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Photovoltaic module decommissioning and recycling in Europe and Japan

– current methodologies, norms and future trends

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Abstract

The thesis points out practical problems of waste management within the Photovoltaic industry and conclusions are based on empirical data.

Benefits for photovoltaic key stakeholders, like module manufacturers, governments and power plant owners are investigated. The conclusions drawn are based on interviews, literature review and online research. So far recycling of crystalline photovoltaic modules is regulated only within the European Union. Current directives governing photovoltaic modules frame the recycling targets in terms of weight. But the loss of resources like aluminium and silver, as well as lead and cadmium leaching have a negative impact on the environment and human health if modules are merely discharged after their life cycle. Eventually these materials will become scarce and affect the future production of photovoltaic modules. Therefore looking at the environmental impact of each raw material is a different, more sustainable approach. Yet, environmental effects are so far not being considered in the stakeholders' decision making. The thesis shows that for manufacturers the main incentives to recycle are profit maximisation and image improvement. Including a recycling strategy into the manufacturing process is therefore actually increases competitiveness within the photovoltaic business. In order to raise awareness for photovoltaic waste, it is suggested to include the photovoltaic modules' decommissioning time into Gantt Charts which might influence photovoltaic owners to purchase modules that are recycled after their life span. A future key development is likely to see recycled materials to be reused for new PV products and substituting materials that are harmful to human health and the environment. An overview of the current technology, legal framework and waste projection for the recycling industry is given in chapter 3 and 4.

Keywords: recyclability, legal framework, societal perspective, photovoltaic modules

List of abbreviations

A	Amorphous
APAC	Asia Pacific
BAN	Basel Action Network
CdTe	Cadmium, Telluride
CIS	Cupper, Indium, Selenium
C-Si	Crystalline Silicon Cells
EAR	Elektro-Altgeraete Register
EVA	Ethylene Vinyl Acetate
Fit	Feed-in-tariff
GESTIS	Gefahrstoffinformationssystem
GW	Giga Watt
ISO	International Organization for Standardization
MEA	Middle East
METI	Ministry of Economy, Trade and Industry
MW	Mega Watt
NF3	Nitrogen Trifluoride
Pb	(Latin=*plumbum*)
	Lead
PV	Photovoltaic
ROHS	Restriction of Hazardous Substances
SVTC	Silicon Valley Toxics Coalition

Sn-Ag-Cu	(Latin= *stannum-argentum- cuprum*) Tin-Silver-Copper
TUV	Technischer Überwachungsverein
WEEE	Waste Electrical and Electronic Equipment

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Introduction

1. Background

In recent years the growing amount of electric-waste has led to a dire state of landfills and increased environmental impact arising from disposure of electronic equipment. Electronic waste including Photovoltaic (PV) modules is nevertheless disposed to open landfills or simply being shipped to third world countries (Lewis, 2010). Though treatment of waste is a global challenge, this thesis focuses on factors that influence the establishment of a Photovoltaic recycling process.

There is a current revolution towards renewable energies in Japan and Europe. The International Energy Agency states that the global solar photovoltaic capacity until 2012 was about 102 Giga Watt (Photovoltaic Austria Federal Association, 2014). With a total amount of 70 GW, Europe is the world's leading region in terms of cumulative installed capacity (Meza, 2014). Besides Europe there are three main players within the PV market: the US with 9 GW, China with 8 GW and Japan with 6.6 GW (Kaizuka et al, 2014). In the Figure 2 Japan is included in the Asia Pacific (APAC) category. Since 2010, China has the highest annual PV module production rate globally (Sandberg, 2014).

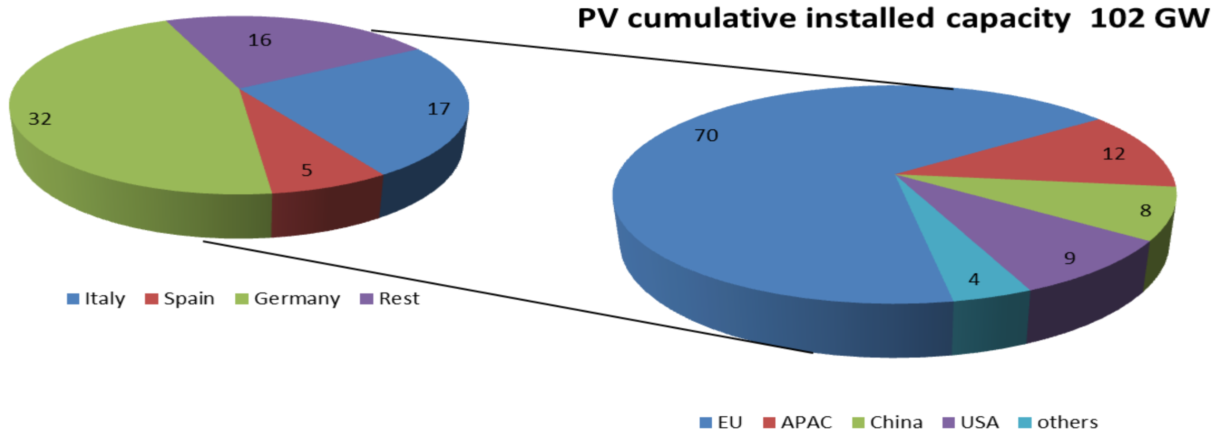


Figure 1: The right pie chart shows the proportions worldwide with the European Union, Asia Pacific (APAC), China and the USA. The left pie chart represents the proportions on the European market.

Within Europe, Germany takes with 32 GW the leading role in PV production and the overall solar energy consumption follow by Spain with 5 GW and Italy with 17 GW, whereas the solar markets in Sweden and Denmark are comparatively poorly developed, because these countries tend to favor wind power (European market players are also shown in Figure 2.).

In 1983 the production rate of Photovoltaic modules had a capacity of 22 Megawatt (MW). So within 30 years the capacity of installed modules grew by a factor of 5000, which turned the PV industry from a niche product to an international business all over the globe. The photovoltaic technology consists of an active semiconductor layer that absorbs light and transforms it into electricity. Typically a number of individual cells are connected together to form a solar module. The Aluminum frame gives the module its' stability.

The manufacturing process includes a number of hazardous materials and the amount and type of chemicals used depends on the type of cell. Thin-film PV cells contain a number of more toxic materials, like gallium arsenide, than those used in the more common used silicon photovoltaic cells.

According to the existing literature available, waste photovoltaic panels, if disposed in landfills without proper treatment, can harm the environment and human health because of

a) Leaching of lead and cadmium

b) Loss of conventional resources (like glass and aluminium and rare metals (like indium, gallium and germanium)

Cadmium has been associated with numerous human illnesses like kidney and bone damage. It accumulates in the natural environment by leaching into ground water and surface water from landfills (Fthenakis, 2008).Due to the reuse of recovered wafers and the recycling of glass and metals the recycling process leads to a decrease of environmental burden further by avoidance of the production of new wafers and material like glass. 1 Ton recycled, Silicon-based PV modules save up to 1,2 Ton CO2 emissions (Fraunhofer Institut IBP, 2012).

Until 2011 about 5 million tons of solar modules had been installed in Europe (PV Cycle, 2011). Looking at the raw materials used for the different types of PV module technology, the amount of raw materials encapsulated in the modules can be calculated. The pie chart shows the proportion of materials encapsulated in PV modules installed in Europe until 2011.

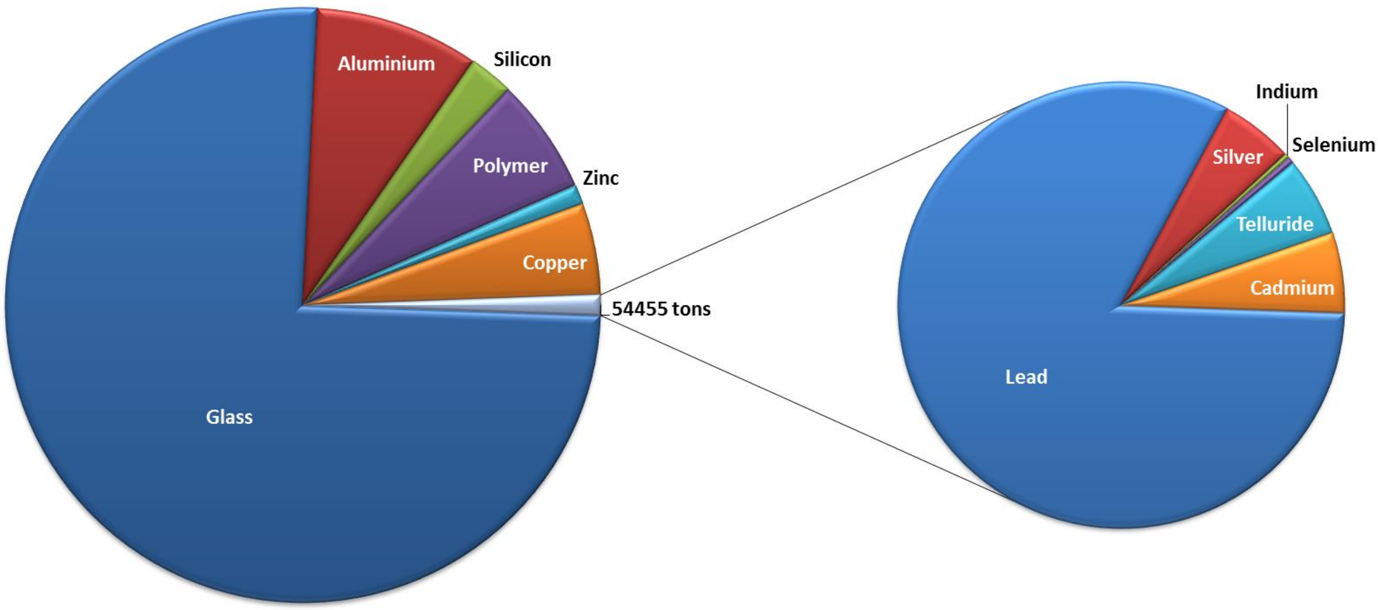


Figure 2: Encapsulated materials in the EU according to the installation rate in 2011

The total amount of glass used for solar modules is 3.771.250 tons. Further are 445.745 tons aluminum, 314.600 tons polymer, and 121.805 tons silicon encapsulated in the installed PV capacity until 2011. About 250.675 tons copper, 53.120 tons zinc and 4.4850 tons lead are used. Cadmium and telluride account for roughly 3.150 tons. About 2.880 tons silver has as well as 255 tons selene and 170 tons indium have been used for manufacturing PV modules installed in Europe.

