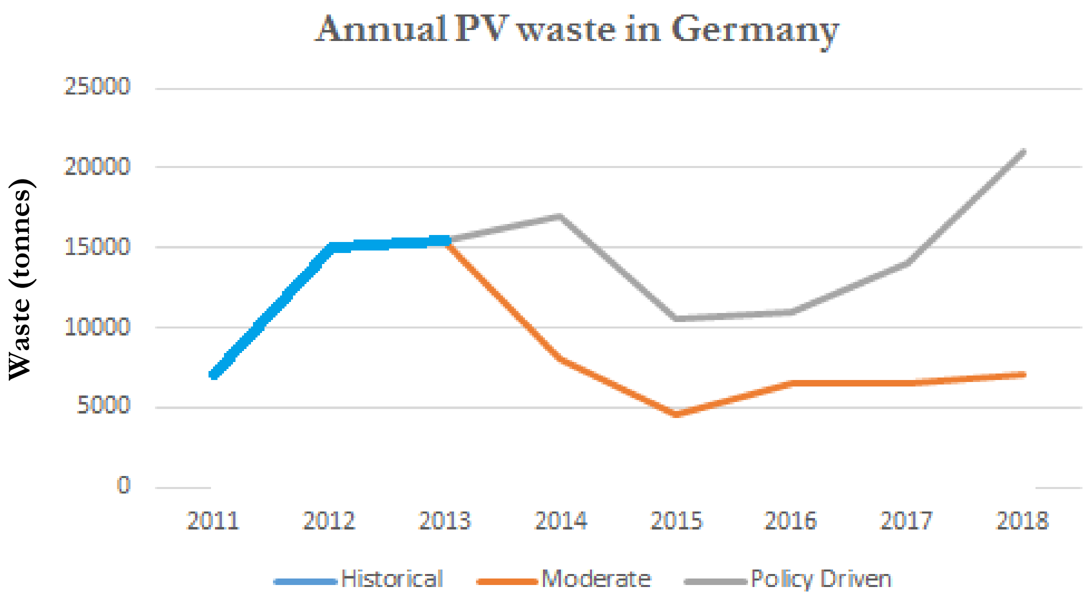

Figure 2-1 Growth of PV waste in Germany
Source Approximate values taken from Bilimoria & Defrenne (2013)

The consequence of this is that Germany will face volumes as significant as 800,000 to 1 million tonnes by 2030, depending upon the loss scenario (early vs. regular loss of panel) and will be one of the leading and largest markets for PV recycling in the coming years (IRENA, 2016). The WEEE Directive (2002/96/EC) was first transposed into the German Law in March, 2005 in the form of the 'Electrical and Electronic Act' or 'ElectroG'. It was revised in October, 2015 in accordance with the new WEEE Directive to include PV in its scope of products (ElectroG2 – October, 2015). It places the entire responsibility of the PV collection and recycling on the producers. The implementation of the waste management practices employed by the country have been so successful that Germany will be the first of the EU-28 to reach profitable economies of scale from its PV panel recycling market (IRENA,2016).

2.3 Italy

Italy's evolution of its handling of WEEE has undergone a drastic improvement since 2008. Even though the WEEE Directive was transposed into the national legislation with passing of the Decree No. 151 in July of 2005, the Italian e-waste collection system was riddled with issues, primarily due to lack of funding and clear legislation that covered the collection and recycling of EEE (Paiano, 2014; Smith, 2013). Moreover, there was no single entity supervising the working of the system and instead collection and recycling was performed by various, un-coordinated bodies who were very in-effective with their working. This led to a failure to comply with the EU regulations regarding e-waste targets (Smith, 2013). Unlike Germany, Italy was late in adopting an EPR approach in its waste management systems and therefore has a shorter history with this principle and less experience (Paiano, 2013).

Separate WEEE collection was introduced in the second half of 2008 and led to a remarkable improvement in the system's performance (Paiano, 2014). In 2010, Italy not only met the EU targets for collection of WEEE (4kg/inhabitant/year) it surpassed this target to collect nearly 30% more waste than 2009, an increase that had not been observed before. In order to provide financial support for proper WEEE disposal, an 'eco-contribution' fee was added to every new device sold by the producer. For professional WEEE, the producers and distributors are mandated to join a collective scheme by paying an annual fee which covers the proper collection and handling of WEEE (Paiano, 2014; Torretta et *al.*, 2012).

In April 2014, Italy became the first major PV market player to transpose the recast EU WEEE Directive (2012/29/EU) into its own national legislation, by passing the Decree No. 49/2014 which was based on the EPR principle and held the producers financially responsible for the transport and recycling of PV across Italy. Solar PV was described as WEEE for the first time under this Decree, which also required all PV producers to join a National Register, responsible for the financing of the WEEE handling system and compliance with the provisions of the Decree, before they started operating in Italian territory. In order to ensure compliance, the Decree held back a certain portion of the government supplied Feed-in-Tariff, to cover the proper disposal and recycling of the panels, which will only be reimbursed if the producers can prove the panels were disposed in a sound manner within 6 months of it being collected (Legislation No. 49, March 2014).

Italy has the second largest PV capacity in EU after Germany, at 19 GW in 2015. The amount of PV waste expected in the country varies from 850 to 20,000 t in 2016, depending upon the loss scenario (Early vs. Regular loss, modelled using the Weibell function) (IRENA, 2016). The country is amongst the front runners for setting up systems to handle this waste, taking steps such as becoming member of PV Cycle as early as 2013, before the other EU nations had even transposed the recast WEEE Directive into their national legislations and is an important case study for this thesis (PV Cycle, 2013).

2.4 Switzerland

Environmental issues have always been given high priority amongst the citizens of Switzerland (Khetriwal et *al.*, 2005). Starting with setting up of the SENS foundation in 1991, which took in 'white goods' such as washing machines, refrigerators, ovens, etc., various systems were established in the country even before the WEEE Directive came into existence (Khetriwal et *al.*, 2005). There is no clearing house in Switzerland, instead the take-back system in the country is run by three private take-back schemes which cover collection, transport and recycling for their member producers, namely SENS (for 'white goods'), Swiss Industrial Association for Information, Communication and Organization Technology (SWICO, for 'brown goods' such as the television sets, radios, computers, etc.) and Swiss Lighting Recycling Foundation (SLRS, which is a contractual partner of SENS, responsible primarily for the collection and treatment of lamps and lighting equipment across Switzerland). Between these three systems, more than 132,000 t of recyclable e-waste was collected in 2015, which translates to a higher rate than the percentage mentioned in WEEE (Switzerland has a higher collection and recycling than that mentioned in the WEEE Directive – about 85%). The Ordinance on Return, Take Back and Disposal of Electrical and Electronic equipment (ORDEE/VREG) provides the required regulatory support for the establishment of the infrastructure for handling the vast and varied amounts of e-waste that is generated in the country. It was passed in 1998 and its most recent revision in 2014 includes solar photovoltaic panels as a separate waste that is to be collected and treated separately from the other e-waste. ORDEE clearly lays down the obligations for return, take-back and disposal that all retailers, traders, manufacturers, importers and recyclers are expected to follow. The system has so far managed to not only meet the required collection, recycling and recovery quotas, but has in fact gone much beyond and as a result has been noted as one of the 'best established e-waste systems world-wide (GIS Watch, 2010). The long history with voluntary take back systems that Switzerland has makes it a valuable addition to this thesis.

At the end of 2014, SENS and Swico made adhering to the European Standards for WEEE collection, logistics and treatment - EN 50625 mandatory. As PV is now included in this category, recycling and closing of the material cycle for PV waste is guaranteed. SENS has since collected small quantities of PV waste, along the lines of 70 t in 2015 from its various collection points (Technical report, 2016). Before this addition, take back of PV was only initiated based on email or fax by the submitter to SENS. Now there are separate collection systems at all SENS collection points and all the necessary processes required to handle this specific kind of e-waste have been put into place (Technical report, 2016). As far as the recycling and recovery of various materials is concerned, based on the composition of the panels, nearly 80 to 90% of the material can be recovered for production of new panels (Technical report 2014). Panels that contain hazardous materials (non- Silicon based cells) are manually separated and treated accordingly, to reduce the possibility of toxic materials escaping into the environment (Technical report, 2016).

Proper handling of PV waste is important for Switzerland since it is seeing a steady increase in the installation and generation of electricity from solar PV panels. It had a total ground capacity of 1.4 GW in the year 2015 (accounting for ~2.5% of the total electricity demand) and this figure is only set to increase given the concerted efforts by the government to provide financial incentives such as subsidy schemes, especially targeted for the residential sector, which has already resulted in a 20% growth in capacity in the year 2014 itself (Densing et *al.*, 2014). At this rate, Switzerland will start experiencing vast quantities of PV waste coming in in the near future and, anticipating this, has already put suitable systems in place.

2.5 First Solar

Founded in the 1999 with headquarters in Tempe, Arizona, First Solar is a supplier of solar panels and also develops its own large solar farms. It has its own Research and Development Unit where it strives to continuously improve the efficiencies of its panels. It produces thin-film, CdTe cells as it is convinced that while ~95% of the current solar market may be dominated by cells made from silicon, solar modules made from cadmium telluride can be developed to have a higher efficiency. While commercially, First Solar manufactured CdTe cells can reach an energy conversion efficiency of 16.4%, efficiencies as high as 22.1% have been reached at its research facilities (MIT Press, 2016). It is the world's largest thin-film solar module manufacturer and currently the only major one in the US. It concentrates only on the utility scale solar market and not on rooftop solar installations (<30 kWp). First Solar panels have the smallest carbon footprint, lowest water use and the fastest energy payback time of any of the PV technology on the market (Sustainability Report, 2016).

Starting in the year 2005, First Solar introduced the PV industry's first fully, voluntary, pre-funded collection and recycling program at all of its manufacturing facilities, globally. It had recycled ~48,000 t of waste modules by 2013 (Andreas Wade, Global Sustainability Director at First Solar, personal communication, 2013). Its manufacturing and recycling facility in the EU is in Frankfurt (Oder), Germany. The Module collection and recycling program initiated by the company is based on the EPR principle and takes all stages of the panel into account; from 'Material sourcing' all the way to 'Recycling' and beyond to improve the 'Product Design'. The whole system is financed by the amount the company deposits in a trust fund at the end of each year and this ensures that the end-user does not have to pay for this service. The current version of the in-house recycling technology at the facilities yields ~90% of module component recovery (including glass which is used in new glass products, Cd and Te which are purified by a third party and reused in First Solar modules) (Krueger, n.d.). In anticipation of the large volumes of PV waste expected in the coming years, the next versions of the recycling process will be more efficient, will have higher recycling capacities (3^{rd} generation – 30t/day and 4^{th} generation – 350t/day) and will be able mobile by the year 2027 (Wade, 2013).

3 Literature Review and Analytical Framework

3.1 Photovoltaic Technology and Waste Projection

Photovoltaic panels (or photovoltaic abbreviated as PV) generate a renewable source of energy by converting the solar radiation directly into current electricity. The solar cell is the fundamental building block of the photovoltaic technology. It is made of semiconductor materials, such as silicon, exhibiting the ***'photovoltaic effect'*** (generating electricity when the light of the sun on falls on its surface) (Trykozko, 1997). The broad categories of solar PV technology are classified as 1st, 2nd and 3rd generation. Crystalline silicon cells represent the 1st generation, while cadmium telluride cells are part of the 2nd generation (next to other thin film technologies). Third generation technologies have not been commercialized on a large scale (Bio Intelligence Service, 2011; Tao et *al.*, 2011).

1st generation: Crystalline Silicon (c-Si)

i. Monocrystalline (very efficient, but expensive, highest purity silicon, sophisticated manufacturing process)
ii. Multicrystalline (or polycrystalline, solar cells cut from multifaceted silicon crystals, most common type, cheaper than monocrystalline)

Except for silver, there are no other raw materials in 1st generation cells that are available in limited quantity, i.e., critical materials. Toxic substances like lead are present in these cells which can leach out into the environment when exposed to nitric acid or acid rain (Auer, 2015).

2nd generation: Thin Film (one or more thin layers of photovoltaic material on surface, e.g. glass, stainless steel or plastic)

i. Amorphous silicon (non-crystalline form of silicon, uses less scarce materials)
ii. Cadmium telluride (CdTe, semi-conductor compound formed of cadmium and tellurium)
iii. Copper indium gallium selenide (CIS or CIGS, newer technology, highest efficiencies of thin film technologies)

Table 3-1 shows the ideal composition of the two types of photovoltaic panels that are present in the market, namely – c-Si and thin film. Crystalline silicon cells make up about 90% of the market share of PV panels while the remaining is thin-film panels (Battaglia et *al.*, 2016).

Table 3-1 Composition of the two different types of solar photovoltaic modules

Material	Crystalline Silicon Modules	Thin film modules	
		CdTe	CIS/CIGS
Glass	74%	95%	84%
Aluminium	10%	<1%	12%
Other components (including rare metals)	16%	4%	4%
Other key materials	EVA (ethylene vinyl acetate – used to encapsulate the PV cells), Tedlar backing film, silicon, adhesive	EVA	EVA
Critical metals included	Silver		Indium, Gallium
Presence of Cadmium and Lead	Lead	Cadmium	Cadmium

Source: BIO Intelligence Service, 2011

3rd generation: Concentrator photovoltaics (CPV) and emerging technologies

i. CPV utilizes lenses to focus sunlight on to solar cells.
ii. Dye-sensitized solar cells
iii. Organic solar cells are composed of biodegradable materials such as organic polymers or small organic molecules
iv. Hybrid cells involve the combination of current technologies on the market and the combination of organic and inorganic semiconductors

Accumulated PV Waste:

Waste production takes place during four major life cycle phases of a PV panel, namely the 'Production' phase, the 'Transportation' phase, the 'Installation and Use' phase and finally the 'End-of-Life disposal' phase (IRENA, 2016). According to the Solar Quarter, 2016, there are three main stages of panel failure:

- **Infant failure**, when the panel ceases functioning four years after the installation
- **Midlife failure**, when the panel ceases functioning between five to eleven years from installation
- **Wear-out failure**, when the panel ceases to functioning after 12 years from installation till its eventual end-of-life

Causes for failure during each stage can vary from inherent system failures, incompetent mounting structure, etc. for 'Infant' stage, degradation of anti-reflective coating during 'Midlife' stage and failures due to excess exposure to mechanical load cycles (such as wind and snow loads) and temperature differences for the 'Wear-out' stage (IRENA, 2016). Based on these stages, Solar Quarter, 2016 estimated a global PV waste quantity of 250,000 tons globally, by the end of 2016, which accounts for approximately 0.6% of the global e-waste and is expected to rise significantly over the coming years. The ratio between new PV installations and the mass of PV end-of-life starts off small (~5% by 2020), but as more of the currently installed panels wear out, this ratio will steadily increase to reach nearly 80% waste volume to the new installation volume by 2050, globally (IRENA-IEA PVPS, 2016). Table 3-2 displays the modelled waste volume values for various European, North American and Asian countries to compare the values observed by some of the leading PV installers.

Table 3-2 Modelled waste volumes of PV waste by country (t)

Year	**2016**		**2020**		**2030**		**2050**	
Scenario (Regular vs. Early loss)	Regular loss	Early loss	Regular loss	Early loss	Regular Loss	Early Loss	Regular Loss	Early Loss
ASIA								
China	5,000	15,000	8,000	100,000	200,000	1,500,000	13,500,000	19,900,000
Japan	7,000	35,000	15,000	100,000	200,000	1,000,000	6,500,000	7,600,000
India	1,000	2,500	2,000	15,000	50,000	325,000	4,400,000	7,500,000
EUROPE								
Germany	3,500	70,000	20,000	200,000	400,000	1,000,000	4,300,000	4,300,000
Italy	850	20,000	5,000	80,000	140,000	500,000	2,100,000	2,200,000
France	650	6,000	1,500	25,000	45,000	200,000	1,500,000	1,800,000
United Kingdom	250	2,500	650	15,000	30,000	200,000	1,000,000	1,500,000
NORTH AMERICA								
United States of America	6,500	24,000	13,000	85,000	170,000	1,000,000	7,500,000	10,000,000
Canada	350	1,600	700	7,000	13,000	80,000	650,000	800,000
Total World	43,500	250,000	100,000	850,000	1,700,000	8,000,000	60,000,000	78,000,000

Source: Remap, IRENA 2016; PV Technology Roadmap, IEA, 2016

According to the above values, Europe is projected to be the second largest PV market by 2050, with Germany, Italy and France seeing the largest waste values coming in (IRENA, 2016).

3.2 Impacts of PV Waste:

3.2.1 Soil and Air Pollution

Despite their known environmental benefits, solar photovoltaic panels are responsible for considerable levels of soil and air pollution. Lead, a heavy metal used in 1st generation crystalline silicon (c-Si) panels, has a potential of leaching from the panel if exposed to low pH substances such as rain or nitric acid. 13% to 90% of the total quantity of lead found in a panel can leach into the surroundings if steps are not taken to ensure that the pH of the panel remains the same as that of the lead it contains (Bio Intelligence Service, 2011). Each panel contains approximately 12.67g of lead, which can result in a leaching potential of anywhere between 1.64 to 11.4g per panel or 75g to 518g per tonne of panel disposed (Bio Intelligence Service, 2011)

Lead has a high potential of accumulating in the environment. If consumed, it can spread through the body and accumulate in the bones. Depending upon the level of lead consumed, it can even severely damage the 'nervous system, kidney function, immune system, reproductive system and cardiovascular system.' In nature, lead accumulation results in loss of biodiversity, stunting of growth rates in plants and animals and damages to vertebrates (EC, 2011)

Another element which also has high pollution potential is cadmium. Associated with 2nd generation thin film photovoltaic panels, it is also a heavy metal that collects in living organisms and has a half-life of 30 years. Thin film panels such as cadmium telluride (CdTe) and cadmium indium gallium silicon (CIGS) contain an average of 4.6g of cadmium. Nearly 7% of this volume of cadmium can leach in case of exposure to low pH substances such as nitric acid or rain (at the time of being landfilled, this percentage increases to 29% to 40%). Average leaching of cadmium can be anywhere between 27g to 153g per tonne of panel disposed. Cadmium has a high toxicity level as well as accumulation potential in humans. It is a known carcinogen and has been known to cause serious pathophysiological changes in case of repeat exposure (EC, 2011).

The total cost associated with the pollution of lead and cadmium from improper handling of PV panels is assumed to be around 1.174 €/g of lead and 0.046 €/g of cadmium. And these figures are only associated with human health damages and exclude damages to the ecosystem (BioIntelligence, 2011).

3.2.2 Resource Loss:

Photovoltaic panels are composed primarily of aluminium and glass. Failure to recycle these resources indicates loss of potentially usable and valuable materials for all types of panels. An average crystalline silicon (1st generation) photovoltaic panel comprises of a total of 74.16% glass and 10.30% aluminium which is present in the frame. In terms of weight, this translates to approximately 16.6kg of glass and 2.3 kg of aluminium which can be recycled in an average c-Si panel. In the case of a second generation, thin film PV (a standard cadmium indium silicon model), 84% of the panel is made up of glass (~9kg of glass), with 12% aluminium in the frame (~1.4kg of aluminium) which are recyclable (Bio Intelligence Service, 2011).

In terms of economic value of these materials, the price of glass in the market was around 50€ per tonne between 2000 and 2009, and that of aluminium approximately 1200€ per tonne in 2011. Recycling of aluminium and glass has been cited as one of the most effective ways of reducing environmental impacts of all the disposal options available, by a study conducted by FORWAST project of the 6th European Framework Programme (Schmidt, 2010).

Another loss from the lack of recycling of photovoltaic panels is that of rare metals such as silver, indium, gallium and germanium. Despite making up only 1% of an average panel composition, the value assigned to these elements is significant. Eventually, an increase in the prices if virgin resources could result in an increase in the cost of the lost resources from panels that could have been recycled. The depletion of stock of natural resources such as aluminium and rare metals, along with future demand, innovative recycling technologies and percentage reusable materials, will influence future market prices (Stolz & Frischknecht, 2016).

According to the prices of aluminium, glass and rare metals in February of 2011, considering the lack of proper recycling, a total economic loss, assuming 100% recycling, was totalled at 146 Euros / panel for crystalline silicon PV panels and 123 Euros / panel for thin film PV panels. Realistically, these percentages would be closer to 100% for aluminium, 95% for glass and 30% for rare metals (Bio Intelligence Service, 2011). Even for these percentages, the loss was still considerable, at 46 Euros/panel for c-Si panels and 37 Euros/panel for thin-film. Table 3-3 presents the total economic loss due to lack of recycling and proper handling of PV panels, based on material prices as of February, 2011.

Table 3-3 Economic loss due to lack of recycling and proper treatment of PV (per panel)

			c-Si module		**a-Si module**	
Material	**Price (per kg)**	**Recovery rate**	**Mass (kg/Wp)**	**Price/Wp**	**Mass (kg/Wp)**	**Price per Wp**
Glass	0.05 €	95%	0.0734	0.0037 €	0.2371	0.0119 €
Al	1.20 €	100%	0.0107	0.0128 €	0.0001	0.0001 €
Rare metals	Variable*	30%	0.0003	0.1989 €	0.0009	0.6086 €
Total				0.22 €		0.62 €
/tonne				2105 €		2349 €

**€ 650 for c-Si panels containing Silver, €700 for a-Si panels with Indium and Gallium (Market prices as of February, 2011)*

Source: BIO Intelligence Service, 2011

3.3 Extended Producer Responsibility as a Management Tool?

The term 'Extended Producer Responsibility' first originated in a report submitted to the Swedish Ministry of Environment, titled *"Modeller för förlängt producentansvar" [Models for Extended Producer Responsibility]* in 1990 by Lindhqvist and Lidgren. At the time of its inception, EPR was viewed as a 'concept' derived from the analysis of several recycling and waste management systems, both Swedish and foreign along with experiences with policy instruments for promotion of Cleaner Production by policy-makers (Lindhqvist, 2001). The concept was further revised in 1991 when it was viewed as an 'environmental protection strategy' and again in 2000, when in his doctoral dissertation, Lindhqvist positioned EPR as a 'policy principle' with the following definition:

"*Extended Producer Responsibility is a policy principle to promote total life cycle environmental improvements of product systems by extending the responsibility of the manufacturer of the product to various parts of the entire life cycle of the product, and especially to take back, recycling and final disposal of the product.*"

The rationale behind the EPR principle is that by making the producers responsible for the economic and/or physical responsibility of the end-of-life management of products, it pushes them to not only account for, but also re-consider all the issues that are associated with end-of-life products (Lindhqvist, 2000). Rational producers would think of ways to reduce the cost associated with waste management which could, in theory, drive them towards options such as substitution/choice of material, design changes for ease of recyclability/material consumption, etc. (Rossem, 2008). Eco-designed products considerably reduce the amount of virgin materials that are required and the associated environmental impacts associated with extraction, processing and manufacturing of these materials (OECD, 2001).

In theory, the concept of EPR goes beyond just simple 'take back'. It establishes a feedback loop between the downstream activities (end-of-life) and the upstream activities (product design) along with the actors that are involved (Lindhqvist, 2000). This distinguishes EPR from other waste management policies such as 'Polluter Pays Principle". It serves as bridge between waste management policies and the product-oriented policies (Davis, 2000). This feedback loop is what provides the right incentives to the producers in order to justify the investments that are required to reduce the end-of-life management cost of the products (Lindhqvist, 2000). For decision makers, EPR can act as a guide for establishing the mix of policy instruments (elaborated in Table 4: Policy instruments based on EPR principle) required to reach a certain target for collection and treatment of the desired products (Manomaivibool et *al.*, *2007*).

Another definition for EPR, provided by OECD, 2001, is *"an environmental policy approach in which a producer's responsibility, physical and/or financial, for a product is extended to the post-consumer stage of a product's life cycle. There are two related features of EPR policy: 1) The shifting of responsibility (physically and/or economically; fully or partially) upstream toward the producer and away from municipalities, and 2) to provide incentives to producers to incorporate environmental considerations in the design of their products."*

This is a relatively narrower definition than that provided by Lindhqvist but it also emphasizes on the post-consumer management of products.

Davis, 1999 states that in addition to the responsibilities, there also needs to be certain incentives and signals associated with the life cycle impacts of a product. These can take the form of policy instruments and can be categorised as administrative, economic and informative (presented in Table 3-4) (Lindhqvist, 2000; Tojo, 2004). Policy makers need to also need legislative measures to enforce these instruments. EPR provides the flexibility and choice to both the producers and policy makers to pick which of the instruments are best suited to the existing market and the local conditions (Carisma, 2009).

Table 3-4 Policy instruments based on the EPR principle

Type of instrument	Mechanism	Significance for cases
Administrative instruments	Collection and/or take back of discarded products	EPR systems in Germany, Italy and Switzerland
	Substance and landfill restrictions	Restriction on use of hazardous substances in electrical and electronic equipment (RoHS Directive), complementary national legislation on landfill waste.
	Achievement of collection, reuse (refill) and recycling targets	Recast WEEE Directive and Member State transpositions.
	Environmentally sound treatment standards	
	Minimum recycled material content standards	
Economic instruments	Product standard	
	Material/product taxes, subsidies	
	Advance disposal fee systems	Adopted in the Swiss system through the 'Advanced Recycling Fee'
	Deposit refund systems	
	Upstream combined tax/subsidies	
	Tradable recycling credits	
Informative instruments	Reporting to authorities	Recast WEEE Directive and Member State transpositions.
	Marking/labelling of products and components	Recast WEEE Directive and Member State transpositions.
	Consultation with local governments about the collection network	Recast WEEE Directive and Member State transpositions.
	Information provision to consumers about EPR	Recast WEEE Directive and Member State transpositions.
	Source separation	Recast WEEE Directive and Member State transpositions.

	Information provision to recyclers about the structure and substances used in products	Recast WEEE Directive and Member State transpositions.

Source: Adapted from Tojo, 2004

3.3.1 Types of responsibilities under the EPR principle

Producers have certain responsibilities allotted to them under the principle. These include liability, financial, physical and informative responsibilities (Lindhqvist, 2000). They should ideally cover the entire life cycle of a product and not be limited by national boundaries, especially in the case of electronics and e-waste since their impact can go beyond to other regions of the world (Hotta et *al.*, 2014*)*. Lindhqvist, 2000 provides a definition for each kind of responsibility:

"Liability: *refers to a responsibility for proven environmental damages caused by the product in question. The extent of the liability is determined by legislation and may embrace different parts of the life-cycle of the product, including usage and final disposal.*

Financial responsibility: *means that the producer will cover all or part of the costs for e.g. the collection, recycling or final disposal of the products he is manufacturing. These costs could be paid for directly by the producer or by a special fee.*

Physical responsibility: *is used to characterise the systems where the manufacturer is involved in the actual physical management of the products or of the effects of the products.*

Informative responsibility: *signifies several different possibilities to extend responsibility for the products by requiring the producers to supply information on the environmental properties of the products he is manufacturing."*

3.3.2 Goals of EPR

There are several schools of thought regarding the overall goals of the EPR principle. Lindhqvist and Lifset, (1998) identified four such schools amongst the scholars and practitioners that ranged from simply regarding EPR as a strategy to divert the final waste product from being conventionally disposed of (landfilled, incinerated, etc.), or 'Downstream EPR' to a more holistic and internalized improvement in the environmental performance of the product throughout its entire life cycle.

Based on different schools of thought, the EPR definition provided by OECD 'Guidance Manual' and Lindhqvist and Rossem, 2005 developed an evaluation tool which can be used to determine the extent to which the policy and programme design in focus reflects the EPR goals. According this tool, there are two main environment-related goals in an EPR programme (Rossem, 2008; Lindhqvist & Rossem, 2005):

Goal 1. Design improvements of products - *the EPR system should provide incentives for manufacturers to improve the environmental performance of products and the systems surrounding the life cycle of the products.*

Goal 2. High re-utilization of product and material through effective collection and re-use or recycling. *This goal can be further divided into three sub-goals.*

***2a. Effective collection** – A primary goal with an EPR policy is to ensure a high collection rate of the product in focus in order to avoid littering and abandoned products in nature. A related goal is to divert selected discarded products from the general waste stream in order to facilitate a more proper end-of-life treatment and utilization of the product and its material.*

***2b. environmentally sound treatment of collected products** – Before being further processed many products need a pre-treatment in the form of dismantling and/or sorting. The aim of this can be to secure special treatment of hazardous components and materials, and to improve the possibilities for re-use and recycling.*

***2c. High re-utilization of products and materials in the form of re-use and recycling** – The EPR implementation should secure that products or their components, when appropriate, can be re-used, and that the materials are recovered and used for substituting the use of virgin materials, thus saving raw materials and avoiding the environmental impacts related to the extraction and processing of these materials*

3.3.3 Common features of an EPR programme:

There are certain features which are commonly found across most EPR models in the EU. These include the following:

3.3.3.1 Producer Responsibility Organization (PRO)

In response to their obligations and responsibilities under the legislation, producers collaborate to form provincial or national collective compliance schemes which see to their assigned legal responsibilities. Industry Financing Organizations, Stewardship organizations, compliance schemes or other similar terms are forms of such collaborations (Rossem, 2008). Along with PROs, compliance schemes can also be offered by waste management and logistics companies or producers can get their own compliance solutions for their respective products (Monier et *al.*, 2014).

PROs or other compliance schemes cover everything from establishing and operating collection points, pick up and transport of the waste products to the recycling and treatment facilities, organizing the treatment and reporting the results to the authorities (Rossem, 2008). This makes them integral to the working of an EPR programme as they provide a common platform for all financial transactions and communication between various actors (governments, producers, waste management firms, retailers and municipal authorities) (Mayers, 2007). The PROs further contract with collection site providers (municipalities, retailers and waste management businesses for B2B and/or B2C products), recyclers and logistics partners to carry out the EPR functions.

The cost for carrying out these functions is levied on the producers and calculated either based on a fixed product charge or on the basis of cost proportional to the amount of product which is placed on the market over a defined period (monthly, quarterly or yearly). The producers recover this cost by charging their customers (through a visible or invisible fee) or by lowering their profit margins (Gregory et *al.*, 2009).

Unlike the earlier iterations of the PRO models, which resulted in monopolistic provincial or national EPR programmes which represented all the domestic and foreign producers of a particular product, through the emergence of the WEEE Directive, at least in the largest EU Member States there is presence of competing compliance schemes with more than one PROs for the producers to choose from (Rossem, 2008; Monier et *al.*, 2014). This competition is considered beneficial for driving down the cost associated with compliance and for improving efficiency of the system.

3.3.3.2 Government programs

Alternatively, there are some instances when the government or a quasi-government/industry board can be responsible for take-back and processing of the end-of-life products. In such cases, the producers are not given significant physical and even financial responsibility over the management of the waste products. Instead the retailers are responsible for collecting the process fee from the consumers at the point of product sale and then passing it on to the government body or the third-party which is managing the entire process (Rossem, 2008). This is less frequently observed model that was not observed in any of the case countries that were chosen for this thesis.

3.3.3.3 Financing models

There are two prominent models for generating and financing of the EPR programmes:

Market-Share model: As the name suggests, in this design the collective compliance systems assign the cost for waste management in accordance with each member producer's market share of a particular product. This model resembles a 'Pay-As-You-Go' (PAYG) system and has two variations – PAYG with visible fee (producer adds fee as separate line in the invoice at the time of purchase of product) and PAYG with non-visible fee (no mention of fee at the time of purchase of product). In both variations, the fee levied on the producer is calculated based on the number of units or per weight (kg) basis of product on the market and is used to finance the management of current waste (Rossem, 2008; Gregory et *al.*, 2009).