The question remains when these amounts of PV systems will lose their value and turn into waste.

Waste derives from the old French term *vastum*, which was originally used to describe a desolated area like an uncultivated field (Barles, 2006). From 1590s onwards, the word *waste* is used for "worthless stuff".

According to Arjun Appadurai commodities are “objects of economic value”. As economic value derives from economic exchange Appadurai argues that politics creates value (Appadurai, 1986).

Since the “*United Nations Conference on Environment and Development*” which took place in Rio de Janeiro in 1992 sustainability became an ideal for governments to face environmental and economic matters (Luhmann, 2010). The conference emphasized the interconnectedness of economic, social and ecological processes (Bärtschi, 2012). The ideal of sustainable development typically involve three major topics: energy savings on the demand side, efficiency improvements in the energy production, and replacement of fossil fuels by various sources of renewable energy (Lund, 2007).

Sustainability originally derives from the forestry sector. The word sustainability was first mentioned by the German aristocrat Carl von Carlowitz (1645-1714) in his book „Sylvicultura oeconomica“ published in 1713 (Weinberger, 1998). Carl von Carlowitz studied forestry during his five year educational trip through Europe. He met the minister of Ludwig XIV, Jean Baptiste Colbert, whose tenor was the reduction of timber harvesting and the restoration and maintenance of the forest (Weiss, 1993). During this time France had to face timber shortages due to shipbuilding needed for the Navy. Timber should be used in a manner that ensures that it is still available for future generations. The Motivation of this forest management was mostly economic and social nature and rather less ecological motivated (Koller, 2009).

Appadurai states that the values ascribed to an object are in constant flux (Miller, 1987).

This value can be emotional, knowledge value, or an object’s ability to be sold on the market (Appadurai, 1986). For a manufacturers the PV panel has an economic value as he can sell it on the market. For the owner it also has an economic value as the PV system satisfies his energy demands. Further the user of a PV device feels good as he invests in a green technology.

PV modules as any other renewable energy source has been promoted by many politics. Especially the feed-in tariffs give an economic incentive to invest in a PV system. Here you get a fixed price for your produced energy for a fixed term of normally 20 years. Another factor that creates value is the warranty time for each product. For an investor in a PV power plant the value of a PV system decreases after the warranty time is over as he wants to invest in the least risky PV system. For a small household or a commercial used PV system the value of a PV system does not decrease as fast as for a PV plant investor. Here the system is normally used to cover the own electricity demand. Therefore residential and commercial PV systems are used even after the warranty time is exceeded.

In comparison to Appadurai, Michael Thompson argues in his „Rubbish Theory: The Creation and Destruction of Value“ that goods do not change over time. Instead it is their social category hat changes. For Thompson, individual actions of buying and selling are not that interesting as they are for Appadurai. They represent only quantitative reductions of the object's value. What is interesting for Thompson is the qualitative step from transient to rubbish, or from rubbish to durable (Thompson, 1979).

Thompson notes how an object's economic or cultural value diminishes over time and finally how some of these objects regain value. For example a car from the 50s might have a high emotional value for car lovers. There are two possible steps of qualitative transformation: (1) a transient becomes rubbish, (2) rubbish becomes a durable.

The social and ecological conditions of the production and of PV modules as well as the question of how to handle the devices when they come to the end of their life should therefore be more elaborated.

The acceptance for a further expansion of Photovoltaic modules for private and commercial use is not only a question of technical evolution. It will be the principal task of European and Japanese policy in the coming years to support the evolution of sustainability within the photovoltaic industry located in Europe and Japan (Patton, 2012).

Manufacturers should ensure that these highly valuable materials are recycled rather than thrown away.

The principal difficulty encountered regarding the recycling of photovoltaic modules is financial. The recycling processes are costly and the waste volumes are still fairly low with regards to industrialising these processes.

Government organizations play an active role in formulating policy and deciding how it will be implemented as well. As comparative model to the European directive on electric waste, the Japanese waste treatment was investigated. Therefore the e-waste situation in Germany and Japan concerning legislations practices were investigated to see what can be learned from their implementations.

Research purpose and research question

To elaborate the importance of PV recycling we need to know the impact from old PV modules that are not disposed properly. The research purpose is to explore and analyse what factors influence large companies to manage PV waste.

The research problem is that Photovoltaic waste is a threat for future societies.

Research questions are:

1. Who are major stakeholders of the PV recycling process and what are their respective roles within the photovoltaic recycling industry?
2. What is the e-waste situation in the European Union (EU) and Japan concerning legislations practices and what can be learned from their implementations?
3. How do manufacturers and users react on governmental decisions?
4. What are the economic, technical and social bottlenecks of the development of photovoltaic recycling?
5. How can entrepreneurs make photovoltaic recycling more profitable?

The thesis attempts to answer these questions by partly applying a social science perspective.

To answer these questions, I first present a description of the current solar PV market in Part 2. I conducted an extensive review on available literature on how the production of PV modules affects the reduction of raw materials and whether photovoltaic technology affects humans and nature.

In Part 3 I conducted interviews and market analyses of key stakeholders, for example module manufacturers and how they benefit from photovoltaic recycling explain and evaluate the current market situation. Further existing laws on photovoltaic waste in Germany and Japan were investigated. Focus was to get to know to what extent recycling is mandatory and who is responsible for PV waste according to national laws. Owners of PV modules (e.g. clients of TUV Rheinland and private owners of PV modules via online forums on PV waste) were asked whether they consider the recyclability and decommissioning already in their purchasing decision.

Theory

Environmental sociology elaborates the relationship between society and environment by describing social processes in which certain environmental conditions become socially defined as problems. The theory applied in the thesis derives from Niklas Luhmann (1927-1998) and Manuel De Landa (1952). Luhmann was a social theorist and developer of system theory (Baecker, 2006). Luhmann puts communication in the place of relationships as the main component of a social system. Human communication is autopoietic and human consciousness is outside of the system. As nature cannot communicate, a society can only adapt to disturbances from nature. According to Luhmann ecology can only be sociologically explored as procedures of information processing on the basis of communication systems. Only if people get together, write petitions and media is reporting we receive a feedback on environmental threats (Beck, 1986). Within Lehmann's book "Environmental Communication" he argues that human consciousness does not depend on human agency. Agency is the capacity of an individual to act independently from structures like social class, gender and customs. Luhmann looks at subsystems like governments, industry and science to investigate whether they meet ecological demands. He comes to the result that each subsystem reacts autonomously. Industry has its own strategies and practices to solve environmental problems: they reduce the ecological problem to its price and goods with no price cannot be treated (Festenberg, 1986). Science investigates the ecological problems without relieving the responsibilities to take the decisions and despite new technologies might have harmful side effects. Politics are responsible for the selection of environmental regulations and depend on the government and its opposition. Therefore they have to take many opinions into account and need to consider the consequences and side effects. According to Luhmann the main failure to achieve sustainability is caused by autonomously acting subsystems. The subsystems investigated in this thesis are governments, manufacturers and the owners of PV modules to see whether sustainability can be reached within the PV industry.

Another theory applied in the thesis derives from Manuel De Landa (1952), a Mexican-American writer, artist and philosopher who promotes the theory of assemblages. Assemblage theory is used as an approach to analyse how actors are shaped around the process of PV recycling. The theory of De Landa is used as a comparative model to the system theory of Luhmann. According to Manuel De Landa social formations are assemblages of other complex configurations, and they in turn play roles in other, more extended configurations. The assemblage approach suggests that social formations are heterogenic and fluid (DeLanda, 2006). Assemblages are composed of heterogeneous elements or objects that enter into relations with one another (Augistine, 2014). Within the thesis both theories are applied to analyse whether PV recycling is an approach that reduces the negative effects of PV disposal. Focus is whether human beings are one of the subsystems of society or a special agent that defines and controls independently.

Methodology

The work place for this thesis was situated at the Solar Energy Assessment Center of TÜV Rheinland Japan in 4-5-24 Chigasaki-Higashi, Tsuzuki-ku in Yokohama. From February to July 2014 Fred Martin, Team Leader Photovoltaic Power Plants Solar Technology Products, supported the research. The assessment center is testing photovoltaic modules' safety aspects, compliance with law and standards, functionality and performance. The TÜV Rheinland Japan further acts as advisor for investors in photovoltaic power plants. Therefore the company is interested in regulations, standards and new technologies also concerning photovoltaic recycling. During this time I had an internship contract with TÜV Rheinland and worked at the Photovoltaics Laboratory (see appendix 3).