Return-Share model: In this model, the fee that is levied on the producer is calculated on the basis of the number of units or weight (kg) of that particular brand of products that are returned through the collection system. There are two ways to calculate this fee. The first way is to take a representative sample of the returned waste stream of a particular category and calculate each producer's fee based on the percentage of all the products of that particular brand. The second way is to weigh all the retuned products of a particular brand and calculate the fee based on this amount. This model also covers orphaned or free-rider products by dividing the costs associated with their management on the basis of each producer's market share (Rossem, 2008).

3.3.4 Collective vs. Individual producer responsibility

An EPR system can be categorized as an IPR system when, during implementation, similar products are segregated based on their brands and their respective producers have control over the end-of-life management of the discarded products. A 'Collective EPR system' is one where similar products, belonging to the same stream, are all treated together irrespective of their brand. Third Party Organizations such as PROs are responsible for the physical handling of the discarded products (Dempsey et *al.*, 2010; Rossem et *al.*, 2006; Rossem, 2008). Of the cases considered in this thesis, besides First Solar, the remaining EPR systems from Germany, Italy and Switzerland are examples of a Collective EPR system.

According to the representatives from the industry, government personnel and experts consulted for the report 'Lost in Translation' by Greenpeace International, published 2006, EPR programs that are based on IPR were better as producers who did invest in improving their product's design to reduce environmental impacts and improve recyclability could benefit from their investment instead of the benefits being balanced out amongst all the other producers that are a part of the collective (Rossem et *al.*, 2006). In a collective system, since the responsibility of handling the products of a particular group is divided amongst all the producers without consideration of brands, those producers that did invest in reducing the environmental impacts of their products would end up subsiding producers who made no such investments.

IPR encourages producers to improve the environmental impacts of their products, reduce the use of hazardous substances and improve the ease of recyclability (Inputs from manufacturers from Samsung, Dell, LG and Electrlux, interviewed for the report 'Lost in translation'; Rossem, 2008). From a financial perspective, for an IPR to work and cover 'orphaned products' (products belonging to producers who no longer operate on the market) as well as the 'free-riders' (producers who skirt their obligations by not providing any support for their discarded products), each producer has to provide a 'true guarantee' at the time of introducing a new product on the market (Rossem et *al*., 2006). A true guarantee is defined as ' *financial guarantee [meant to]prevent costs for the management of orphan WEEE from falling on society or the remaining producers and the guarantee system must be such that producers are able to enter and exit a particular compliance scheme.*' (Recital (20), WEEE Directive 2002/96/EC)

According to the findings of Tojo (2004) and Rossem (2008), EPR related legislation does provide the necessary incentives for producers to invest in environmentally – friendly design changes in their products. However, there is a notable difference in the level of willingness among producers in fulfilling and going beyond their responsibilities, depending upon whether they are responsible for the end-of-life management of their own respective products (IPR) or if the producers of the same product group fulfil their responsibilities towards end-of-life management of the products together, regardless of the brand (CPR) (Rossem et *al*., 2006; Rossem, 2008; Atasu & Subramanium , 2012). This is because if producers have to deal with their own waste products, they will be more incentivized to use recycled materials in their product or use materials that will reduce overall cost for them by not making them invest in hazardous waste management (CPA, 2007). They would also be interested in designing their products for re-use and easier disassembly which would further bring down the costs

IPR systems can also exist within a collectively-organized schemes as producers can purchase 'services' from collective – schemes for brand- specific collection and recycling if there are actors who can provide these services already present in the market (Mayers, 2007).. As long as the compliance schemes follow the same process as any other solution and the producers fulfill their EPR obligations, it is possible for completely collective compliance schemes to be individually financed and have IPR (Rossem et *al*., 2006; Atasu and Suramanium, 2012). Examples of MS that have implemented such a system for certain EEE products include (Rossem et *al*., 2006)-

- **Switzerland and Netherlands:** Computers used in offices are taken back by the producer or the contracted party and the cost is internalized into the price of the products
- **Sweden and Norway:** Products taken back by an intermediary company, arranged by the producers and cost internalization.
- **Netherlands:** Used batteries from business users are brought back by the end users to specific dealers, contracted by producers along with recyclers and the cost is internalized into the product.

IPR is essentially the policy tool that, by making the producers financially or physically responsible for their own products, ensures proper life cycle management of that particular product.The case of the German solar panel manufacturer and recycler, First Solar, will be presented as case study in the 'Findings' section to understand the impact of IPR on EPR systems for PV panels.

3.4 Framework for evaluating EPR systems: The Intervention theory

This thesis makes use of two separate frameworks for different outcomes and to address the different Research Questions. The first framework is a comparative system framework which is used to assess the performance of a collection system based on its three key elements namely – system architecture, context and performance. It was developed and published by Murphy, Gregory and Kirchain in 2012 and is used to provide a comprehensive overview of a system's functioning. Each element of the framework consists of several subsections that are used to denote the varied recycling systems and how they fulfill the three main functions of any recycling system – collection, processing and system management. The framework is depicted in Table 3-5.

Table 3-5 Murphy, Gregory and Kirchain (2012) framework for recycling system evaluation

System characteristic	Function	Recycling System A	Recycling system B
System architecture	Product scope		
	Collection method		
	Management structure		
	Financial structure		
Context	Population		
	Area		
	Wages		
Performance (In relation to target achievement)	Annual costs, collection, processing and management		
	Annual quantities		
	Environmental Impact		

Source: Adapted from Murphy et al., 2012

The system architecture defines the design characteristics of the system, while the context defines the 'geo-economic landscape' of the system and the performance evaluates the system's ability to reach its environmental goals while simultaneously being economically efficient (Murphy et *al*., 2012). While this framework is useful in understanding the objective, quantifiable performance of a system based on external factors, the author felt that in order to get a holistic grasp of all influencers of a system's performance, it was also necessary to include intrinsic ones such as producer cooperation in the system, panel design, ease of recyclability, etc. In order to make a well informed conclusion on a collection and recycling system's performance, it is crucial to understand the influence of these factors. Thus, while this was the framework chosen initially, the author felt a more in-depth review of the systems was required and choose the more comprehensive and inclusive framework – The 'Intervention Theory for Environmental Policy evaluation' developed by Evert Vedung, 1997. The Murphy framework will be used to address the statistical performance of the systems compared in Sub-research Question 2 of RQ1 and the Intervention Theory will be used to go beyond and assess the systems' indirect consequences as well.

Chen (1990) defines a programme theory or an intervention theory as "*a specification of what must be done to achieve the desired goals, what other important impacts may also be anticipated and how these goals and impacts would be generated.*" An intervention theory has what is known as 'micro steps or linkages' between the intervention or program and the ultimate outcome. It is based on the assumptions that determine how the intervention is theoretically meant to work (Rogers et *al.*, 2000) Simply put, an intervention theory defines how an intervention is supposed to work which can then be compared to eventual implementation and outcome. Intervention theories are not meant to only describe how a policy instrument is supposed to work. Instead they can be used for guiding the evaluation of the outcome of the intervention, how it was implemented and what were the effects in practice (Tojo, 2004).

The following elements are considered at the time of framing intervention theories: (Vedung, 1997).

• **Actors:** decision-making entities, e.g. authorities, companies, non-governmental organizations and individuals. The actors include agencies implementing the policy instrument and target groups, i.e. the targets of the instrument.

• **Inputs:** which are used by the administration to produce outputs. Such resources as personnel and finance, but also matters coming from the target groups that the agencies take into account or respond to, e.g. a permit application.

• **Outputs:** matters that the target groups are faced with, e.g. a permit and its specific conditions.

• **Outcomes:** the actions taken by the target groups because they are faced with the outputs, but also the consequences of these actions. Outcomes can be further divided into immediate, intermediate and ultimate outcomes.

Figure 3-1 presents the stages of the theory from the input (What is the goal of the theory/program?) to the final outcome (Substantial result that can be compared to the outcome that was expected). Intervention theories serve two important functions when it comes to evaluations of policy instruments: first, these theories can establish the effects and targets areas of each instrument. Second, they can also identify the outcomes and steps to collect data on. In this manner, when a policy instrument is evaluated, intervention theories can be used to interpret the results.

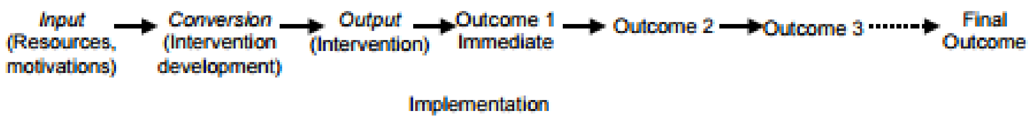

Figure 3-1 Key elements of an intervention theory

Source: Tojo, 2004 (adapted from Vedung, 1997)

4 Research Design and methods

This chapter describes the research method used in this thesis, starting with the analytical framework used for EPR policy evaluation, moving on to the approach used for responding to each research question, onto a more detailed background on the case selection method and finally the process followed for data collection.

4.1 Analytical framework

The focus of the evaluation of the recast WEEE Directive legislation and its subsequent transposition into the national legislation of the three cases, is the environmental effectiveness of these policies.

When evaluating an EPR programme based on its intrinsic goals (Section 3.3.2 – Goals of EPR), Tojo, 2004 states that the elements that should be focused on are not the actions of the government (such as education, information, provision of social services, taxation, etc.) but how the primary actors, i.e., the industry stakeholders are implementing their responsibilities in order to meet these goals set forth in the EPR programmes. Every EPR programme has immediate outcomes upon implementation and intended outcomes the programme hopes to achieve. Using the intervention theory to recreate the process steps of the programme and taking the final outcome as that of 'Total life cycle environmental improvement of product' (ultimate aim of EPP; Lindhqvist, 2000), Tojo, 2004 has identified three immediate outcomes namely:

- *Upstream changes:* Changes in design of products and associated measures
- *Development of downstream infrastructure:* Infrastructure for collection, transport, recycling/reuse/final disposal of the various components of the products
- *Establishment of feedback mechanisms:* Communication channels between the upstream and downstream actors

These three outcomes have been deemed 'essential' for an EPR programme to be able to reduce the total environmental impacts associated with the end-of-life management of the products (Tojo, 2004). Under each outcome are certain steps that the actors can undertake. The general intermediate outcomes of an EPR programme that will also be used for this thesis and that lead to the final outcome of total life cycle environmental improvement are (Tojo, 2004; Richter and Koppejan, 2016):

- Eco-design improvement of panels
- Improved waste management practices
- Closing of material loops for all resources

On the basis of the data available and the intervention theory where explicit outcomes (goals/outputs) are wanting, the following framework, presented in Figure 4-2, is achieved which will be used for policy evaluation from the perspective of environmental effectiveness.

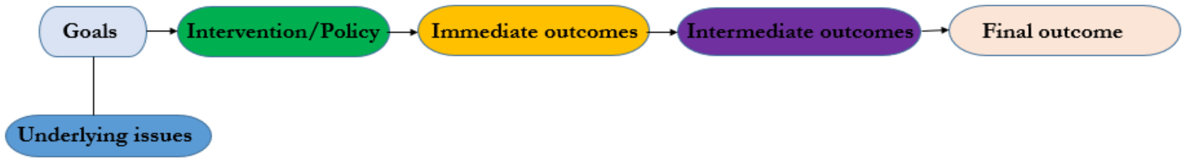

Figure 4-1 Framework for EPR policy evaluation

Source: own, adapted from Richter, 2016, Tojo, 2004 and Pellegrino, 2016

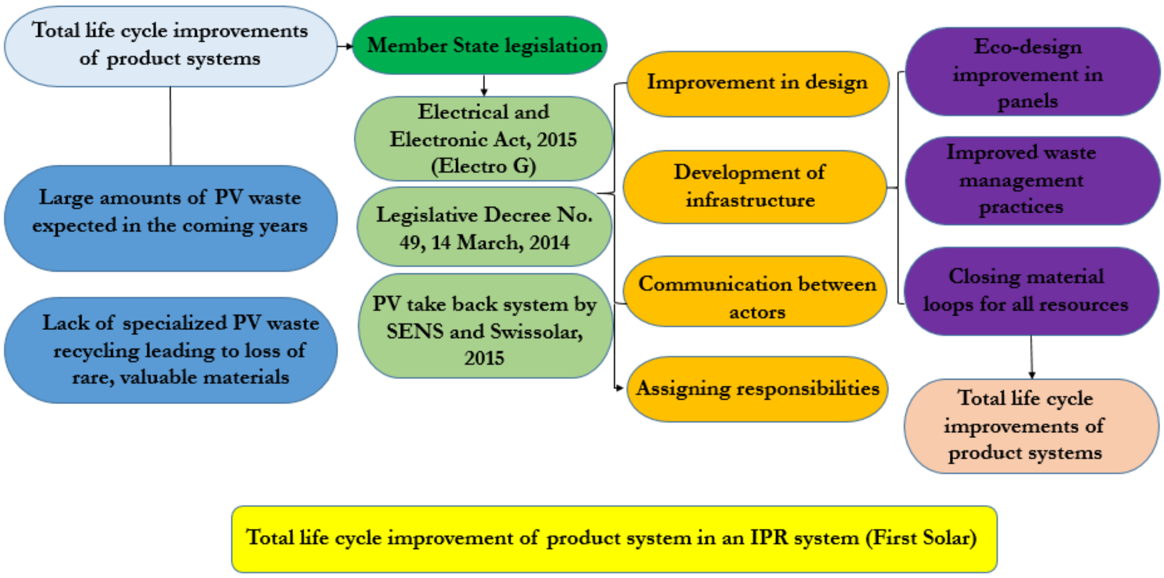

Figure 4-2 Final framework with elaboration for EPR policy evaluation in Germany, Italy and Switzerland vs. IPR system at First Solar

Source: own, adapted from Richter, 2016, Tojo, 2004 and Pellegrino, 2016

The thesis will follow a four step approach for research and analysis. The first step of the process is the 'Policy description stage' which is based on the intervention theory. The second step is the 'Data collection' stage from various sources including interviews with stakeholders and quantitative data collection from reports, Eurostat, national registries and personal communication. The third stage involves 'Data analysis and evaluation' using the framework described above. And the final stage is the 'Findings and discussion' stage which will discuss the outcomes of the analysis and revisiting the research questions. This stage will also include suggestions for future research in this field. Each case country will be examined individually throughout the four stages. Table 4-1 describes the research approach for each research and subsequent sub-research question.

Table 4-1 Methodology adopted to address individual research questions

S. No.	Research question	Methodology
RQ 1	**How does each case system work?**	Literature review. Stakeholder interviews
SRQ1.1	What are the national laws transposed by Germany, Italy and Switzerland for solar photovoltaic waste management from the recast WEEE Directive 2012/19/EU?	
SRQ1.2	Who are the main stakeholders involved and what are their responsibilities?	
SRQ1.3	What are the EPR practices that were motivated by these policies in each case country?	
RQ2	**How have these systems performed so far?**	Quantitative data analysis

SRQ2.1	How have the systems performed in setting up infrastructure and meeting targets?	Stakeholder interviews Literature review
SRQ2.2	How have the systems performed in relation to the goals of EPR?	
SRQ2.3	What are the challenges to the adoption of these practices?	
SRQ2.4	Are there instances of IPR practices within the systems? If yes, how does the system work and how has it performed so far?	
SRQ2.5	What (if any) are the potential gaps concerning the EPR goals in the case systems for photovoltaic waste based on these findings?	Stakeholder interviews

4.2 Case study method

The three cases of Germany, Italy and Switzerland were chosen after an initial review of the WEEE literature which identified these countries as the few that had either transposed the recast Directive into their own legislation or had adopted their own policy on specific PV waste handling and had started seeing PV waste coming into the newly established systems (Statistics Germany, 2017; SENS/Swico recycling, 2016; PV Cycle, 2016). In addition to this, a quantitative review of the installation figures for solar energy revealed Germany and Italy as leaders amongst their European counterparts for several consecutive years (IRENA, 2016). As a result, the amount of waste that is expected in these two countries is also maximum amongst all other European states (evident from Table 2-2 in the 'Literature review section). The German recycling industry, in addition to having made several pioneering strides in introducing advanced and specialized recycling technologies that improve the recovery and recycling rates from waste panels, has also managed to establish a system that will become financially profitable in a few years (IRENA, 2016).

In addition to this, each system is unique in its transposition and implementation of the recast WEEE Directive; from categorisation of PV and financing model for end-of-life management to waste collection schemes and incentives (Paiano, 2015; Khetriwal, 2005; Tojo and Rossem, 2007; personal communication with stakeholders). Therefore, this case selection is based on the 'least similar' case selection suggested by George and Bennett, 2005 since these countries share very little similarities in the systems adopted, which include the scope of product covered by the national legislation, financial responsibility for end-of-life product management (expect in Switzerland where the 'Advanced Recycling Fee' is paid upfront by the consumers at the time of purchase of panel) and the key actors involved. This makes for a dynamic and interesting mix of systems, with their successful initiatives and unique challenges, which will contribute towards making this thesis as topical and robust as possible. Stakeholders from the various levels of the implementation chain (companies, municipalities, coordination bodies, etc.) of the systems were also interviewed for qualitative data collection, which further adds a multi-level analysis angle to the thesis.

In addition to studying these three EPR systems for PV waste management, an interesting case study on a successful, Individual Producer Responsibility model for PV waste management, aka the take-back and recycling system started by First Solar, will also be studied. The aim of this research is to provide practical inputs on a mostly theoretical debate of Individual vs. Collective

Responsibility models, see how it functions differently and what its benefits are. Learnings from this research will also be useful for policy makers and industry practioners to further improve the system.

4.3 Data collection

Data for this thesis was collected from several sources via different approaches (otherwise referred to as the 'triangulation method'). This method allows better validation of the findings from the stakeholder interviews via the analyses of relevant document and records. Without relevant literature analysis an integral component of the 'case study approach' is neglected and the study becomes more of an 'interview approach' study (Yin, 2009). According to Thomas A. Schwandit, 2007, "*Triangulation is a means of checking the integrity of the inferences one draws. It can involve the use of multiple data sources, multiple investigators, multiple theoretical perspectives, and/or multiple methods.*" These approaches are that are used under this method are:

Literature review:

Academic literature and journal publications form the backbone of this research. Key insights were derived using the framework outlined by Tojo, 2004 and its adapted application in Richter, 2016. Other sources included company reports, academic literature on recycling practices, WEEE management and innovations in the field, LCA studies on panels and consulting reports. Case based literature was derived from official websites (Country specific WEEE Directive recast) and discussions in the form of grey literature in academic documents.

Quantitative data:

The main source for quantitative data ('PoM', 'Waste collected', 'total waste recycled', 'Recovery/Reuse', etc.) was sources such as Eurostat, National registries, municipal waste organizations and Producer Responsibility Organizations from the three case countries. Follow up via email/phone communication was performed to crease out the disparities found in the data. Most of the quantitative data that was available on the above mentioned platforms was dated and pertaining to the previous categories of the WEEE Directive (i.e. the 10 categories before the recast Directive was introduced - Eurostat).

Interviews:

The intervention theory was used to identify the key stakeholder categories, following which literature review and the 'snowballing' technique was used to identify key personnel within each category. The categories included producers, recyclers, government bodies, municipal waste organizations, experts, PROs, International organizations, etc. These have been presented in Figure 4-3.

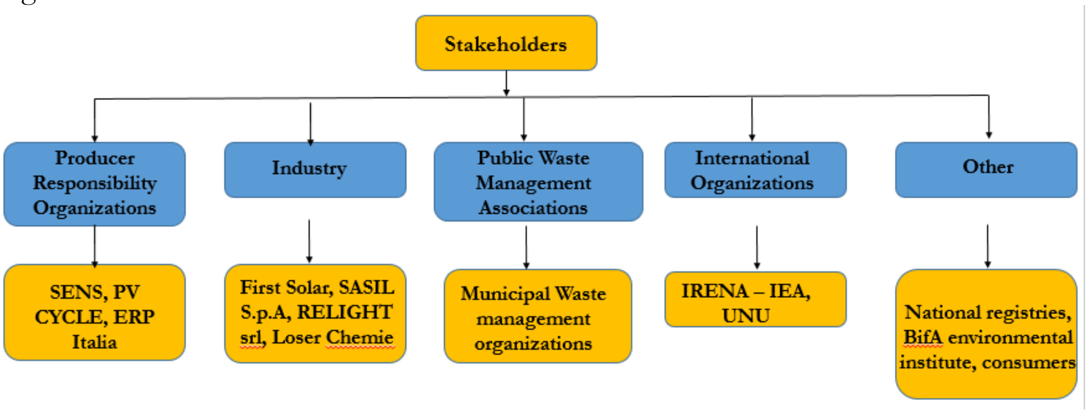

Figure 4-3 Stakeholder diagram

Source: own

A full list of interviewed stakeholders and their respective positions can be found in Appendix A.

An interview protocol was developed for each category of stakeholder, attached in Appendices B-D. Interviews were often of a semi-structured nature, open to additional comments, questions and inputs from the interviewees. A total of 12 interviews were conducted of which 2 were in person and the remaining via telephone calls and email correspondence. Proper recording of the notes post the interviews, in the form of transcripts was made to better analyse the information received and compare it with the findings of the literature review.

Observations:

As mentioned in the previous section, 2 of the 12 interviews were conducted in person at the sites of the recycling facilitates (SASIL Spa and RELIGHT srl, Italy). The advantage of visiting the sites over a simple face-to-face interview was that it allowed the author a first-hand exposure to working of the facility and how it handled the WEEE, specifically PV that was brought to its facility. While this included the technological process that is used (capacity of waste handling, transferability, economic feasibility, etc.), it also covered transport and collection resources provided by the companies and understanding how well was the system equipped to handle management of waste PV modules. In addition, it was also useful to identify other issues with the system that would not have been covered otherwise (labour requirements, how much equipment is required, challenges related to infrastructure, etc.). These observations have been integrated into the sections presenting the 'Findings and analyses.

5 Findings and analysis

This section presents the findings from the different methods used for this research: literature review, quantitative data analysis and stakeholder interviews. These findings are structured along the analytical framework. The implementation chain for the policy intervention is mapped out in Figure 5-1, based on the findings via the literature review and the input from the interviews.

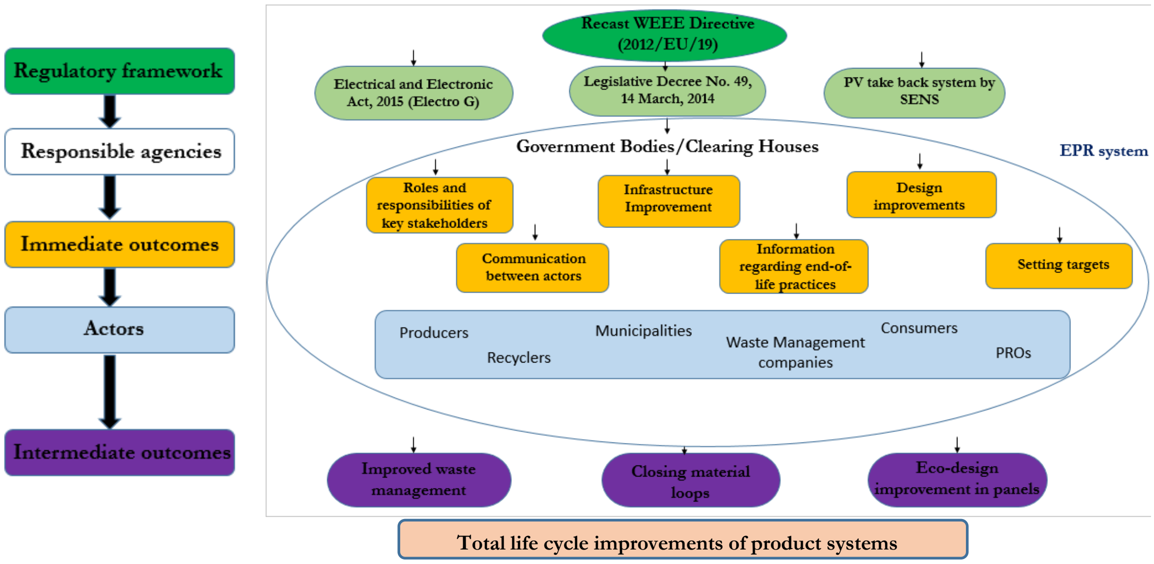

Figure 5-1 Intervention theory for the recast WEEE Directive

Source: Own, adapted from Richter, 2016 and Pellegrino, 2016

The figure is an extension of the intervention framework presented in section 3.1 ('Analytical Framework'). The process steps on the left are the main steps of the intervention that are being evaluated in this thesis. The focus of the evaluation to see if these results have been successfully implemented or not. The EPR system is delineated within the dark blue sphere and in yellow are the main outputs of the intervention. The purple boxes represent the three main intended outcomes of the policy. In between the Immediate and the Intermediate outcomes are the key system actors that have responsibilities in order to fulfill the final outcome of 'Total Life-Cycle improvement of the product system'.

5.1 EPR in Europe: Findings from Germany, Italy, and Switzerland

5.1.1 Germany

The revised WEEE Directive was transcribed into the national legislation in October, 2015 via the new 'Electrical and Electronic Act' or the ElectroG2 Act. The Act succeeded the initial ElectroG1 Act and like its predecessor is responsible for the 'putting on the market, recovery and recycling of electrical and electronic equipment' in Germany. It extends the responsibility of the producer, importers and resellers to include the complete life span of the products they put on the market and requires of them to cover the charge of taking back and disposing of the WEEE.

Under the provision of the ElectroG1 Act, there were 10 product categories in total and PV modules were not included under the scope of the Act. The collection target was 4kg of old appliances per inhabitant per year and would remain constant across the years. There was no obligation to declare the quantity of WEEE recovered and recycled. In addition to this, the public waste associations did not have reporting obligations under the Act and foreign manufacturers and distributors were not required to registers themselves in case of direct sales of consumer products directly to the German consumers (Electrical and Electronic Equipment Act, 2005).

It defined the following aspects of the system functioning:

- Scope of the equipment covered under the law and the producers, importers and resellers affected (Article 2 - Scope & 3)
- Design and other considerations for new EEE and (Article 4 – Product Design & Article 5 – Prohibited substances)
- Duties and responsibilities of the Clearing House (Stiftung EAR) (Article 6- Clearing House, Registration and Financial Guarantees)
- Labelling of registered products (Article 7 – Labelling)
- Separate collection of WEEE, producer obligation, treatment and recovery of collected WEEE and reporting and information obligations (Article 9 – Separate Collection, Article 10 - Producer Obligation to take back WEEE, Article 11 – Treatment, Article 12 – Recovery, Article 13 – Producers' Information and Reporting Obligation)
- Clearing House (Stiftung EAR) responsibilities and organization as well as other competent authority responsibilities (Article 14 – Clearing House Responsibilities, Article 15 – Clearing House Organizations, Article 16 – Competent Authority Responsibilities)
- Setting up of a 'Designated Agency' by the Competent Authority and its responsibilities (Article 17 – Authority to Designate, Article 18 – Supervision, Article 19 – Termination of Designation)
- Other provisions (Article 20 – Commissioning of Third Parties, Article 21 – Appeals and Judicial Review, Article 22 – Costs, Article 23 – Regulatory Offences, Article 24 – Transitional Provisions and Article 25 – Entry into force)

The new 'ElectroG2' Act came into force in Oct, 2015, bringing PV modules under its scope. It defined 'Photovoltaic modules' as '*electrical devices intended for use in a system designed, assembled and installed for the generation of electricity from solar radiation energy*'. There several modifications that were included in the Act (Reorganization of the Electrical and Electronic Equipment Act – ElectroG2. Oct, 2015):

- The total categories of products will go down from 10 to 6 and PV modules (including old modules) will be included in **group number 6**
- 'Historical Equipment' includes PV that was WEEE and put on the market before the 24th of Oct, 2015
- There is an obligation to declare the recovered and recycled WEEE by the parties that place the modules on the market
- The minimum collection rate was increased to 45% of the average quantity of EEE that was put on the German market in the three preceding years (before 2016)
- This rate will be further be increased to 65% by 2019

As per the revised Act, all PV modules are to be registered starting 1st Feb, 2016. This obligation also extends to all equipment with built in PV modules and installation supporting equipment (ElectroG2, 2015). All Producers, Importers, OEM producers, Distance Sellers and Dealers are required to register their products with the Clearing House before placing it on the market, provide financial guarantees, manage nation-wide take back, provide empty recycling containers, recycle the WEEE according to the provisions of the law and report back on the results and also report take back and recycling values of the WEEE to the Clearing House. In addition to this, the law also has 'Product Design' requirements for the concerned stakeholders (ElectroG2, 2015).

5.1.2 Italy

The revised WEEE Directive was transposed into the Italian National legislation via the '*Attuazione della direttiva 2012/19/UE sui rifi uti di apparecchiature elettriche ed elettroniche (RAEE)*' or the '***Legislative Decree No. 49/2014***' as it is more commonly referred to. It came into force on 14th March, 2014 with publication of the 'Ordinary Supplement of the Official Journal No. 73, 28th March, 2014'. It came into force on the 12th of April, 2014. Its two main objectives were to

- Reduce or prevent the negative impacts of EEE, from development to production, all the way to EEE waste management
- Reduce negative impacts and increase resource efficiency in order to achieve sustainable development objective

It defines WEEE as '*electrical and electronic equipment which is waste according to Article 183, paragraph 1, letter a) of Legislative Decree 3 April 2006, n. 152. It includes all components, subassemblies and consumables integrated in the product which the owner discards, or has the intention or requirement to discard*' and outlines the recovery and recycling targets for this waste stream (Legislative Decree 49/2014 - Appendix V).

PV panels are categorised as EEE in the Decree and included in **Group 4 equipment**, pursuant to Ministerial Decree 185/2007. The producers of PV are expected to fulfil their legal requirements as mentioned in the Decree by either joining a special, non-profit consortium which has been approved by the Ministry of Environment and Territory or form their own system of managing the handling of their products (Article 8). The Decree also distinguishes between 'old PV waste' (PV panels sold before the 12th of April, 2014) and 'new PV waste' (PV panels sold after the 12th of April, 2014) and panel of 'domestic origin' (nominal power of plant < 10kW) and 'professional origin' (nominal power of plant > 10 kW) (Article 4).

The exception to this Decree are plants that benefit from the 4th Feed-in-Tariff and the 5th Feed-in-Tariff schemes (Ministerial Decree 05/05/2011 and 05/07/2012, resp.). In order to benefit from the FiT scheme, plants were required to send the Gestore dei Servizi Elettrici (GSE, Supervisor for the Electric Services) a certificate verifying their joining a consortium for waste collection, recycling and recovery of photovoltaic panels. Since the consortiums were already responsible for waste management, the owners of these PV plants are exempted from all obligations (IEA, 2013).

5.1.3 Switzerland

The Swiss system is based entirely on the EPR principle in that the physical and the financial responsibilities for the end-of-life of a product lie entirely with the manufacturers (Wager et *al.*, n.d.). The e-waste program started by SENS, Swico and SLRS was based on the EPR principle before it was mandatory by law (Khetriwal et *al.*, 2005) The 3 PROs manage the waste on behalf of their member producers and provide hundreds of collection points across the country for WEEE collection.

There is no official legislation for PV waste modules management at present (Roman Eppenberger, Head of Operations Dept. at SENS Association, personal communication). As management of PV waste falls under the purview of SENS, starting 2015, it began a cooperation with Swissolar (Trade association devoted to policy issues regarding the solar industry) and expanded to include PV in its WEEE scope, guaranteeing its recycling (SENS Technical report, 2015). In addition to this, at the end of 2014, SENS and Swico made adhering to the European Standards for WEEE collection, logistics and treatment - EN 50625 mandatory. As PV is now included in this category, recycling and closing of the material cycle for PV waste is guaranteed.

In addition to this, the VREG is also being completely revised to include PV in its scope. The main motivation behind this is the retrieval of the valuable materials used on PV modules (Eppenberger, personal communication). As a result of this revision, the 'Advanced Recycling Fee' can also be used to finance the recycling of PV waste modules (SENS Technical report, 2015).