Photovoltaic industry journals, national government documents and market reports have been investigated through a discourse analysis. Further scientific papers were investigated to get to know to what extent solar modules can be recycled today. Focus was to investigate to what extent production of PV modules affects the reduction of raw materials and if and how photovoltaic technology affects humans and the environment. Special focus was on publications from the *European Photovoltaic Solar Energy Conference* in 2012 and 2013. Renowned research and industry experts from the global PV sector can submit abstracts to the conference programme. The conference takes place each year and covers the entire scope of innovations in PV technologies, applications, markets and policies. Since 2012 research on photovoltaic waste was published at the conference and has been investigated while looking at the narratives of these texts at large. How governments in Germany and in Japan were investigated while looking at laws concerning photovoltaic and electronic waste are investigated in Chapter 3. Focus was to identify who has to take the responsibility for the decommissioning and recycling, as well as to what extent recycling is mandatory in each country. Governmental directives were investigated through a discourse analysis. Therefore I looked what has been said and in what historical and social context it has been said. Publications on the PV power conferences were investigated while starting to look when first papers on cadmium and lead leaching were published and when governmental legislations or manufacturers answered to these publications.

For Photovoltaic owners information on how to handle their old devices is very important as they have to integrate costs for recycling into their purchasing decision. In online platforms, like *photovoltaikforum.com*, forums on PV waste were investigated. Within this online platform questions concerning photovoltaic waste are discussed in forums. Focus was to know how residential PV system owners handle old photovoltaic devices and whether they consider the recyclability in their purchasing decision. Further members were asked what they do with old or broken modules (whether they repair the modules on their own or resell them, where they resell them and to whom). There are several forums that cover specialized topics from photovoltaic insurances to photovoltaic waste. Every member can open a new discussion thread, pose and answer questions. Future innovation concerning photovoltaic recycling is most likely to be done by manufacturers. Therefore manufacturers were interviewed in order to know how they respond to this decision. What disadvantages and advantages they see and how they could benefit from this responsibility. During the PV Expo held in Tokyo from the 26th to the 28th February 2014 twenty manufacturers were asked about their position towards PV recycling, five manufacturers were also willing to answer a short questionnaire (Appendices 1-2). The Solar Energy Assessment Center of TÜV Rheinland had a booth to represent their services at the Expo. The International Photovoltaic Power Generation Expo was held in the framework of the World Smart Energy Week and as an answer to calls from industrial, governmental and academic circles for the opportunity to exchange ideas and opinions. The three day event attracted about 80,000 visitors from all over the world, showcased the most advanced developments related to the R&D and manufacturing of solar cells and photovoltaic technology of the more than 1400 exhibitors from Japan and abroad. The PV Expo was organized by Reed Exhibitions Japan Ltd, at Tokyo Big Sight. Concurrent shows such as the 2nd International Wind Energy Expo & Conference, 9thInternational Hydrogen & Fuel Cell Expo, 4th International Rechargeable Battery Expo, 3rdEco House & Eco Building Expo, 3rd International Smart Grid Expo and the 4thProcessing Technology Expo gave the overall event additional attraction. On the PV Expo industrial, academic circles meet to exchange ideas. Within the three days the manufacturers with the world's largest photovoltaic production, like Suntech, First Solar, Yingli Solar and Sharp, showed their new products. This was the possibility to get in touch with the leading manufacturers and to investigate their strategy for photovoltaic recycling. The questionnaire was conducted from booth to booth. As many of the manufacturers were clients from the TÜV Rheinland they were willing to answer the questionnaire or to have an interview. Questionnaires were answered from the manager of each manufacturers´ booth. The main purpose for manufacturer to take part in the PV Expo was to show and sell their new PV systems. Therefore I first had to ask at each desk whether I could speak to manager of the booth, who knows the company's strategy on PV recycling. In the Japanese business world you first have to present a business card with name, the name of the company for whom you are working, the address and phone number of the company to a new person. The TUV Rheinland Company equipped me with about 50 business cards that I could hand out to the manufacturers. First you have to bow and present your business card with both hands. This procedure had to be done at each booth before I started to talk about the questionnaires. A questionnaire is a research instrument consisting of a series of questions for the purpose of gathering information from respondents like opinions and interests. Advantages of questionnaires are that they are cheap and do not require as much effort from the questioner as verbal surveys and it is more simple to compile data. In addition, interviews with the same questions written in the questionnaires were investigated, as personal interviews increase the return rate.

Besides working on my thesis I tested PV modules according to performance standards and assisted engineers during project handling with market research activities for large scale PV power plants. For example I included the decommissioning time for a 24 MW power plant into the working plan for investors. I contacted investors of already decommissioned PV power plants and asked how much time they needed for each step of the decommissioning process. The investigated investors were customers of TÜV Rheinland. Further I tested PV modules according safety standards. One is the outdoor exposure test and measurement of the temperature coefficients. This test’s purpose is to determine the effects of deterioration under outdoor exposure conditions. TÜV Rheinland checks visual defects, maximum output power, and isolation resistance. After significant temperature variations cycling from -40 degrees to 85 degrees, visible defects are checked and that the module’s isolation is maintained. During an impact test from a 50 kg load the resistance is checked. The Temperature coefficient measurement determines amperage, voltage, and peak power temperature coefficients. This test may be performed under natural lighting or with an insolation simulator.

TUV Rheinland is an independent company that is testing PV modules according to safety and quality standards. Therefore no ethical problems arose from the collaboration with TUV Rheinland.

2. PV waste projection

In 2013 the share of renewables in electricity production in the EU (incl. hydro) was 28%. Sweden produced about 53% of their energy production in renewable technologies. Japan produces about 13% of their energy production with renewables (Enerdata, 2014). The global share of renewables is 22 %. Hydropower has the highest contribution followed by wind and solar energy, last is energy from biomass (Siemens, 2014).

Currently about 90 % of the PV panels sold are based on crystalline silicon cells (c-Si), only roughly 10 % are thin film cells produced with Cupper, Indium, Selenium (CIS) or Cadmium, Telluride (CdTe) techniques.

PV technology

Since 1839, when the French physicist Edmund Becquerel, discovered the photovoltaic effect, PV technology has evolved rapidly (Green, 2002).

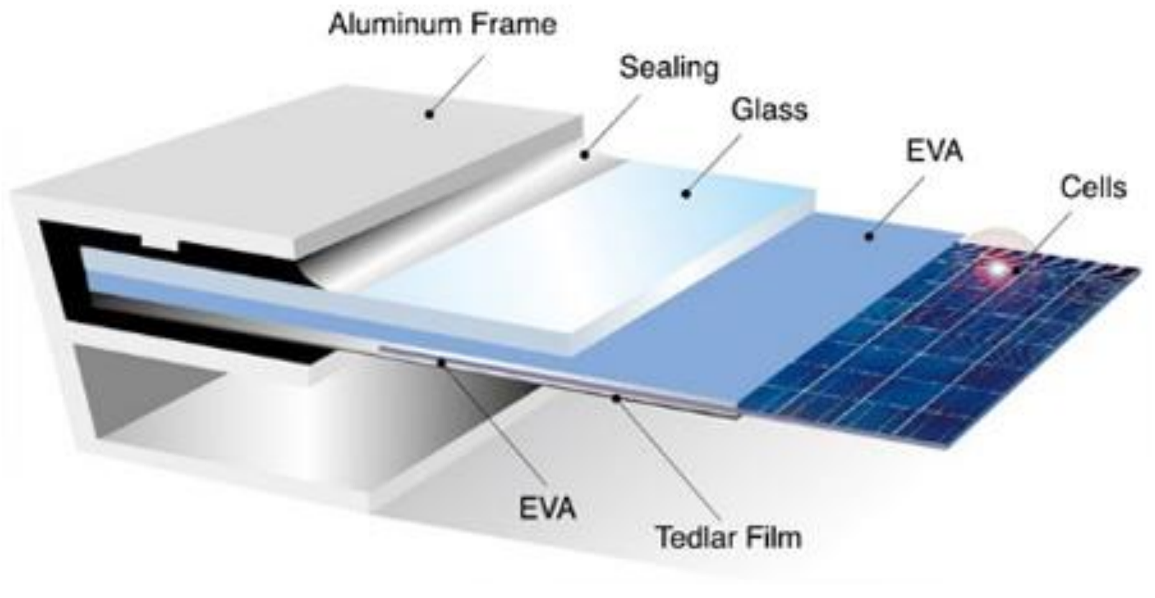


Figure 3: Silicon Solar Cell Structure (RITEK, 2014)

Glass protects the solar cell and its' resin of Ethylene Vinyl Acetate (EVA) from the environment (Appleyard, 2009). The materials used for manufacturing PV modules might differ depending on technology. There is a distinction between first, second and third generation PV modules. Poly and mono crystalline silicon (Si) modules belong to the first generation, whereas thin-film technologies like Cadmium-telluride (CdTe), amorphous (a) and copper-indium-selenide (CIS) modules are considered as second generation. The third generation includes technologies that are not available on a large scale, like concentrator photovoltaic or organic solar cells (Tao et al, 2011).

In general resemble the raw materials contained in PV modules those used in computers.

First Generation Solar Modules

Silicon-based modules do not require any raw materials, which could become scarce in the near future. Electrical contacts in silicon-based cells are made out of metal compounds e.g. aluminium, silver and sometimes lead or cadmium oxide. Silicon accounts for 26 % of the mass of the earth's crust and aluminium is also readily available, only the use of silver may pose problems. Toxic substances in Silicon based cells contain lead in the cell metallization layer and in the solder.