There is no sense of competition between the three systems as *"the small scale of the market and high logistics costs due to a very dense collection point network and expenses due to the different languages spoken in the country would render a variety of systems(plus the necessary clearing between the systems) extremely expensive."* (Swico, 2017).

5.1.4 First Solar

When First Solar introduced its take back system in 2005 for its PV panels, there was no regulatory obligation that required the company to do so. The motivation behind this initiative was twofold:

- **Sustainable solution:** In a unanimous decision, company leaders decided that scaling up of operations at First Solar would include take back and recycling system. This would reduce their environmental footprint as a company amongst other environmental benefits (First Solar Sustainability report, 2016).
- **Closing the loop for essential materials:** Cadmium, a by-product of Zinc ore refining, is used in First Solar modules instead of being disposed of or stored. But the company faces severe global regulatory scrutiny for its use of Cd. In addition, Te, a by-product of copper refining, is a material with possible supply risk in the future (Houari et *al.*, 2013). It is categorised as a 'critical material' and is amongst the most commonly cited metals that are subject to supply constraints (Houari et *al.*, 2014;). By introducing a take back system and recovering these materials for further use in new panels, First Solar not only has a steady reserve of these materials, but also avoids exposure to price volatilities for materials like Te (Sustainability Report, 2016).

5.2 System performances

As is evident from the previous sections, each country has adopted a unique system for implementing the necessary requirements for managing end-of-life PV modules. Using the Murphy et *al.* framework described in section 2.4 (Framework for evaluation of EPR systems) to compare the specific components of the systems, the different elements can be mapped out. Table 5-1 presents the features of the individual systems.

Table 5-1 Comparing the features of the EPR systems in Germany, Italy and Switzerland

		Germany	**Italy**	**Switzerland**
Context				
	Population (million)	81.4	60.8	8.3
	Area (km2)	3,57,376	3,01,338	41,285
System architecture				
Legislative responsibilities	WEEE legislation	ElectroG2 Act – Oct, 2015	Legislation No. 49 - March 2014	ORDEE/VREG - 1998 (Revised 2005)
	Scope of products	Photovoltaic - Group 6	Small household appliances, consumer equipment, office automation, computer appliances, lighting devices and Photovoltaic - Group 4	EEE for households, fitness, wellness, leisure, toys, pet supplies, electrical tools and Photovoltaic *
	Collection Responsibility	Municipality/ Producer	Municipality/ Producer	Dealer/Producer/Disposal company
	Financial responsibility	Producer	Producer	Producer/End user
	Information responsibility	Municipality	Municipality	PRO
	Collection points	~11,600	~4000	6000
	Main PROs	PV Cycle, Take-e-way	PV Cycle, Eco-PV	SENS, SLRS, Swico
Performance**				
Collection and	Average tonnes 'Put on the Market' (2012-14)	484.828	196.402	-
	Collected (t) (2014)	152.008	71.306	50
	% recycled of collected	**82.20**	**68.9**	**-**
	% recovered of collected	**92.7**	**83.2**	**-**
	Kg per capita collected in 2014	0.186	0.117	0.602

Source: Eurostat 2017; Pia Aline, PV Cycle, 2017; SENS/Swico Technical report 2015, 2016

**All the products that fall under the purview of SENS*

*** Values presented are an aggregation of the total values under Category 4: Consumer Quipment and Photovoltaic panels*

5.2.1 System architecture

Except for Switzerland, the final financial responsibility for the management of WEEE and waste PV modules lies with the producers. With the imposition of the ARF, Swiss manufacturers and importers pass on the cost of collection, transport and treatment of the waste onto the distributors and dealers who in turn pass it on to the end users which are the customers. Although, at the moment most producers do not transfer this fee onto the customers as yet as it is too small (~40 Euro/ton; Eppenberger, personal communication). The physical responsibility for providing and managing the collection points lies with the public waste organizations in the case of Germany and Italy. While in Switzerland, the VREG states that disposal of waste equipment can take place by handing the equipment to a *"dealer, the manufacturer or importer, a disposal company or a group collection point for electronic equipment"*. Practically, most of the producers (~ 90%) are a part of the SENS/Swico take – back system, therefore, the physical responsibility of the take back takes place at the collection points provided by the network across Switzerland. There is no separate collection of PV modules at any of these collection points.

The task of providing information to consumers regarding their responsibilities when disposing of WEEE (including PV modules) lies with the municipalities in Germany and Italy. Various actors have taken up the task of informing the end users regarding proper disposal of waste PV modules, from manufacturers regarding their own brand of modules to the PROs who conduct community events to educate consumers and involve them in the collection and recycling. In Switzerland, consumers tend to trust the competencies of the organizations SENS and Swico and do not enquire particularly about the system's workings (Eppenberger, personal communication). SENS does however, provide information on the take-back system's workings and the infrastructure available to the end users for disposal on its website for the conscious consumers. There is also a map of where the collection points are located so consumers can identify which point is closest to their location.

5.2.2 Performance

As there is no separate data available for the amount of PV 'Put on the Market' of 'Waste collected' to compare the system performance, data for the 'Consumer equipment and photo panels' will be used as proxy data for the comparison of the performance of the EPR systems in Germany and Italy. Data from the Technical reports of SENS/Swico, where available, are relied upon to analyses the working of the Swiss system.

Both Germany and Italy are in the top 10 for the '% waste collected' of the total products that were 'Put on the Market' in the year 2014, for category 4 – 'Consumer equipment and photovoltaic panels' (Figure 5-2). Since WEEE became a separate category of waste in 2008, Italy has seen a significant rise in the amount of collected and recycled WEEE (Smith, 2013).

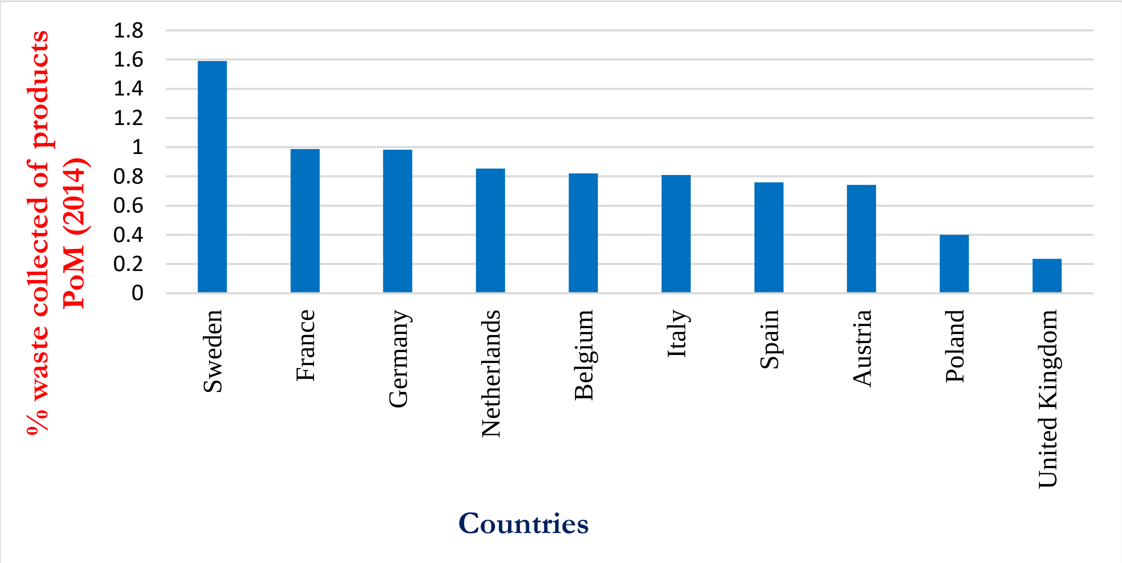

Figure 5-2 % waste collected of total Consumer Equipment and PV PoM

Source: Eurostat, 2017

But when it comes to waste collected per kg per capita, these figures change considerably. While Germany does perform better than the EU average of 1.285 Kg/capita, Italy lags far behind. (Table 5-2).

*Table **5-2** Kg/capita of 'Consumer equipment and photovoltaic panels' collected in 2014*

Country	Waste collected from households (Kg per capita)
Sweden	3.462
Denmark	3.036
Finland	2.893
Norway	2.493
Luxembourg	2.297
Belgium	2.142
Ireland	1.926
Austria	1.73
Germany	**1.705**
Netherlands	1.645
France	1.512
Croatia	1.445
Liechtenstein	1.384
Czech Republic	1.212
Estonia	1.049
Italy	**0.948**

Source: Eurostat, 2017

It is necessary to point out that the data for this category is variable depending upon the Member State and its own categories that PV and the other equipment's will fall under. Therefore, these statistics are representations of the actual system performance. With a total of 240 t of PV waste collected from 2014-16 (SENS Technical reports 2014, 15, and 16), Switzerland is seeing an ever increasing amount of PV waste trickling in the WEEE collection system. With a recovery rate of more than 80% and a collection rate of 16kg/capita in the year 2015, Switzerland is certainly amongst the top performers of WEEE management, comparable with the EU Member states (Eppenberger, personal communication; SENS/Swico Technical report, 2016).

5.3 Improved waste management practices

5.3.1 Roles and responsibilities

The EPR systems in the country have been adopted to suit the requirements mentioned in the respective legislations and fulfil the obligations of the various actors.

5.3.1.1 Italy

According to the Legislation No. 49, 2014 and on-ground implementation of the system, Figure 8 presents the various actors and their roles in the Italian EPR system. All EEE producers (including PV producers) have the responsibility of reporting their 'Put on the Market (PoM)' product amount and the subsequent waste collected to the National Register – Registro AEE, which falls under the jurisdiction of the Ministry for the Environment, Land and Sea. Based on the amount reported, Registro is required to publish the market share of each producer. Coordination and allocation of waste volumes is performed by body – CdC RAEE. The collection points are supplied by the local municipalities. When a container is filled till its maximum capacity, the municipalities inform the CdC. Based on certain criteria (proximity to collection point, certifications, etc.; Serena Sgarioto, part of R&D Manager at RELIGHT srl, communication, 2017) CdC allocates waste WEEE (which includes waste PV panels) to be collected and recycled by certain recyclers. The communication to both producers and recyclers takes place via collective schemes which are in direct contact with CdC RAEE. These schemes handle the logistics of WEEE collection and transport to end recyclers (Figure 5-3).

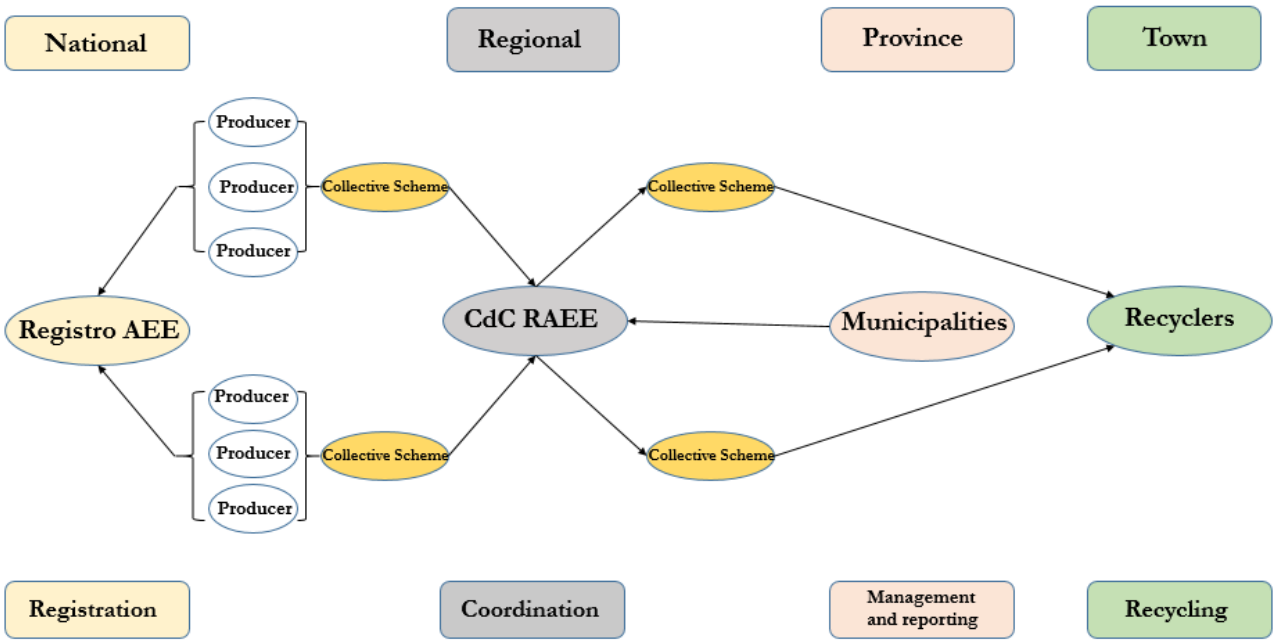

Figure 5-3 The multi-level Italian EPR system

Source: own

5.3.1.2 Germany

The ElectroG2 Act, 2015 allocates certain roles and responsibilities to certain actors along the EPR system implementation chain. The EPR system with allocated roles of key actors is mapped out in Figure 9. The Act outlines the provision for a 'Clearing House' (Stiftung EAR) which is the central body for the producers (including PV producers) to report their annual product PoM and the waste production. Each producer is required to register with the EAR before entering the German market and is provided with a unique number which is to be used during all business transactions. Producers have the option of joining a collective systems for covering their take-back obligations for WEEE or can set up their own take-back system. WEEE is disposed in collection points provided and maintained by the local municipalities. Once a container is full, the municipalities inform the Stiftung EAR which then, based on the market share of the producer, allocates number of containers to the appropriate producers for pick up and treatment. If the producer is part of a collective system, e.g. A PRO such as PV Cycle (which is most often the case), the PRO will then carry out these obligations on behalf of its member producer (Figure 5-4).

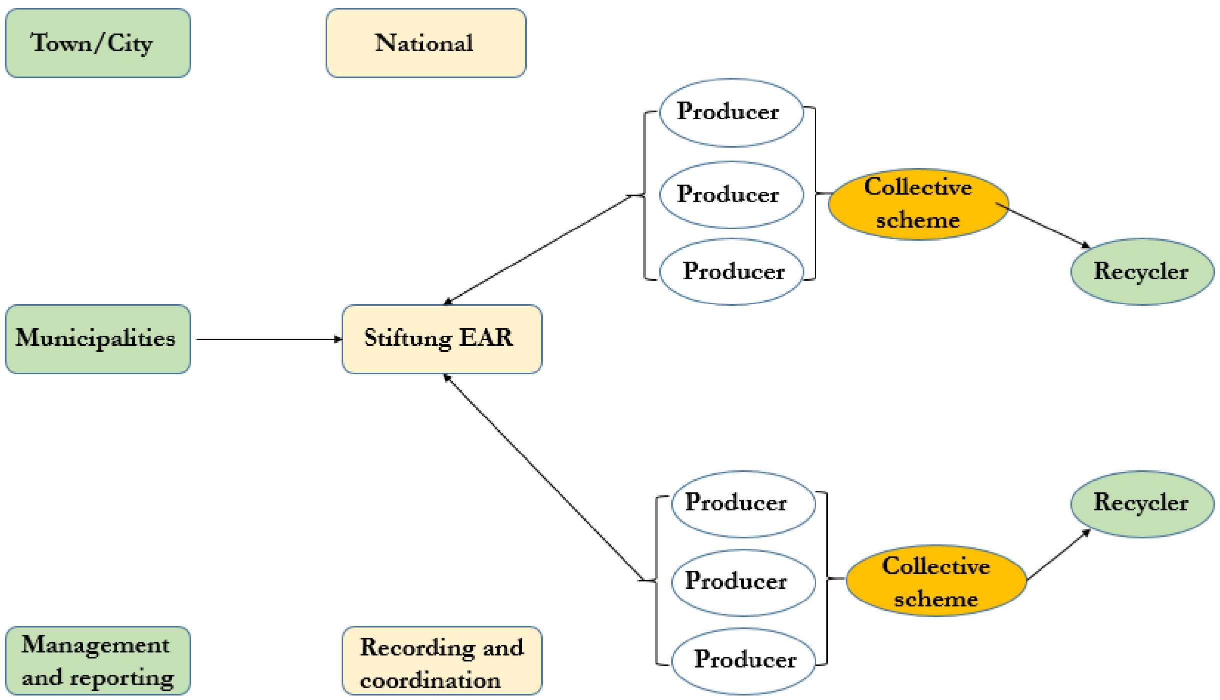

Figure 5-4 Multi-level EPR system in Germany

Source: own

5.3.1.3 Switzerland:

Management of end-of-life PV modules falls under the purview of SENS eRecycling. SENS has been taking back modules since 2014 (Technical report, 2015). Before being formally introduced in the scope of products managed by SENS, PV take-back was triggered by an e-mail or a fax from the user who wished to dispose of it (Technical report, 2014). Since January 2015, small quantities of PV waste can be disposed of at all SENS collection points (Technical report, 2016). The overview of the take-back system is mapped out in Figure 10. Since Switzerland has no National Register for PV producers, only those producers who are a part of the SENS system are provided with a unique identity. There is no obligation in the VREG for producers to be a part of this system. They also have the option of being part of any other collective system or form one of their own (Eppenberger, personal communication). The only obligation PV producers have is to take back, free of charge, waste modules from end users (who pay the ARF to cover the treatment of their end-of-life modules) and ensure that is it treated in a proper manner. SENS takes care of this obligation for its member producers. At present, all PV modules collected in Switzerland are transported to two float glass recyclers based out of Germany as there are no float glass recycling facilities in Switzerland (elaborated in the succeeding sections) (Figure 5-5).

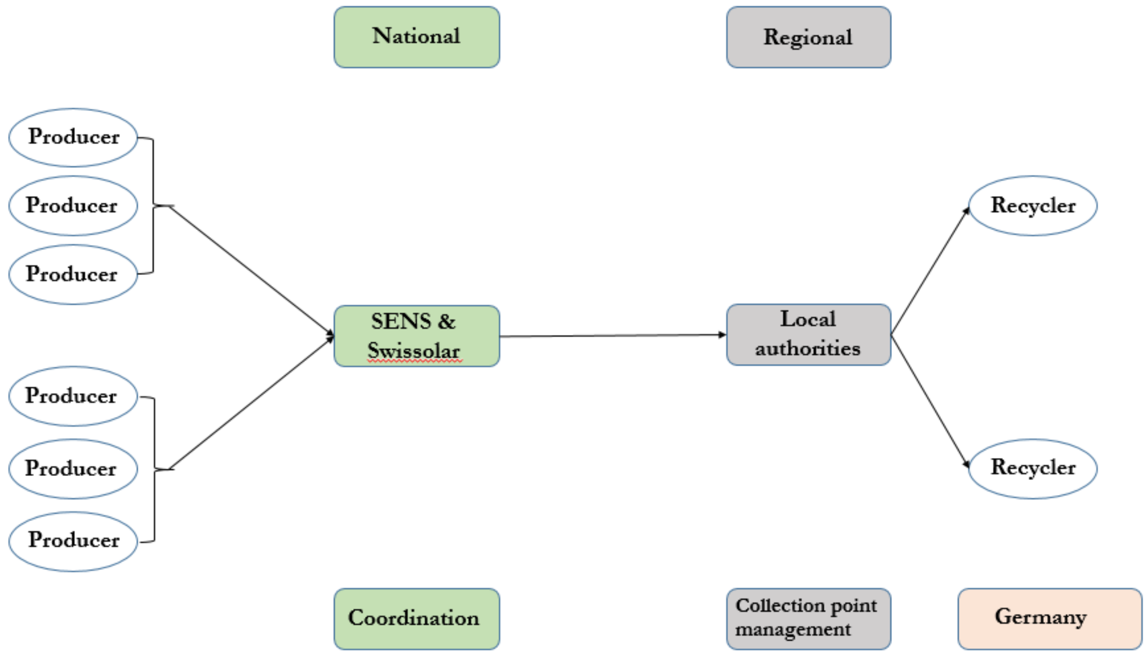

Figure 5-5 Multi-level EPR system in Switzerland

Source: own

First Solar: First Solar introduced a 'pre-funded, module collection and recycling programme' in 2005 for all its panels. This programme included the collection, packaging & transport of end-of-life modules to the nearest First Solar recycling centre and was financed by the 'end-of-life management fee' being included at the time of module purchase. Since the introduction of the new WEEE Directive, the system has been modified to comply with the needs of the legislation:

Old take-back system:

For the modules that had become waste before 2012, the customers would call/email using the contact details and instructions provided to them at the time of purchase of a FS module and FS in turn would contact its transport partner/s who would then collect and transport the panel to the nearest recycling facility.

New take back system:

The legislation required First Solar to join a Producer collective-compliance scheme for the markets where First Solar is currently operating. FS is also required to report to the Clearing House – Stiftung EAR regarding all the amount of new panels it places on the market and the waste PV volumes that it collected for a certain period. Customers have the additional option of dropping off the waste panels at any of the municipal collection sites. Once the container is full, the municipalities will alert the EAR. But unlike the case with other producers, First Solar also has its own collection system and receives volumes of PV waste via this channel as well. The Stiftung EAR takes this into consideration and deducts this volume from the total waste volume presented by the municipalities, which lowers the market share of the company in the market.

For funding of the recycling activities, starting 2013, First Solar introduced a new program called the 'Recycling Service Agreement' (RSA). In this program, the customers are offered a two- year contract which commits the consumer to recycling for that period. After this period is over, the contract is extended in two years blocks with price flexibility, so the customers can benefit from any price decrease. The approach for this program is based on the 'pay-as-you-go' model, with global coverage and is not binding for the customers, i.e., they still have the option to opt for alternate recycling vendors (Hagendorf et *al.*, 2017).

5.4 Infrastructure Improvement

According to Article 5 of the new WEEE Directive, "*Member States shall adopt appropriate measures to minimize the disposal of WEEE in the form of unsorted municipal waste, to ensure the correct treatment of all collected WEEE and to achieve a high level of separate collection of WEEE, notably, and as a matter of priority, for temperature exchange equipment containing ozone-depleting substances and fluorinated greenhouse gases, fluorescent lamps containing mercury, photovoltaic panels and small equipment as referred to in categories 5 and 6 of Annex III.".* To ensure separate collection and treatment of WEEE, in addition to the municipal collection points across the countries, this responsibility was also undertaken by the PROs operating in Germany and Italy. PV Cycle currently operates its own collection points in addition to the ones operated by the industry and has partnered with local transport and recycling companies (specifically in Germany) to provide nation-wide services and recycle the waste within the country which makes more economical sense. All producers are very aware of the infrastructure that is available to them (Pia Alina, Head of commnications at PV Cycle, personal communication).

The real issue that was brought to light regarding the infrastructure for PV waste management was not collection or transport, but specialized treatment facilities. Italian WEEE recycling firm RELIGHT srl has been accumulating a few tons of PV waste in the WEEE that it is allocated by CdC RAEE over the past few months (~2/3t over 6 months; Daniele Gotta, Head of R&D at RELIGHT srl and Sgarioto, personal communication). While frame from the panels can be separated and the aluminum retrieved using the in-house CRT recycling technology, the rest of the panels are stored for such a time as when there will be advanced technologies that will be able to extract the entire components from the rest of the panels. The image below shows stored Crystalline-silicon panels at the storage facility of RELIGHT.

Figure 6-1 Stored waste PV panels at the storage facility at RELIGHT srl

Source: own

A similar faith awaits the panels received at mining and recycling company – SASIL SpA in Biella, Italy. Herein lies the disconnect in closing the cycle for material recovery, i.e., while the panels are being collected and transported to the recycling companies, the lack of specialized PV waste recycling technologies is a major hurdle in material recovery and reuse.

Switzerland started seeing few waste panels coming in the waste stream in 2014. PV waste collection and recycling before 2015 was initiated via calls/emails from the customers (SENS Technical report, 2015). Starting 2015, SENS collaborated with Swissolar (Trade association for policy related to solar energy industry) for take back of PV and included it in the scope of WEEE disposed at its collection points **(B2C modules < 5% of the total volume)**. Plant owners/dismantlers can contact SENS when they need to dispose of their waste modules and SENS will contact its transport partners who will collect the panels and transport them to special collection points where they are stored until sufficient tonnage of waste is accumulated and then they are transported to PV recyclers **(B2B modules)** (Eppenberger, personal communication)**.** The system followed by SENS requires the waste PV modules to be separated on the basis of 'hazardous and non-hazardous' composition. Waste Movements Ordinance (VeVA) code 16 02 16 categorizes silicon-based cells as 'Without Hazardous components', while thin-film CdTE and CI(G)S modules as containing hazardous substances. The silicon based modules are processed by two float glass recyclers in Germany as Switzerland has no float glass recyclers (Eppenberger, personal communication). These recyclers only utilise the plate glass and aluminium frame, while the semiconductors are not recycled (SENS Technical report, 2016). As for the CdTE and CIGS panels, their disposal still remains unresolved as currently they are stored till technologies can be developed that can isolate the toxic substances – cadmium and selenium (SENS Technical report, 2016, Eppenberger, personal communication).

First Solar: First Solar only sells business/professional modules with a power rating of > 30kWp. But since solar panels have been categorized as 'dual use' by the EAR that means FS also has to cover the possibility of First Solar modules turning up at municipal collection sites (post-residential use). In order to cover this legal obligation, First Solar joined the waste management association – Zentek GmBH, which provides nation-wide services for collection, transport and even recycling for all WEEE. In this way, First Solar operates an 'Individual Producer Responsibility' (IPR) system which is a part of a collective take-back system due to legal obligations, but does not actively make use of its services.

First Solar's IPR system for collection and recycling of its own PV modules has been very successful, with the state-of-the-art recycling process recovering 95% of the semiconductor material used in the modules and 90% of the glass which is then refined to a point where it can then be reused in the new module production. The process is continuously evolving with the 3rd generation process recycling as much as 30t/day and the 4th generation process aimed at recycling 350t/day. The company also aims to drastically bring down the cost of recycling in the coming generations.

5.4.1 Communication with Consumers

The Member States are required under the WEEE Directive to make provisions for informing the end users of EEE from private households regarding end-of-life practices for the WEEE. These include information for separate disposal of WEEE, the collection points available to them, '*their role in contributing to re-use, recycling and other forms of recovery of WEEE'*, the potential impacts of improper WEEE disposal on the environmental and human health due to the presence of harmful substances in the EEE and the meaning of the symbols on the EEE (Article 14). All the stakeholders who were interviewed all agreed that communication regarding the treatment of WEEE to consumers was of great importance to the overall performance of the EPR system, though there were varying opinions on how important or necessary this

responsibility would be for PV panel waste, given its relatively small volumes as compared to other WEEE.
There were various methods employed by the actors to undertake this responsibility. In Germany, take back schemes such as the European Recycling Platform (ERP) Germany only communicate with their immediate consumer group which is the industry itself. In case of ay communication with the consumers, it is performed by the producers (Michael Gormann, ERP Germany, email correspondence).
In contrast, the Italian counterpart of ERP, ERP Italia, views communication towards consumers to be of great importance and has undertaken several community-wide initiatives to not only inform the consumers of the benefits of proper EEE disposal but also provide hands on opportunities to involve society in final disposal, that have resulted in definite increase in the collection rates for certain waste categories (Samantha Charalambous, ERP Italy, email correspondence). So far, the association has undertaken campaigns for battery collection and is giving a great deal of attention to WEEE collection. It has started using social media to help increase citizen awareness (e.g. ERP Italy has developed a mobile application which locates the closest collection point) and has organized several events to encourage them to correctly recycle WEEE (e.g. Information stand during the Udine Marathon weekend where runners could recycle WEEE up to 5kg and receive merits) (Charalambous, email correspondence). Recyclers such as RELGHT srl have information regarding separate disposal of different WEEE at their own collection points, to inform consumers on how to sort the WEEE before disposing it in the containers (Sgarioto, personal communication).
Besides this mode of communication, there is little or no further interaction with the consumers by the recyclers (Sgarioto, RELIGHT srl; Ramon Lodovico, CEO at SASIL SpA, personal communication).

According to SENS Head of Technical operations, Mr. Roman Eppenberger, consumers in Switzerland are not particularly interested in learning about how their waste panels are handled post disposal (personal communication). Consumers trust in SENS and Swico's ability to manage the waste and are unwilling to go beyond to learn the process. SENS, SWICO and SwissSolar have put up information reading recycling and reuse of certain key comments of the panels such as glass, aluminum, etc. on its website for general information (personal communication).

First Solar: First Solar have made attempts on their websites to educate their potential customers regarding the environmental and energy performance of their panels. Sustainability reports contain information regarding the life-cycle impacts of the panels, superior efficiency, greenhouse gas displacement and advanced composition design of First Solar panels, also detail the company's 'Recycling Program' that was the first voluntary global, industry wide program introduced in 2005 and helped set an example for peers to follow (Matthais et al, 2013; First Solar Sustainability Report, 2016). This was a 'pre-funded, unconditional' take back system introduced at all the manufacturing facilities of First Solar globally, even before there was any legislative requirement to do so (Wade, Global Sustainability Director at First Solar, personal communication). Once the recast Directive was introduced, the company received demands from the consumers who purchased their panels to include the end-of-life treatment price in the price of the panels which would give them the freedom to choose which end-of-life service to use. Along with this information, First Solar also provides information regarding collection facilities once the panels have reached the end of their life span on the panel itself. In this way the consumers know that the panels were separately collected and are not to be disposed-off along with the other unsorted municipal waste (Wade, personal communication).

5.5 Closing Material Loops: Recovery of Valuable Materials from the Collected Panels

5.5.1 Material recovery

The common and primary motivation that was cited in all the interviews for convincing manufacturers and recyclers to invest in specialized PV waste recycling was the secondary raw materials that could be derived from the process and the subsequent benefits of using them, esp. over primary materials. PV waste has already started being collected and stored to a point its tonnage warrants economic feasibility (Yi et *al.*, 2016). As mentioned in the previous sections, the two main factors that influence recycling of PV are the potential harm to the environment and human health in case of leached harmful substances such as cadmium, lead, etc. and the expected potential shortage of critical, non-renewable raw materials that will be faced by the industry if recycling is not administered (Yi et *al.*, 2014). Additionally, for the producers and recyclers, the potential economic value recovery from the recovery process also plays an extremely important role. The cumulative installed capacity of PV panels installed worldwide is 274.19 GW, which translates to approximately $26.05 billion in recoverable metal value (Yi et *al.*, 2014).

Dr. Wolfram Palitszch of the German chemical company Loser Chemie (L.C.) has also developed a recycling pilot plant for thin film technology that produces no waste post the recycling of the panel (personal communication). The technology involves a 'Physical/Optical' step where the module is opened using a laser and a 'Hydrometallurgical' step where a liquid solution is used to dissolve all semiconductors and back conductors using a biodegradable solvent. The glass cullets are sold to float glass recycling firms and the metallic solutions (containing only the metals – Cd, Te, I, G, and Mo) is sold to a refinement company which use this solution as raw material for other metallic products. Dr. Wolfram calculated that 1 ton of the recycled glass cullet that was used instead of primary material saved up to 6 ton of mined material and 25% of the energy required (recovery, 2012; personal communication). The amount of PV waste received by the company varies from nearly a 100,000 panels coming in one week to absolutely none over the course of the remaining three weeks of the month (L.C. does not have collection or transport system, power utilities make logistical arrangements once L.C. agrees to take in their waste – a B2B model). This makes having a large storage facility on site a key requirement where the panels can be stored for over 2 to 3 months before being recycled.

The 'Full Recovery End-of-Life Photovoltaic' (FRELP) project at the Italian recycling firm – SASIL SpA was started as a joint venture between SASIL, PV Cycle and the Stazione Sperimentale del Vetro S.c.p.A (Figure 6-2). It was financed under the 'LIFE+' programme by the EU and lasted from July, 2013 till March 2016, when the lack of sufficient PV waste coming in resulted in termination (Lodovico, personal communication). The aim of the project was 100% recovery and reuse of all the waste PV panel components – Glass, aluminium, silicon, metal wire connector and improve the quality of 98% of the recovered Si-base PV panels to reach saleable quality (FRELP, n.d.).