Second Generation Solar Modules

In contrast to first generation modules, in second generation thin-film modules harmful substances and scarce materials are being used. Already during the production process are harmful gases like nitrogen trifluoride (NF3) released to clean the coating systems and residues of this gas can escape into the atmosphere. NF3 is 17.000 times more harmful to the environment than carbon dioxide (Tyagia et al, 2012).

Cadmium has reserves of about 490.000 tons. Compared to that, the tellurium reserves are with only 48.000 tons very low (Tao et al, 2011). Metallic cadmium is found in zinc ores and influenced by the zinc market demands. Tellurium is a semi-metal, extracted mainly as a by-product from copper and lead ores.

Cadmium telluride (CdTe) is a solid material created by the reaction of Cd and Te in gas- or liquid-phase. CdTe is a very stable material evaporating at 1050 ºC and can be dissolved in acidic media. When exposed to atmospheric moisture it may decompose thus being able to react with water and oxygen at elevated temperatures (Alsema, 2007). According to the German hazardous material Bank GESTIS (Gefahrstoffinformationssystem) cadmium is categorized as dangerous waste and it is forbidden to burn materials containing CdTe. Though thin-film manufacturers state that their modules are safe during their life-time. Still the question remains, how to deal with the encapsulated CdTe material in case of module breakage.

Harmful substances like cadmium and lead (Pb, latin=*plumbum)* have the highest environmental and health risk. Lead is a toxic metal that, if ingested causes increased blood pressure, decreased fertility, nerve disorders, and memory or concentration problems. It can dissolve in acid environment occurring in municipal waste landfills. Exposing lead to a pH between 3 and 4 such as nitric acid or acid rain incites harmful substances leaching of lead out of a broken solar module (Monier et al, 2011).

Alternative thin-film modules containing little or no Cd are based on amorphous silicon (a-Si) or copper indium selenide (CIS). Selenium is classified toxic, and has especially when oxidized a poisonous effect, that means it should not be fired. CIS PV production accounts for about half the worldwide indium consumption (Hartleitner, 2011).

In contrast to CIS, in amorphous silicon (a-Si) technology the semi-conductor is applied to materials prepared by deposition from gases that means the atoms show no crystalline structure, but are amorphous, i.e. unordered. The advantage is that the semiconductor can be applied also on flexible and curved materials. A-Si cells contain the lowest amounts of toxic substances, only lead is used in the solder.

Excursus on existing recycling systems

In some countries like Germany there already exists a satisfactory deposit system for beverage cans and pet bottles. Upon purchase a deposit is paid on top of the price, after use the cans can be returned to the location of purchase. The deposit functions as financial incentive, as well as proof that the items instead of being discarded have been correctly recycled. For PV modules a deposit system like that is difficult to establish because the modules first need to be dismantled properly before they can be collected and returned. PV modules are categorized as electronic waste (E-waste) and it is more difficult to dispose E-waste compared to other kinds of waste. In recent years the growing amount of E-waste has led to a dire state of landfills and increased environmental impact arising from disposure of electronic equipment. Also, because the scarceness of materials there is a growing interest in recovering and effectively re-using the valuable resources contained in PV modules. Electronic waste including PV modules is nevertheless disposed to open landfills or simply being shipped to third world countries like Ghana (Lewis, 2010). Much of our trash is immediately hidden from our daily life, which makes it easier for us to forget about it and be wasteful. But in fact the problems are not solved only relocated.

Accumulated waste today

Although most PV manufacturers give 20-year lifetime warranties for their modules, it does not mean that after 20 years the PV module has reached the end of its life. Further, manufactures guarantee that during the lifetime of their solar panels not more than a 20 % drop per panel in the amount of electricity produced will occur. Slow corrosion of the PV modules leads to metallization discoloration, power degradation and degradation of semi-conducting and metallic materials .Modules for example as solar-powered satellites were originally designed to withstand environmental impacts in space (Bailey et al, 2002).

Today most of the originally installed PV modules are still operating, but there are a large number of failure rates due to broken modules. The annual field failure rate of modules that are older than 5 years is estimated to be around 0.1 % (Mani, 2009). Until 2008 a cumulated solar energyproduction of 16.229 MW had been installed worldwide (Photovoltaic Austria Federal Association, 2014), of which16, 23 MW had to be replaced so far. The annual field failure rate on up to 5-year-old modules is said to be 0.005 % (Mani, 2009). From 2008 until 2012, about 85.927 GW had been installed of which 4,3 MW showed failures. In total there have been about 20, 5 MW loss due to field failure rates until 2012.

So there have been 20.500 tons broken modules due to field failures until 2012. On top of that failures during installation, transport and manufacturing needs to be considered. Already during the first steps of installation and transport about 2 % of the PV modules are being damaged.

Until 2012, 102 GW have been produced of which approximately 1GW was lost due to modules damaged during transport and installation. Within the manufacturing process about 0.1 % of the PV modules break (Fraunhofer CSP, 2013). The power of solar modules that had to be discarded because of manufacturing failures accumulated up to102 MW until 2012.

In total there had been a 2.166 MW loss due to failure rates until 2012. This results in globally about 216.600 tons broken modules until today. The weight of PV waste would be that of 200.000 compact cars.

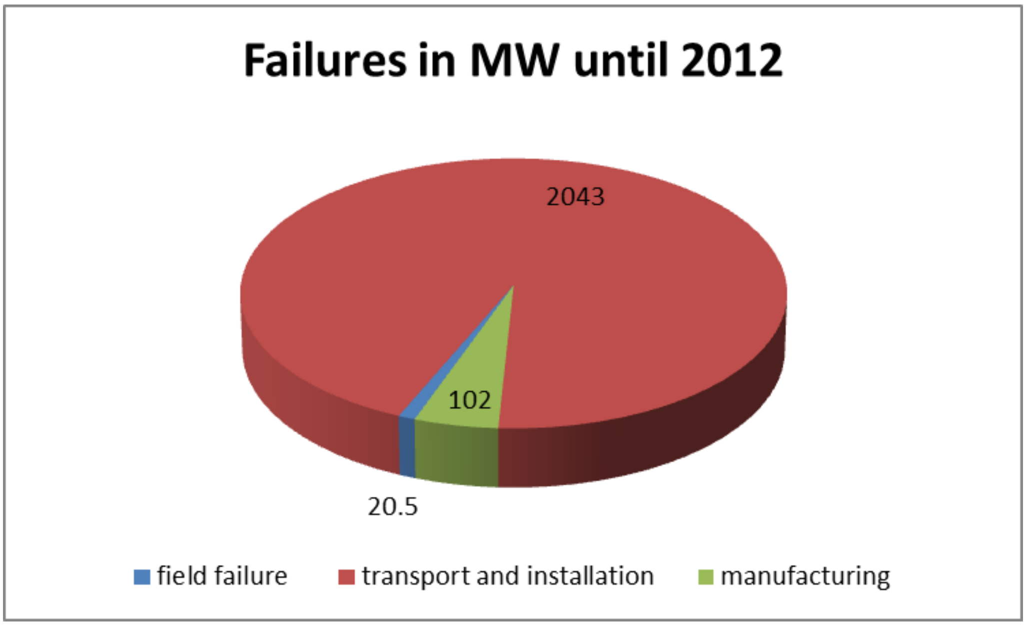


Figure 4: Cumulative energy loss in the EU because of field, manufacturing, transport and installation failures

3. Assemblages

Governmental incentives assemble from diverse elements like institutions, consultants and social groups. This brings together diverse actors like labours, entrepreneurs, scientists and activists. Further diverse objectives, like profit, property, efficiency and sustainability need to be considered. Actors involved in PV waste are those who assemble to address the need of PV waste recycling or the substitution of toxic substances within the PV technology and invest with strategic purpose to produce desired outcomes and avert undesired ones.

Assemblages forge connections between actors and links objectives together (Li, 2007). According to Murray Li assemblages forge alignments in order to link together the objectives of the actors involved like governments, industry and users. Companies involved in consulting, market studies, technical studies, training and project management are supporting the development of photovoltaics. To raise awareness about the topic of life-cycle thinking and waste management among the PV industry workshops were organized and a number of presentations were given at conferences like the Workshop on Life Cycle Analysis and Recycling of Solar Modules within the 19th European Photovoltaic Solar Energy Conference held 2004 in Paris.

Several events where researchers, NGOs and manufacturers meet, are held during the year to promote photovoltaic technology and applications, like the PV Expo in February 2014. Within the European 6th Environment Action Programme the promotion of a strategy on the prevention and recycling of waste were discussed (Wild-Scholten, 2005).

Arguments to ban toxic substances within the PV industry come from NGOs like the Non-Toxic Solar Alliance (NTSA) in Berlin. This NGO was created by researchers and their main demand is the substitution of cadmium in photovoltaics.

German Photovoltaic standards do not develop its own photovoltaic standards but adopts those prepared either by the International Electrotechnical Commission or the European Committee for Electro technical Standardization.

European environmental legislation like the WEEE (waste electrical and electronic equipment) and ROHS (restriction of the use of certain hazardous substances) directives have been implemented in national law.

The European Commission has in December 2008 proposed to recast the Directive on waste electrical and electronic equipment called WEEE. The discussions in the decision procedure and the negative evaluation of an environmental agreement submitted by the photovoltaic industry have shown that the option of including photovoltaic panels in the scope of the WEEE Directive was analysed, in order to provide a solid ground for the discussions between the legislators on this specific issue.

In 2010 The European solar industry started a campaign to exclude photovoltaic solar panels from the recast directive on the restriction of certain hazardous substances (RoHS), which was debated by the EU institutions.

European Photovoltaic Industry Association (EPIA) and PV Cycle said that the PV industry will suffer from policies that have set up for electrical and electronic household appliances (PV Cycle, 2009).

While applying ROHS' directive to PV modules the EU's environmental and energy security cannot be achieved. Further an immediate substitution of materials under this directive might not be available.

Associations and professional organisations such as Bundesverband Solarwirtschaft in Germany, are very active in promoting the PV technology and in organising links with the market and the public authorities. (Durand, 2011)

The revised version of the Waste Electrical and Electronic Equipment Directive (WEEE) was published on 24 July 2012 in the Official Journal of the European Union (Directive 2012/19/EU), following a co-decision procedure between the European Commission, the European Parliament and the Council. These actions can be referred to the theory of assemblages. Today, there are three main actors in the photovoltaic business:

1. Governments: main actors in the PV recycling process,
2. Users: need to be informed how to handle PV waste,
3. Manufacturers: have to compile with legislations on PV recycling.

These players have different incentives how to deal with photovoltaic waste.

Government

A governmental approach should secure that old PV modules do not harm the environment and humans. Therefore advocacy and expert prescription need to be brought into a plausible alignment. European laws are not necessarily in effective possession and need to be guarded on a national level. Governments are the regulators in the photovoltaic industry and have an important role. Most of the current demand is generated by governmental incentives, like the WEEE (Dreimann, 2010). Recycling systems are political projects that affect people's lives in different ways. E-waste recycling is affected by policies of international organizations, like the OECD and the EU. The OECD's Extended Producer Responsibility and the EU's WEEE as well as Restriction of Hazardous Substances Directive (RoHS Directive) and Registration, Evaluation, Authorisation and Restriction of Chemicals called REACH Regulation have a major influence on the formation of E-waste recycling.

From the economic point of view the pure silicon, which can be recaptured from the used cells, is the most important material due to its cost and shortage. But still the economic motivation to recycle most PV modules is unfavourable without appropriate policies.

Eight years ago the European Union Waste Electrical and Electronic Equipment Directive (WEEE) as well as the Restriction of Hazardous Substances Directive (RoHS) came into effect and prohibited the use of lead in consumer electronics made in the EU.

According to the WEEE, electrical and electronic equipment put on the market must not contain lead above a maximum input of 0.1% by weight. Solders without lead are based on tin, copper, silver, bismuth, indium, zinc and traces of other metals. Solders made with Sn-Ag-Cu (Tin-Silver-Copper) are used by 66 % of Japanese manufacturers. The American PV manufacturer, ASE Americas, uses a Pb-free solder in their modules since 1993 (Fthenakis, 2008). In terms of technology, it is possible to completely substitute lead. European Member States are allowed to implement more stringent policies than formulated within the WEEE (Hischier, 2005). Intention is to reduce the disposal to landfill, provide a free producer take-back scheme and to improve product design in order to prevent electronic waste. Further the recoverability, reusability and/or recyclability should increase.

Within the WEEE it stated that consumers have to return their waste equipment free of charge (Savage, 2006). In Germany these places are called „Wertstoffhof".

Theory of WEEE

The WEEE directive responds to a variety of national policies (Savage, 2006).

The countries already having WEEE management schemes in place like Belgium, Denmark and Sweden shaped the WEEE Directive. The WEEE recycling scheme El Kretsen in Sweden, El Retur in Norway and SWICO in Switzerland were role model for the WEEE Directive. Sweden has a recycling rate of 90%, only Switzerland has a higher rate with 97%. The recovery rate in Sweden was 2002 8kg per capita. Within the WEEE Directive countries have to achieve a yearly collecting rate of at least 4 kg per capita and a recycling rate of at least 65% (European Commission, 2006).

Difficulties:

The identification who is responsible for developing and framing the legislation and systems in individual countries was difficult. The responsibilities between industry, the Member State governments and the European Commission are not clearly defined within the directive.

For example the responsibility for achieving the 4 kg target was discussed at a review seminar. Member States argued that it is the producer responsibility whereas industry said it is the responsibility of State governments (Savage, 2006).

Other discussion were about the responsibility for product scope and categorisation. Member states are responsible for the identification of equipment covered by the directive. The Commission's advice, whilst available, is non-binding. Further discussions were about how to track goods and producers moved between Member States. The decision at which point municipalities and retailers have financial and operational responsibility is difficult (European Commission, 2014).

The outcome of the discussions led to two different management systems within the EU: the clearing house management scheme and a collective management scheme.

The collective system is established in many countries that already had a recycling strategy. Here one company is responsible for collection and recycling (Savage, 2006).

The clearing house model is again a national framework in which multiple partners (producers, recyclers, and waste organisations) can provide services. The government ensures that there is a register of producers and defines the allocation mechanisms, and reporting and monitoring systems. Collection of WEEE from Households in Germany provides an example for the clearing house model. Municipalities operate and finance the collection points. A new container for PV modules will be added probably in 2015. Municipalities in Germany may recover collected WEEE themselves. In Germany there is no old for new take back at retailers.

The producer responsibility is proportional to the share of EEE marketed in current year. The Central Register calculates fees based on his waste stream only if the producer provides evidence of his share.

There are pros and cons with both systems. National collective schemes are considered to be simple and most effective route to collecting and recycling WEEE. In smaller countries with low volumes of waste a national clearing house is not profitable. Additionally, the collective system is already established in many countries (Savage, 2006).

The market-based systems does not necessarily provide an incentive for additional environmental or behavioural improvements beyond that stipulated in legislation.

Laws covering PV modules in Germany

Every PV module needs to be registered via the national WEEE registration or the appointment of an authorized representative for each country, and marked with a crossed-out wheelie bin (Labelident, 2010). The symbol identifies the need for separate collection.

The producer is obliged to pay for the disposal operations. Further the customer needs to be informed about the treatment facilities of the product's composition and its disposal. It remains up to each state to punish illegal e-waste exporters. The customer must first de-install the panels in order for them to be classified as a waste product. After that the producer has to bear all of the waste management costs, including transport (Clover, 2014). The manufacturers have to take responsibility for modules recycling according to their market share. Modules from manufacturers that went out of business have to be taken care of still existing manufacturers. Germany implemented the WEEE Directive in the "Act Governing the Sale, Return and Environmentally Sound Disposal of Electrical and Electronic Equipment" also referred to as ElektroG. Module handling must meet the 80 % weight recovery quota. Meaning that out of a 12 kg module 9,6 kg need to be recycled. There is no restriction on what substances have to be recycled. As the main substances used in PV modules is glass and aluminium the recycling quota does not address toxic substances necessarily. Besides the WEEE directive there is the Waste Framework Directive (2008/98/EG) made by the European Parliament and Council together with the EU Act (EG)

Nr.1013/2006 addressing PV-recycling. The waste framework directive gives waste definitions and introduces the polluter pays principle. Furthermore it is required that waste must be treated without harming the environment (Gesetz über das Inverkehrbringen, die Rücknahme und die umweltverträgliche Entsorgung von Elektro- und Elektronikgeräten, 2013).

Restriction of Hazardous Substances (ROHS)

The RoHS directive prohibits hazardous substances used in electronic and electronic equipment. Substances used in PV modules and included in the RoHS are lead (Pb), cadmium (Cd). For cadmium there must be less than 0.01% of the substance by weight. For lead there must be no more than 0.1% of the material, when calculated by weight at raw homogeneous materials. The area of application is the European Union (European Commission, 2006).

Reach: Registration, Evaluation, Authorization and restriction of Chemicals

Manufacturers and importers of chemical substances including PV modules must obtain information on the health and environmental properties of their substances in a registration dossier. The agency checks whether the dossier meets the requirements. The agency hands out authorities to companies that adequately control substances of very high concern (SVHC) like Cadmium and lead (Clover, 2014).

Japan- a comparative model

Language, media messages, institutions, values, and behaviour form cultures. Culture can be described as the characteristics of a group of people defined by their language, religion, cui-sine, social behaviour, music and arts (Hatayama, 2009).

Whether a national character exists is a complicated question because any answer is based on certain assumptions about the nature of nations and identity. Most concepts that nations use are simplistic, like Japanese tend to be polite and Germans organized. Nations are formed by groups of people who identify themselves as a group and belong to a recognizable social subset. A nation is, in large part, an accident of history, language and politics (Tilly, 1975).

Japanese and German differences concerning waste practices depends on different legislations on PV waste.

Japan enacted in 1998 a recycling law for household appliances that forces the industry to recover and recycle used products. Waste in general is divided into industrial and non-industrial categories. E-wastes are recognized as “bulky trash” among non-industrial wastes and need to be disposed at home appliances store. Industrial waste is the responsibility of the waste generator, whereas the consumer is responsible for the municipal waste. A retailer takes responsibility for taking back any of the appliances it sold and for delivering it to its manufacturer, where it is treated. Manufacturers need to meet a recycling quota up to 60 % of their devices. The law governing the recycling of home appliances was launched 2001.