Figure 6-2 FRELP prototype machine at SASIL SpA under the LIFE+ project

Picture source: own

First Solar: The recycling process invented by First Solar for its modules currently yields a 95% recovery of semiconductor material and 90% of the glass (First Solar Sustainability report, 2016). Of the recovered and recycled semiconductor material, 12.5% of it was used in new PV panel production in 2014 (Wade, personal communication). And the recycled glass is reused in production of new glass materials. Stolz, 2016 calculated that for the unframed CdTe PV modules recycling carried out at First Solar, using 100% recycled glass cullets retrieved from the process in the production of other glass products, reduces the energy consumption by 30% as melting of glass cullets takes less energy as melting of limestone and silica sand (Sinha et al, 2012; Held & Ilg, 2011). Additionally, using recycled glass avoids the consumption of primary materials and the emissions from their mining and refining. This translates to significant decrease in the geogenic CO2 emissions associated with the process (Stolz et *al.*, 2016, Matsuna, et *al.*, 2012). When put in the context of the fact that the market for thin-film is slated to increase from <5% in 2016 to 25% in 2020, this benefit becomes even more important (Bio Intelligence, 2011). By setting up its own collection and take back system for its modules, First Solar has established a continuous flow of waste PV coming back into its system and thereby avoided the common challenge all recyclers and experts alluded to that affects the performance of the industry; i.e. *acute shortage of tonnage of PV waste* (Lodovico, SASIL SpA, Sgarioto, RELIGHT srl, Eppenberger, SENS Association, personal communication).

Table 5-3 displays the current and projected waste values for PV as predicted by various sources including – PV Cycle, ERP Italia, SASIL SpA and European Commission.

*Table **5-3** PV waste projection for the years between 2010 till 2050*

Source	Country	2010-17 (t)	2030 (Mt)	2040 (Mt)	2050 (Mt)
PV CYCLE	Germany	8,500	-	-	-
	Italy	2,500	-	-	-
SASIL SpA	Italy	~1,800	-	-	-
Stiftung EAR	Germany	144	-	-	-
SENS	Switzerland	~70	-	-	-
EC	Europe	~0	0.20	2.00	4.21
PV CYCLE	Europe	~0	~0.16	~1.96	~5.4

Source Personal communication; Stiftung EAR, 2017; Bio Intelligence Service, 2011; PV Cycle Annual Report, 2015

5.5.2 Setting quantitative targets and treatment standards

While low waste volumes was mentioned as a definite deterrent to investment in specialized PV recycling technology in the interviews, there was another challenge that came to light when conducting the interviews: since PV panels were covered under category 4 of the recast Directive (and Group 6 in Germany and Group 4 in Italy), the collection and recycling rates were presented for that entire category, with no way of knowing how much of the total PV produced was actually treated and how (Charalambous, CdC RAEE and Wade, First Solar, email and personal correspondence). Dr. Wolfram stated that "*For this [PV collection, recycling and recovery] to work, properly, PV modules would really have to be classified in a category of their own, as was done, for instance with lamp recycling*" (recovery, 2012).

Additionally, there are no prescribed standards for treating the PV waste that arrives at the WEEE recycling facilities. In an attempt to address this gap, the European Commission has issued a mandate ('MANDATE TO THE EUROPEAN STANDARDISATION ORGANISATIONS FOR STANDARDISATION IN THE FIELD OF WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT (DIRECTIVE 2012/19/EU (WEEE))', 24th January, 2013 or **M/518 EN**) as required under Article 8(5) of the recast WEEE Directive, to the European Standardisation Organizations to set standards for the treatment (includes recovery, recycling and preparing for re-use) of WEEE (Section 3(1)). These standards are expected to cover the entire range of products outlined in Annex 1 of the WEEE Directive. As per the Mandate, "*In order to facilitate the self-assessment and documentation of compliance with the Directive by operators, and to facilitate a possible adoption of binding minimum quality standards by the Commission, the standard(s) shall distinguish between normative treatment requirements derived directly from the legal text of Directive 2012/19/EC, especially Annex VII, and between informative treatment requirements going beyond the strict requirements of Directive 2012/19/EC.*"

The European Committee for Electrotechnical Standardization (CENELEC) is one of the three European Standardization Organizations responsible for development of European Standards (ENs) and is working on the 'EN 50625-2-4' series (Treatment requirements for photovoltaic panels) and the 'TS 50625-3-5' series (Specification for de-pollution – photovoltaic panels). These have not yet been published but are expected by the second half of 2017 (EC, 2017; Wade, personal communication). If everything goes according to plan, it will be adopted in all EU countries as of 2018 or 2019 as the binding state-of the-art technology in the revised WEEE Directive.

5.6 Eco - design

There are multiple definitions of eco-design. According to Fiksel, 1996 eco-design is a process "*that develops a product that meets cost, performance, quality, as well as environmental attributes of a product by integrating environmental aspects into product design engineering process.*" Another description is provided by Karna (1998) "[eco-design] *is a process that reduces the environmental load of a product in its entire life cycle by considering environmental aspects of a product in the entire product development process.* And finally ISO (2002) provides a definition of eco-design as follows "*an activity that integrates environmental aspects into product design and development.*"

There are opposing views on whether EPR as an instrument can drive eco-design considerations. Some studies have argued in favor of EPR being a motivator, driving consciousness amongst producers for eco-design (Lindhqvist, 2000; 2000; Tojo, 2001; OECD, 2001a; Hanssen et *al.*, 2003; Tojo, 2004) as it gives the producers technological freedom to develop better solutions that internalize the cost of waste management. Others oppose this viewpoint, alluding to a weak correlation between the two (Kivimaa, 2007; Gottberg et *al.*, 2006) and external factors influencing the change such as reduced cost, competition and market opportunities (Veerman, 2004; Stevens, 2004). Furthermore, there is also the argument that there is not enough incentive in the WEEE Directive as it is currently implemented to justify looking at design considerations of complicated, long-lasting EEE (Richter, 2016).

While producers and recyclers are interested in looking at design improvements for 'ease of recyclability' and 'environmentally - friendly design', the main motivation behind these are the economical benefits from reduced use of valuable material and sustainable supply of raw materials by reusing the recovered components (Wade, personal communication). According to Dr. Wambach, the long life span of PV panels also discourages any investments in design changes as by the time the panels will come back for recycling, the technology would have moved on to newer, more efficient designs. Additionally, from an economic standpoint, investing in such design changes is still not feasible, most of the research projects have been shelved for a more favorable time. Efforts have to be made to design the panels *with* reused and recycled materials (Wambach, personal communication).

EPR legislation on its own may not be sufficient for driving eco-design in products, but combined with directed legislation in the Directives (Eco-Design and Energy Labelling Directive) and the proper incentives, it could encourage more interest in this direction (Alina, PV CYCLE, personal communication). In addition to the environmental and economic benefits of investing in eco-design, another motivator that could drive design changes is the customer attitude (Wade, personal communication). If customers at the time of purchase value products with a lower carbon footprint over other features, then producers would be interested in investing in products with a design that could lower the total carbon footprint. For example, First Solar and Apple recently entered into a PPA. Apple is known for investing in ways to reduce the carbon footprint of their products and being very open and transparent about their production ways. According to Mr. Wade, this attitude spilled over into the meeting and the first point of query was the carbon footprint of First Solar panels and what the company was doing to further bring it down (personal communication). Higher customer consciousness and value placed on environmentally positive products could certainly motivate more producers to change the design of their products to make them more eco-friendly.

As for improvements in the design for 'ease of recyclability', Dr. Wolfram's opinion also concurs with Mr. Wade's. Customers are interested in the greenest products on the market and "*If a producer cannot show a customer that all the parts of the PV panel are recycled and there is no waste, he will lose out in the competition. Public opinion is of great importance to a manufacturer and this is excellent motivation to invest in a complete green solution for recycling."* (Wolfram, Loser Chemie, personal communication).

5.6.1 Communication between Actors

According to the Association for the Collective Organizations (the 'WEEE Forum') the "*The increased flow of information from recyclers to manufacturers through participation in the collective take-back system will enhance the knowledge and sophistication of product designers.*" (Rossem et *al.*, 2006). Article 4 'Product Design' of the Directive states that "*Member States shall, without prejudice to the requirements of Union legislation on the proper functioning of the internal market and on product design, including Directive 2009/125/EC, encourage cooperation between producers and recyclers and measures to promote the design and production of EEE, notably in view of facilitating re-use, dismantling and recovery of WEEE, its components and materials.*"

There were varied responses received from the interviews but it was clear that there was no dedicated channel for flow of information between the recyclers and manufacturers. Loser Chemie innovations are presented at high-profile forums such as the InterSolar conferences (Exhibition platform for solar industry), IEEE events in Washington, IFAT show (Trade fair doe Waste management) and communicated directly to the producers who contact them for managing their PV waste (Wolfram, personal communication). As there is no explicit mention of producers interacting with the recyclers and vice versa in the German national legislation, interaction between downstream and upstream actors can take many forms. Despite the limited interaction, Dr. Wolfram and his team strive to enhance their solutions according to ever evolving PV technology available in the market. "*We develop our system in the same ways the modules are developed for more efficiency"* (personal communication). Despite these efforts, there is limited interest in investing in L.C. technologies as yet and most of the funding for the projects comes from the Saxony government, Germany and the EU ('Horizon 2020' project).

As mentioned before, CdC RAEE manages the waste allocation system for PV in Italy via collective schemes. The recyclers that are a part of the scheme and responsible for the collection and treatment of the PV have no interaction with the producers (Sgarioto, RELGITH srl, personal communication). All attempts at developing technology for material recovery are initiated by the company on its own initiative. The pipelined 'ReClaim' project is an advanced recycling innovation for the reclaiming of 'gallium, indium and rare earth elements' from PV and Solid State Lighting that was motivated by the vast volumes of PV waste the organization expects in the future (Sgarioto, personal communication). A similar feedback was received from Mr. Ramon of SASIL, who had no clear channel of communication with the manufacturers and had to promote the FRELP project via conferences and other forums (Lodovico, SASIL SpA, personal communication).

5.7 Existing Challenges to the Adoption of the Regulations

There were numerous problems that were identified during the literature review and the interviews with the adoption of the new WEEE Directive at the Member State level for end-f-life management of PV. Figure 6-3 highlights some of the key areas where the challenges have been identified in the EPR systems that were analyzed. These challenges will be addressed in the following section.

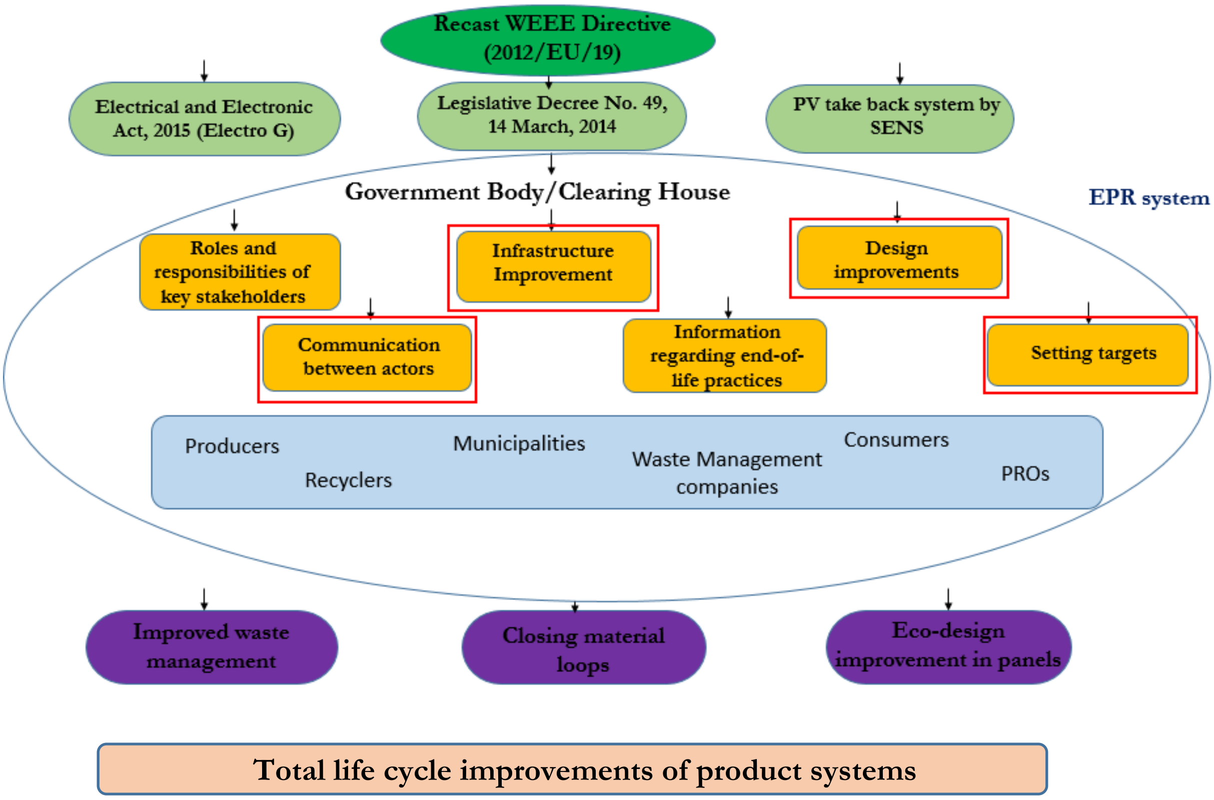

Figure 6-3 Challenges identified within the EPR systems

Source: Own, adapted from Richter, 2016 and Pellegrino, 2016

5.7.1 Infrastructure Improvement

Treatment of PV waste is still in its 'Design phase' (Latunussa et *al.*, 2016). Due to the lack of specialized PV waste recycling technology, most of the panels that are collected along with the rest of the WEEE are either sent outside of the country for treatment or are stored until such time when commercial scale, PV waste specific technologies will be available. At present, the small amounts of PV waste that are coming into the system do not encourage much interest or investment in such solutions as the economic gains are not favorable. The waste projections by PV Cycle and the Bio Intelligence in its report to the European Commission show sizable volumes of PV waste coming in only after 2025 (see Table 8). Since these volumes are expected to remain low till then, getting funding for research projects that will develop these technologies is also difficult. Case in point is the FRELP pre-prototype solution which, while being a part of the LIFE+ EU programme, is still devoid of funding since 2014 as there isn't sufficient volumes of PV waste coming to justify continuation of the funding (Lodovico, personal communication; FRELP, 2016). It is also unclear who will pay for the development of these technologies. Will the onus fall on producers alone or will the consumers through funding programs on national/pan – EU levels contribute to the research?

5.7.2 Setting Targets

Without separate collection and recovery targets for waste PV modules, it was difficult to determine 1) how the systems had been performing so far and 2) how much % of the PV waste was actually being recovered and reused. Then there is also the problem of improper disposal of the PV panels. The lead content in PV modules is above the limit set for inert waste landfills but still lies within the limit for ordinary landfills (BioIntelligence, 2011). Electronic waste, PV waste included, is still sent to landfills, leading to toxic substances leaching into the environment and loss of precious resources (Lewis, 2010; Latunussa et *al.*, 2016). Thus, setting of separate recovery rates and treatment standards for PV waste is very important for proper management of this waste stream.

5.7.3 Design Improvements

The interest in improving the design of panels to reduce their environmental footprint and make them more recyclable friendly is not – as there no real incentive to do so. Besides the volumes of PV waste being too small to justify the investments, whatever benefit can be derived from improvements that might reduce the overall environmental impact of the panels (by using recovered material instead of virgin material) will be negated in a collective system or balance out some other producer's high environmental impacts. Therefore, in addition to separate collection, recycling and recovery targets for PV, there is also a need for targets on use of recovered material in the production of new panels which will then motivate research in panel designs that can consist of recovered material that will not affect the efficiency of the panel.