Used products are collected by municipalities and retailers. The system is financed by fees, a mechanism not often used by producer responsibility-oriented policies and programs in Europe. Consumer pays for discharging waste roughly 20 Euro for a television or 35 Euro for refrigerator. First televisions, air conditioners, refrigerators, and washing machines were covered by Japanese law but was extended to personal computers and copiers on a voluntary basis. Until today PV modules are not covered by this law. However, Japanese association of PV system judgment started the service to collect Photovoltaic Modules in January, 2014. The association collects 8 Euros (1,200 yen) per one piece of Photovoltaic Module (Yamamoto, 2014). Retailers, local government and organisations like AEHA that collect electronic equipments are obligated to transport the collected materials to consolidation centres operated by two manufacturer consortia. One group included Electrolux, GE, Matsushita and Toshiba. The second group is run by Daewoo, Sony, Sanyo Hitachi and Sharp. There a few collection systems provided by local governments that charge higher fees than those charged by retailers (European Commission, 2006).

There are recycling companies for metals and electronic materials in Japan like Daewa that recycle Photovoltaic modules. As for now, the recycling methods are not well established within the solar industry. PV modules are crashed into pieces and landfilled (Hayashi, 2014).

Japan does not allow CdTe in batteries. There are exceptions to solar panels in Japan. CdTe modules are allowed as long as manufacturers guarantee for its' disposal. For crystalline modules the recycle responsibility rests on the owner of PV modules.

The most important disadvantage of this system is illegal dumping and export. About half of the post-consumer use home appliances discharged by households have been discarded at landfill sites without proper treatment. Already an illegal dumping hotline has been established (Y. Matsufuji et al, 2005).

Differences- Japan/EU

Japanese WEEE Take-back System is a Consumer/Retailer based system, whereas Europe has two models: a collective and a clearinghouse model.

In Japan consumers pay an end of life fee to the retailer to finance the product disposal and treatment. The retailer passes the equipment on to one of two industry consortia who are responsible for the collective management of WEEE in the specified categories. The 200 consolidation and bulking centres are private. Retailers and local government can provide electric waste from the retailer. There are about 12 treatment centres for each consortium that is specialised in an electronic waste group (Savage, 2006).

Old appliances can be returned while purchasing a new item. AEHA operates in areas with no retailer services (Savage, 2006). The Japanese pre-treatment fee creates an economic incentive to increase reuse and develop product lifespan. But it also encourages illegal dumping.

The early adoption of mandatory recycling targets in Japan has encouraged higher recycling and recovery rates in Japan than in Sweden. But higher collection rates have been achieved within the collective scheme.

Europe collects more waste than Japan (Savage, 2006). Market intervention is regarded a policy alternative in some countries (Japan, EU) whereas legislation in other areas (US) might be influenced by a value system that promotes deregulation.

The consumer in collective scheme like Sweden can return his old product to the retailer on purchase of similar product or he leaves WEEE at municipal collection points. In Japan the user is responsible for return of WEEE to retailers and hast to pay Pre-Treatment fee and transportation fee. Whereas in Sweden the retailer has to accept WEEE under the new for old rule, Japanese retailers are obligated to accept designated WEEE and to transfer WEEE to Producer bulk collection points. The retailer can pass charge on to the consumer. In the collective scheme the producer has to cover the collection and treatment costs of WEEE while meeting environmental targets. The producer further hast to provide information to households. The producer in Japan are obliged to take back products at bulk collection points from retailers and have to achieve recycling targets under Japanese legislation.

Municipalities in Sweden must manage collection points for household consumers. In Japan municipalities can transfer WEEE to producer bulk collection points by paying fee. Municipalities may charge consumers and can treat WEEEE themselves.

Figure 5: TUV Rheinland booth on the PV Expo

Photographer: Agathe Auer

Manufacturers

Manufacturers are dependent on the overall demand for solar PV products. They develop and apply technologies. Therefore future innovation concerning photovoltaic recycling is most likely to be done by manufacturers. Suppliers to manufacturers (equipment and raw materials) can also act as technology provider. They can shape the industry in times of undersupply of materials (Dreimann, 2010).

During the PV Expo held in Tokyo from the 26th to the 28th February 2014 twenty manufacturers were asked about their position towards PV recycling, five manufacturers were also willing to answer a short questionnaire (Appendices 1-2). The figure below shows the statically summary of the key questions.

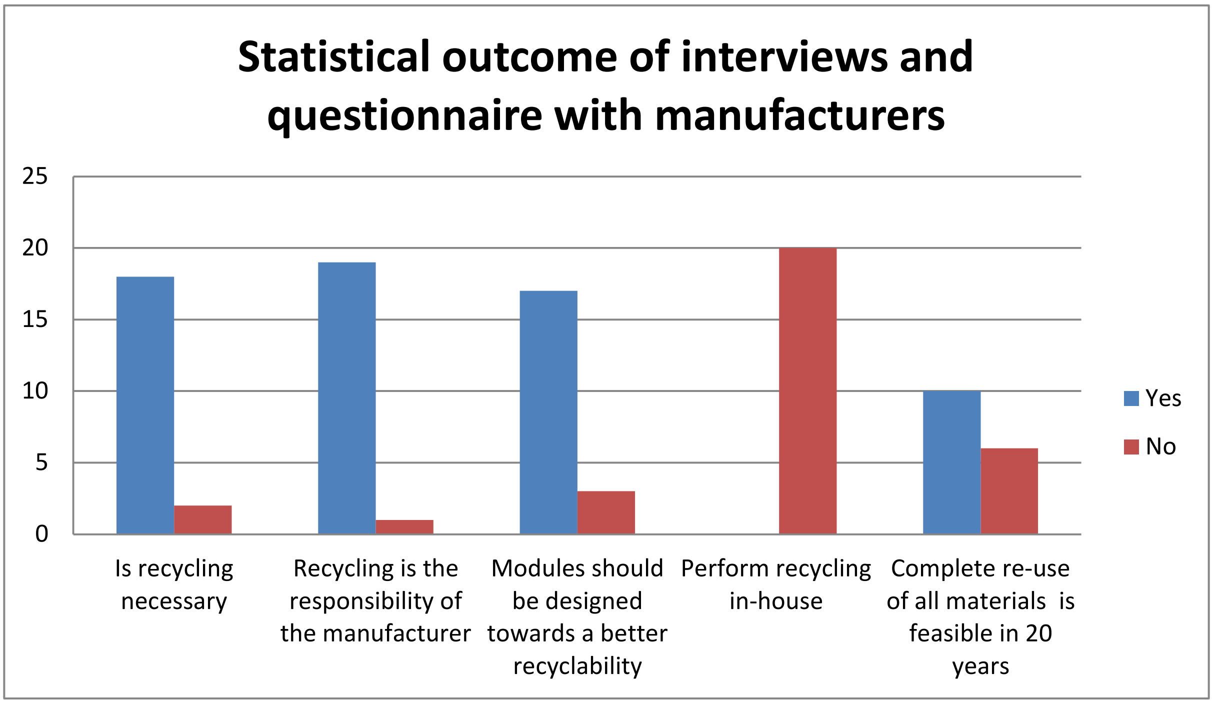


Figure 6: Statistical summary of key questions answered by 20 manufacturers. The output is based on interviews and questionnaires.

The main impression was that manufacturers consider recycling as ecologically necessary. Furthermore they agreed that specialized recycling companies should handle PV waste instead of treating the old devices in their manufacturing facilities.

The main motivation for recycling is the lower energy input compared to processing raw materials. 90 % claimed that the recycling should be the responsibility of the manufacturer. This leads to the impression that manufacturers want to be entitled to manage the encapsulated materials. Further the manufacturer stated that modules should be designed towards a better recyclability. The development towards a higher recyclability safeguards that the materials can be reached and reused again. Sixteen out of twenty said that recycling is necessary because it is less energy intensive than processing raw materials. Six out of twenty said that recycling is beneficial because it helps to stop the reduction of raw materials. Four out of twenty manufacturers stated that recycling is beneficial because it improves the company's image. Until today the recyclability of photovoltaic modules is not

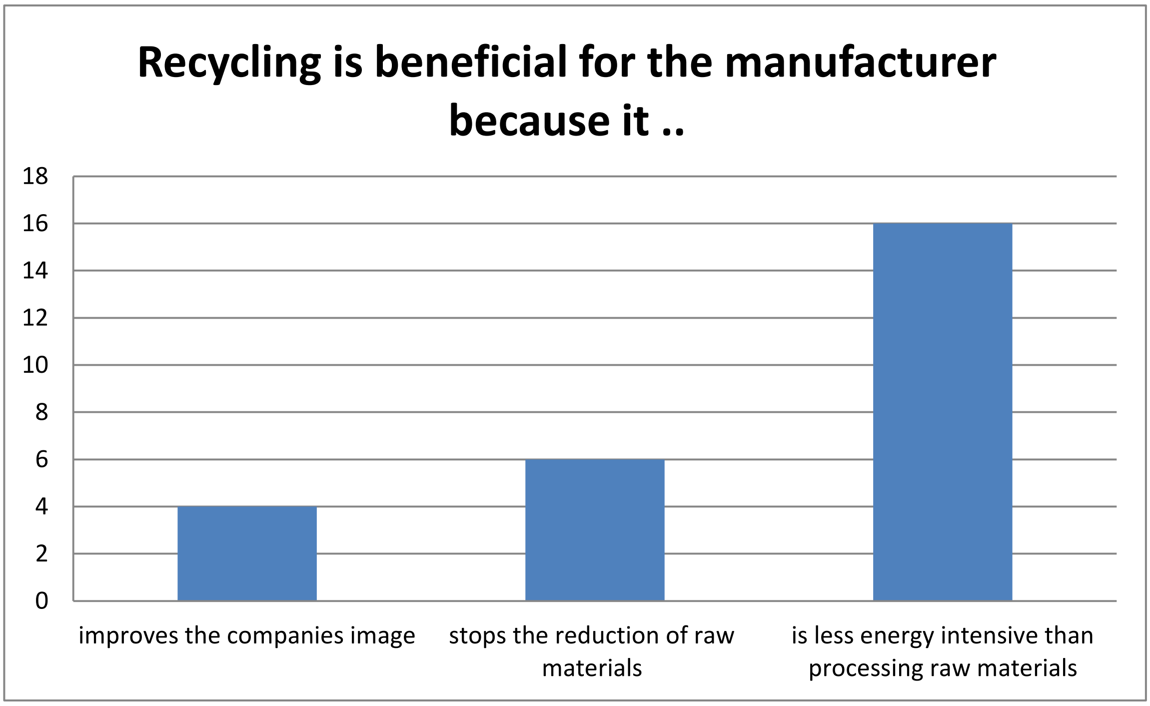


Figure 7: Main motivations for the manufacturers to recycle PV modules. The output is based on interviews and questionnaires.

considered in the purchasing decision of photovoltaic customers. Only two manufacturers stated that they do not consider recycling as necessary because they do not see any economic benefit in it today.

In 2007 European PV producer created the PV-Cycle which built up recycling plants (Kaesler, 2013). PV-Cycle maps modules discarded by the end user or damaged during transport or installation. Collected modules from PV-Cycle are re-melted in Belgium to black glass. Companies like Maltha or Reiling are in charge of the melting process (Reiling, 2012). In 2011 PV-Cycle collected 1 500 tons of modules. As comparison: in Europe the number of sold modules was 1 400 000 tons in 2011. Until 2012 modules treated by PV Cycle has been so far 9 200 tons. Only 1% is said to be from modules that have reached the end of their life (Kaesler, 2013).

Also manufacturers outside the EU have built up recycling facilities. Until today recycling processes on a big scale exist for Crystalline and Cadmium-Telluride modules. For the recycling process of crystalline silicon panels the Deutsche Solar’s treatment is operating and for the treatment of cadmium telluride panels First Solar’ procedure is used. Deutsche Solar is operating since 2003 with factories only in Germany. First Solar has factories in Germany, US and Malaysia and are recycling PV waste from their own manufacturing scrap since 2003. First Solar includes contact information for recycling on the back of each PV module. Recycling PV modules is already a business.

The American organization Silicon Valley Toxics Coalition (SVTC) lists manufacturers with a view on their recyclability and sustainability (Barber, 2013). In 2013 most sustainable manufacturers were Trina Solar, Yingli and Sun Power. First Solar was number five. In order to achieve the highest score 95 % of the PV module needs to be upcycled. For recycling none of the manufacturer got the highest points (Silicon Valley Toxics Coalition, 2013). One reason why manufacturers do not consider recycling strategies in their manufacturing process is uncertainty within the PV market. Whether a future generation of photovoltaic modules could be completely recycled stays unclear. Only ten manufacturers believe that a complete re-use of all materials is feasible wihin the next 20 years. Until today there have been 1627 PV manufacturers worldwide. As comparison: there have been 2500 manufacturers for the car industry. PV business is changing rapidly and manufacturers do not know whether they survive on the market in order to recycle their end-of-life modules.

How do manufacturers and users react on governmental decisions?

Manufacturers and banks invest in large photovoltaic power plants to feed their produced electricity into the public grid and receive the feed-in-tariffs.Utility-scale power producers usually have a purely economic interest and are mainly driven by economic aspects.

These power plants will be decommissioned after 20 years of the installation, when the subvention scheme ends. Within the EU high amounts of decommissioned solar modules will be available from 2020 onwards.

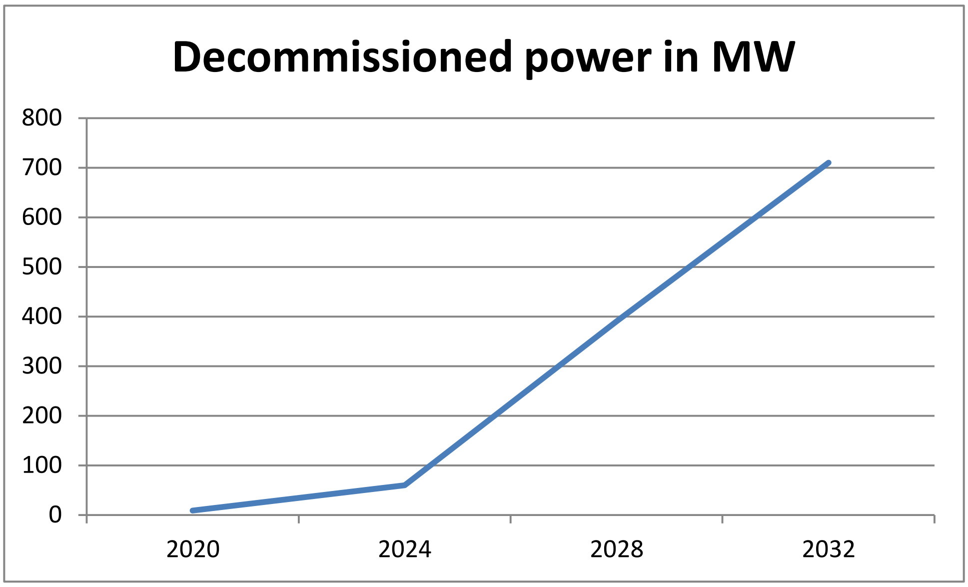


Figure 8: Power of decommissioned PV modules in the EU from 2020 to 2032

Investors consider old PV modules that have exceeded the warranty time as worthless. After the modules are decommissioned they do not have any practical value for the owner. If the power plant is situated in the European Union, the manufacturer needs to take care of transport and recycling in the near future. In Japan only the decommissioned thin film modules are in the responsibility of the manufacturer.

For private owners used solar panels are a bargain, unless they are not totally damaged. PV modules are labeled as worthless if they do not generate energy anymore. Owners of old or not entirely broken modules do not consider them to be worthless. Parts of the modules are put into existing systems with a broken component (Diermann, 2013).On the Expo in February 2014 ten owners of PV modules were asked whether they consider the recyclability during their purchase decision. All of them denied. If their module is broken and cannot be repaired they rather look if they can reuse some part of it instead of throwing it out. The first

1 MW solar park was built by Atlantic Richfield Oil Company at Lugo near Hesperia, California at the end of 1982. Another power plant followed in 1984 with 5.2 MW in Carrizo Plain. Both have since been decommissioned and were sold on the second market for used PV modules. These modules were included in small domestic applications. The largest solar parks currently operating have capacities of 250 MW is First Solar's Agua Caliente plant in South-West Arizona (Jordan, 2012).

There is a second-hand market for PV modules and inverters.Repair and resell companies like “SecondSol” or “Milk the sun GmbH” are emerging. These platforms allow investors to view the income, size and Feed-in-Tariff (FiT) rates of global projects. Benefits include lower risks associated with construction of the PV power plant. Looking at the cut of feed-in tariffs it is more likely that existing power plants receive higher subsidies (Krause, 2013).If the PV plant is transferred, the original warranty will be continued. If the plant is de-constructed and the modules are re-constructed elsewherethe warranty usually does not continue.

Second Sol owner Frank Fiedler states that on his platform modules are traded with an average age of 4 years (Fiedler, 2014). Other options to buy and sell used modules are internet platforms like eBay or magazines and newspapers.

PV second market mainly consists of three sectors.

1. Refund modules for failures, burglary and outfall.

   After one year of the last product release of one manufacturer particularly none of these modules can be bought on the first market. The second market offers modules in this case. In the EU already 20-30 MW have been sold.

2. Modules for repowering. This includes repaired and second choice modules. In the EU the market volume is about 100-150 MW today.

3. Vending of modules from company insolvencies. This market has a volume of 10 MW (Fiedler, 2014).

Reusing is already well established within residential power plant owners. PV modules or parts of it are used again to generate energy. A whole business to prepare PV modules for its reuse has been set up. Here the modules are checked, cleaned or repaired in order to be reused again.