5.7.4 Communication between Actors

There was a clear breakdown of communication between the upstream and downstream actors in the systems that were studied. With Clearing Houses and PROs forming the link between producers and recyclers, there was little communication that was taking place between these actors. As most producers are a part of collective take back systems, for them to understand where their module design can be improved to improve recyclability or recovery of material cannot happen unless they get specific feedback from the recyclers. All initiatives to improve the panel design or develop specialized recycling solutions are taken separately by the two actors and at their own initiative.

5.8 Individually Responsible Producer Performance: First Solar

First Solar has invested considerably in research and innovation of its panels. From improving the design, such as modifications to use recycled components (Te), making it more modular to improve recyclability, etc. in addition to successfully running the industry's only individual take-back and recycling program for its panels (First Solar, 2010). While there are instances of other EEE firms taking steps to support similar IPR policies (eg. Dell offers free take back of computers of any brand as well as its own at the time of purchase of a new Dell computer (Global Recycling Policy), all Sony products are covered under free take back in North America; other firms who strongly support IPR include HP, ElectroLux, Samsung, etc.), the author is not aware of any other such IPR initiatives in the solar industry (CPA, 2007).

When it comes to operational performance, First Solar's systems are sound in terms of recycling capacity. For example, in the year 2010, the total amount of PV waste in Germany was estimated at 3300t (PV CYCLE, 2010). In comparison, the amount of PV waste that First Solar recycled through December of 2009 alone was over 1600 tons of 'manufacturing scrap, warranty returns and pre-mature end-of-life modules' (Kruger, 2010).

6 Discussion and Conclusion

Research question 1 and its sub research questions on the working of each system, transposition of the WEEE Directive, EPR practices motivated by these policies and important stakeholders in each system has been addressed in sections 5.1 (EPR in Europe) and sections 5.3 (Improved waste management practices) through 5.6 (Eco-Design). RQ2 on how these systems have performed so far (in terms of meeting targets and for EPR goals) and challenges faced by the system have been addressed in sections 5.2 (System performance), sections 5.3 through sections 5.6 and section 5.7 (Existing challenges to the adoption of the regulations). This section will address the last sub research question of RQ2 on possible oversights and gaps in the legislations based on the finds of the previous sections and make recommendations for improvement of the system.

SRQ2.5 *What (if any) are the gaps (concerning the EPR goals) in the existing policies (at the EU level) for photovoltaic waste based on these findings?*

The three goals of EPR namely – Improved waste management practices, Closing the loop for material recovery and improving the eco-design of the products have been met with varied levels of success by the three systems. Part of the reason for this varying degree of achievement is that there are oversights in the legislation as a result of which there are system failures in practice. Some of these identified oversights are addressed in Section 5.7 in the form of challenges in the system and it is possible to make certain recommendations to overcome these gaps in the transposition and adoption of the recast Directive:

- **Improving communication between recyclers and manufacturers:**
  While there are several entities that can coordinate the various implementation steps between a panel production and its final transport to the recycling companies at the end of its life, this prevents any direct communication between the manufacturers and recyclers. Communication between key actors is an important feature of an EPR system to provide a feedback mechanism to the producers on design improvements.
  Individual Responsibility schemes, started by the producers themselves can be a way out as it is possible to develop several hybrid models that can make use of strengths of both the Collective systems and Individual systems.
- **Introducing incentives to move beyond the bare minimum targets:**
  Another shortcoming is the lack any of real motive for producers and recyclers to strive for more than just fulfilling the legal targets mentioned in the Directive and move towards the bigger goals of the Directive. The current interest of producers lies with design improvements to enhance the efficiency of the panels and not the benefits that can be derived from investing in proper end-of-life management.
  While industry stakeholders do consider the legislation to be an important motivation to collect and treat the waste PV panels, this motivation ends at meeting the target rates. Except for a few pioneers, the remaining producers need more of an incentive or reason (specific qualitative standards for recycling of waste PV panels) to move towards more long-term goals.
- **Improving the EPR system implementation:**
  Since there is no mention of steps for EPR system planning and execution, in practice the result is a breakdown in the implementation chain as panels are collected along with the WEEE but instead of being treated, are stored on site till such a time when specialized waste treatment facilities are available or the volumes are high enough to be transported to neighboring countries where proper management can take place.

6.1 Reflections and Conclusion

The following section will address the soundness of the methodology for research, the framework used and the generalizability of the results from this thesis.

6.1.1 Research Design and Methodology:

The aim of this thesis was to understand and evaluate the EPR systems in place for the end-of-life management of solar PV waste in Germany, Italy and Switzerland, following the transposition of the recast WEEE Directive and other factors. Three types of research methods were used for addressing this aim: literature review, stakeholder interviews and quantitative data collection. This data was then analyzed using a framework for policy evaluation.

Except for a few studies, the rest of the literature comprised of online information (websites, etc.) and grey literature. The validity of this information is not verifiable and poses a limitation. Thus, the interviews served the added purpose of supporting these finds by providing in-depth practical knowledge of this industry and key stakeholder perspectives. Given the vast expanse of the research scope (looking at the 3 EPR goals for all 3 case countries), the literature review focused more on getting an overview of the systems and initiatives that stood out. By not focusing on a specific region or country, the literature review was purposely kept broad to provide a more general overview of the systems. In addition, only material flows were addressed through literature review as data on economic flows was limited given the competitive nature of this information. This can also be seen as a limitation as it hinders any kind of financial analysis and conclusions regarding the effectiveness of the system in this regard.

The 'Least similar' case study approach by George and Bennett, (2005) was used with the intention of increasing the applicability of the findings and covering more such similar systems and scenarios that could be similar to the situation in one or the other case country. Germany, Italy and Switzerland covered a wide range of system structures and initiatives to improve the relevancy of the outcomes of this thesis.

The interviews that were conducted covered a wide range of the key stakeholders that were involved at various levels of the systems. The information gathered from the 12 interviews helped validate the finds of the literature review and identify where the challenges were in adapting the existing WEEE systems for handling PV waste. Despite repeated efforts on behalf of the author, several stakeholders did not respond to attempts at establishing contact. Of the stakeholders that were interviewed, there was varied levels of interest in responding to the questions that were asked by the author. While some were eager and actively contributed to not only responding to the questions, but also suggested further topics for the author to research on in an attempt to improve the overall quality of the thesis. No interviews were conducted from the Ministry of Environment, Land and the Sea, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Registro RAEE or Stiftung EAR as no response was received to any of the attempts made by the author to reach them. Interviewing policy-makers and enforcers would have provided valuable insights into the overall picture of how the WEEE Directive has been transposed into each country and where are the challenges in implementation. A key category of stakeholders that was purposely not interviewed was that of the distributors, primarily with the intent of covering the major stakeholders in each of the systems. As distributors did figure prominently in the interviews or the literature as a challenge in the system functioning, it was considered best to focus more on other key stakeholders. In retrospect, if the research could have been for a longer duration, this category of stakeholders would have also been included as their input would be further add to understanding on-ground challenges to the implementation of the systems.

6.1.2 Analytical Frameworks:

There are two analytical frameworks that are used in this thesis with the intention of going beyond just a general system assessment and analyzing deeper aspects of the systems. The Murphy et *al.* (2012) framework gave a good overview of the basic elements of the three systems, based on which a fairly well informed conclusion can be drawn on the objective performance of the systems. The second framework is based on Vedung's (1997) commonly used framework for policy evaluation and maps out each system using the intervention theory. The policy evaluation is done based on how well the three goals of EPR are met by each system namely 'Improved Waste management practices', 'Closing material loops' and 'Eco-design of products'. Evaluating the attainment of these goals or attempts made in the direction of their fulfillment fits into the scope of the research and ultimately addresses the research questions.

Scoping down to the most important of practices under each of the three goals helped guide the evaluation and keep it relevant. To the author's knowledge, evaluation of the PV waste specific management systems in Germany, Italy and Switzerland using the two frameworks or other similar frameworks has not been done till date.

6.1.3 Generalizability:

The generalizability of the findings differ for the outcomes from the various research methods. The findings from the literature review are generalizable nationally and at the EU level for the most part. The findings of the quantitative analysis are generalizable on a national level as each Member State has different volumes of PV waste coming in depending upon when the installation took place and thus is at various stages of system adaptation response. However, since all EU Member States transposed the new WEEE Directive and have had time to adapt their existing systems to meet the stated targets under the legislation, certain aspects of these findings could be applicable to outside of these case countries. The findings from the stakeholder interviews are not fully generalizable as they are specific to the stakeholders that were interviewed and contingent on their views. As the findings from the literature review, stakeholder interviews and quantitative analysis for the three cases are quite compatible, the author can confidently state that these findings can be used to present a fairly accurate picture of the EPR systems for PV waste management in each of the three case countries.

6.2 Future Research

This thesis provides a good starting point for understanding where the potential gaps in the implementation of the WEEE legislation could possibly be and dwell deeper into them. By choosing to perform a comparative analyses instead of focusing on a specific region in one of the three case countries, the findings provide an overview of the three systems instead of more in-depth insights. While the author choose to go ahead with this trade-off between an in-depth research into one case study versus a more horizontal research into multiple case studies, future research can explore difference in regional system performances to understand on-ground, contextual factors that could influence these performances.

Furthermore, the cases that were chosen for this thesis, namely Germany, Italy and Switzerland, were chosen with the idea to provide a picture of three very different system adaptations of WEEE related legislations. It is also possible to use a 'Most Similar' or other variations of the Case Selection approach and choose high/low performing systems to understand the drivers/barriers behind their high or low performances.

One of the issues that was developed as the research progressed was that of Individual Producer Responsibility schemes and their benefits. While this thesis focused on one such case, i.e., that of First Solar, it would be interesting to see how IPR schemes would perform in other EU

Member States, especially since this topic ties so closely with that eco-design and incentives for design improvements and can be studies together.

And finally, this thesis focused solely on the recast WEEE Directive and its transposition into the two case countries of Germany and Italy. Supplementing legislations (e.g. the Eco-Design Directive, the Ecolabelling Directive, etc.) and their influence on the EPR systems was not studies in great detail. This is a limitation that the author recognizes as these legislations were brought up in the interviews as possible motivators. Studying their influence on the systems would also be interesting in order to understand different policy interactions, synergies, trade – offs and scope for improvement.

6.3 Conclusion

Proper end-of-life management of waste PV panels is a priority from both reduced environmental impacts point of view (leaching of harmful materials into the surrounding, decrease in environmental impacts from use of recycled materials and recovery of critical resources) and an economic angle (valuable material recovery). Countries in the EU being early adopters of this technology have already started seeing end-of-life panels coming in for recycling have taken various steps to adapt their existing WEEE systems to include this new stream. German recyclers and manufacturers already have cases of pilot initiatives for specialized recycling solutions while their Italian counterparts are following suit. While PV remains a small issue for stakeholders in Switzerland, the country has nonetheless taken steps to ensure its proper treatment by including PV in its already highly efficient take-back system. There are still, however, challenges to fully optimize this systems, from the point of view of meeting EPR goals and scaling up systems to meet future demands.

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Appendix A: List of Interviewees

Company/Organization	Interviewee	Stakeholder category	Date of interview	Type of interview
SENS Foundation	Roman Eppenberger - Head of Operations dept.	PRO	31st March, 2017	Skype
PV CYCLE	Pia Alina - Head of Public Affairs and Communication	PRO	1st March/10th April, 2017	Skype + Email
First Solar	Andres Wade - Global Sustainability Director	Manufacturer/recycler	22nd March, 2017	Skype
Loser Chemie	Dr. Wolfram Palitzsch - Chief Technology Officer	Recycler/Technology development	18th April, 2017	Skype
European Recycling Platform Germany	Michael Gormann - Country General Manager	PRO	8th May, 2017	Email
Zentek GmBH	Achim Gibson - Project manager Sales	Take Back system	24th May, 2017	Email
SASIL S.P.A	Lodovico Ramon - CEO	Recycler	20th April, 2017	In person
RELIGHT srl	Serena Sgariotio - R&D Unit/ Daniele Gotta - Plant Manager	Recycler	19th April, 2017	In person
CdC RAEE	Sara Mussetta - Technical and Administrative secretariat	WEEE Coordination across Italy	5th April, 2017	Email
European Recycling Platform Italy	Samantha Charalambous - Italy Marketing Manager	PRO	9th May, 2017	Email
Ex - PV CYCLE, BifA	Karsten Wambach - Project manager, Process Engg.	Expert	15th Feb, 2017	Skype

IRENA - IEA	Andres Wade - Global Sustainability Director	Expert	22nd March, 2017	Skype

Appendix B: Sample Interview Guide

This interview will be conducted for a master thesis at Lund University. If you wish, no third parties other than our fellow students and the IIIEE research staff will see its contents. Sensitive and internal information will be treated confidentially.

The aim of my research is to analyze the systems in place for the management of waste PV modules in Germany, Italy and Switzerland and evaluate them from a physical as well as policy performance perspective. All the major stakeholders in the implementation chain of the systems will be contacted in order to obtain a holistic overview of each system and draw well-rounded, valid conclusions. Since _____ is an organization/company representing a key stakeholder category, getting your inputs will be very useful for my research.

The way this interview is structured is that I will start with a few general questions about _____ and then move on to more in-depth and specific questions. As this is a semi-structured interview, if at any point you are unsure about a certain question or you would like more time to respond to it, we can always come back to it later. In case you may feel uncomfortable responding to a particular question, please let me know.

Appendix C: Sample questions for manufacturers

- What is the process your company follows for PV recycling? What are the advantages/disadvantages of this process?
- What is the use of the recovered glass, Cd and Te? Is it used in PV production or in some other form?
- What happens to other materials like plastic, metals, etc.?
- What other critical materials are recovered from this process and in what percentage?
- Is there any form of communication regarding end-of-life practices that is conveyed to the consumers?
- Has your company ever invested in an LCA report for recycling/recovery vs. other disposal methods to estimate their environmental impacts?
- What was the main motivation behind including PV panels in your recycling services?
- How does the collection and take-back mechanism work for the PV panels?
- What are the collection rates that your company has achieved so far for PV waste?
- What is the area covered by your recycling services for collection of panels?
- Is there any form of interaction between you and the National Regulator/Clearing House during the course of you company's operations?

Appendix D: Sample questions for PROs/Take-Back schemes

- What are the issues faced by the PRO when taking on a new member country for integration into its working? How does the PRO communicate with other stakeholders such as producers, recyclers, government authorities, etc.?
- How does the PRO co-ordinate with the national recycling agencies?
- Is the membership fee taken from the full time and associated members the only way this entire system is financed? Is the historical waste covered under the fee that is charged? Has this fee changed since 2009?
- How willing are producers to be a member of the PROs services? Is there any communication with the producers regarding the practices for end-of-life of the product?
- Does the PRO have its own set of targets for PV waste collection, recycling and recovery or does it follow the targets set under the _____? How are the collection, recycling and recovery rates calculated? How has the system performed so far?
- What happens to the collected panels? Does the PRO also recycle the panels?
- Is there any form of communication regarding **end-of-life practices** that is conveyed to the consumers/end users (included in the workshops, conferences, etc.)?
- Did the PRO face/is facing any challenges regarding the management and recycling of PV panel waste?
- Have you seen any instances or initiatives towards more environmentally friendly designs for the solar panels? What motivated these designs? Are producers interested in incorporating ease of recyclability into their panel design?
- Will Extended Producer Responsibility (EPR) be a likely motivator in the future for pushing producers towards going beyond just complying with the targets for PV? Innovate beyond the bare minimum? Can there be other factors driving eco-design?
- Is there enough incentives for producers in general to be interested in investing in eco-design and material loop closing PV recovery technologies? Are the National legislations put in place for PV recycling motivation enough for producers to go beyond trying to achieve the minimum targets and invest in better products?
- What do you think is the future of PV recycling? Will producers and recyclers be interested in investing in the above technologies and if yes what will be the motivator? Economic feasibility, environmental concern, sustainable consumption or legislation such as the Directive and the EPR principle?

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