4. Practical insights at the planning of a PV power plant

Also during the establishing of PV power plants the decommissioning should be thought through. Within Gantt charts tasks are displayed against time. This allows seeing what the various activities are and when each activity begins or ends. The Gantt Charts used are provided by TUV Rheinland and show every action from designing the plant to the approval. In this study case six Gantt Charts of PV power plants with up to 24 GW have been investigated to set up the average times for designing the power plant, land preparation, mechanical assembly, modules, test phase and approval (Appendix 3 on enclosed CD). Land preparation is the most time consuming with 18 weeks. It includes preliminary works like the

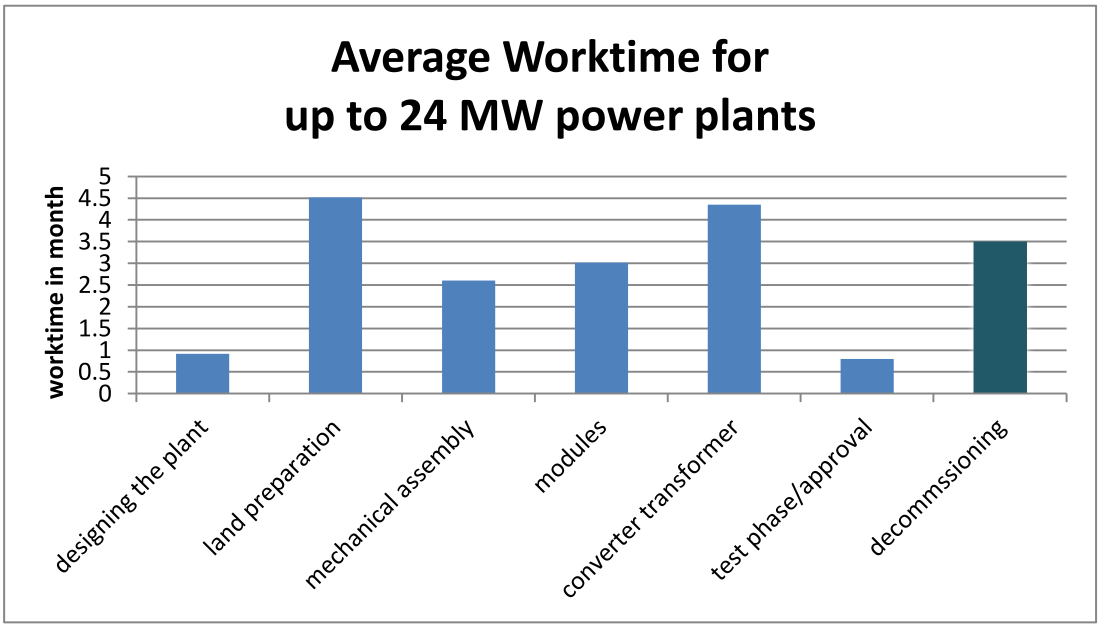


Figure 9: Average work time in Japan

setup of fences and land clearing but also civil works from earthworks, roads, trenches to structure erection. The second most time consuming part in building a PV power plant is referred to converter transformer. Mechanical assembly need 10 weeks and includes the structure supply on site and assembly, wiring and grounding network. Tasks belonging to modules and involving their assembly, connection and on site supply take three months. Test phase and approval take about three weeks and the design of a power plant needs almost one month. None of the provided Gantt charts included decommissioning in the time line.

If the decommissioning is already considered during the design of the power plant, special material can be used in order to recycle them after the life-time. This can include the use of ground screws instead of concrete foundation in order to avoid ground contamination (SAN DIEGO GAS & ELECTRIC, 2012).

The decommissioning proceeds in reverse order of the installation. First PV facilities need to be disconnected from the utility power grid. Modules should be collected and given to recycling companies.

Electrical interconnection cables need to be removed and recycled. Aluminum racking and electrical devices like transformers and inverters also need to be removed and recycled. Fences and concrete foundations should be removed and treated by recyclers(Belectric, 2011).

The project site can be either restored to its original condition or to other uses.This includes mainly site repairs and seeding. In the US detailed decommissioning plans have been undertaken stating that for a 20 MW power plant the decommissioning time is about 100 working days or 3.5 months (REFERGY, 2012). Many steps can be undertaken side by side and reduce the duration.

According to the Japanese recycling company “Nextenergy” the cost of dismantling is roughly half the construction expense. While considering the decommissioning during the establishment of PV power plant these costs can be reduced.

5. Recycling processes

Todays' technology can recycle about 80 % of the PV module in terms of its weight. The first step is the disassembly of the aluminium frame and junction box which is done manually (Arranz, 2013).

Crystalline modules

The table below shows recycling treatments that are used by recycling companies and manufacturers.

Treatments for crystalline cells		Companies using this treatment
Physical/Mechanical	Shredding	PV cycle
Chemical	Etching	Sharp, BP Solar,
Thermal	Pyrolysis	Deutsche Solar AG, First Solar
	Melting	
	Combustion	

Table 1: Recycling treatments for crystalline cells

Down-cycling

Down-cycling is a form of recycling in which waste materials are converted into lower value forms than the original materials were used. Materials are down-cycled because of material degradation or contamination.

Especially the flat glass recycling industry treat old PV modules as they mainly consists of glass. To reintroduce the material into the flat glass recycling process three steps are necessary:

1. Pre-processing

2. Shredding

3. Processing in the flat glass recycling line

First junction box and frame are removed.The silicon cell is embodied in a layer of EVA polymer that enables the cell to be laminated to the polymer back as well as the glass front sheet. The broken PV cell is fed to the glass recycling line.Here the cell is manually pre-sorted and the laminates are crushed off.

Ferro particles are still mixed with the glass and disturb the glass recycling process. The glass resulting from PV modules has to be mixed with standard glass to be reintroduced in the glass industry (Hartleitner, 2011).

Upcycling

Upcycle refers to the process where materials are reintroduced to the original production chain. There are already modules on the market which are made from recycled materials.

Research to recover the intact silicon wafer includes thermal and chemical methods.The solar cell array lays sandwiched between an ethylene vinyl acetate (EVA) and back film. These materials can be removed thermally. The EVA and back films evaporate within this process.Hereafter80 % of the cells are mechanically intact. After removing the EVA and back film the cells can be separated and processed. Disadvantage of this process is the emission released to the air.

The solar cell is then subjected to various etching steps to remove the metal contacts, the anti-reflection coating and diffusion layers.

Another approach is the liberation of the laminate components by chemical dissolution of the EVA. Disadvantage of the chemical treatment is that a high amount of chemicals remains to be disposed after the process.

After the evaporation or dissolution of the EVA, the silicon solar cellneeds to be purified. Here the remaining layers (antireflection, metallizationlayer) are removed. It is possible to recover the silicon substrate suitable for reuse. Stage surface cleaning of silicon PV cells is carried out using chemical (potassium hydroxide solution) or laser techniques.

Non silicon based PV modules

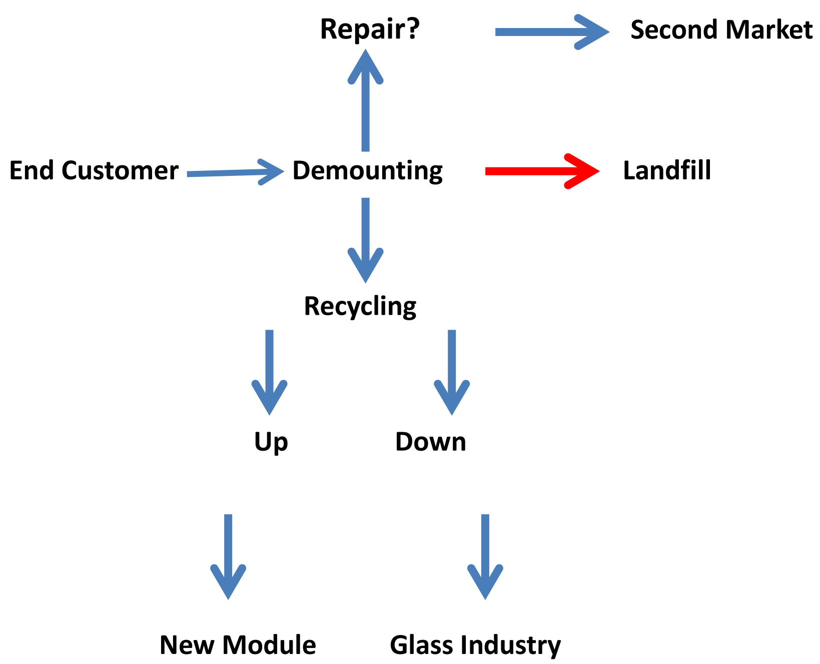
First Solar is currently recycling their CdTe PV modules. The recycling process starts crushing the module. This recycling process is designed to recycle 90 % of glass and 95 % of the semiconductor material contained.

After the shredding the material needs to be solubilized in a chemical bath (hydrogen peroxide, acid sulfur) to liquefy the coating. Than the detaching is taking place for the separation of liquefied coating and other material like glass. The next step is the sorting of the materials in a vibration filter. Here the solid materials like EVA/Glass are separated from the liquid containing the metal. The EVA is deposited and collected. Glass falls through the screen to a chute andis cleaned. After the rinsing of the glass it iscollected into containers for recycling.

The metal compounds are precipitated in three stages with increasing pH. Sodium hydroxide is added in this process. The solids settle and form a metal rich filter cake. This filter cake is sent off for processing by a third party. The cake is processed to semiconductor grade raw materials and can be used in new solar modules (focus, 2009).Disadvantages within the recycling of thin film modules are contaminated sand and toxic dust during the process.

The recycling needs less energy than the production of primary materials. Furthermore emissions are cut down compared to the primary production (Mehta, 2013).The production of a new module with 72 silicon wafers has an energy demand of 306 kWh, whereas the recycling of this module needs 92 kWh (Müller et al, 2006). Rising energy cost also contribute to a recycling revolution.

In general a PV module can either be repaired or directly sold on the second market. If the module cannot be repaired, it should be recycled. A module can be either upcycled to become a new module out of recycled materials or down cycled in the glass factory. Another opportunity for an old module is to be shift abroad in landfills.PV modules are commercially available since 1970 but 2001 significant installation started. A large number of modules will come to the end of their life in 2020. A PV module has a life expectance of 50 years.



Design for recycling

A recycling strategy already starts during the design of a PV module. The end of life of the product should already be considered when developing or enhancing a PV module(Fischer et al, 2012). It should be ensured that materials can be recycled (Gómez et al, 2011). In

Japan, researchers try to change the design of the wafer to ensure a better recyclability. Since today there has been no technical realization. The idea is to include a protective layer in order to ensure a better removal of the solar cell. The problem of this research project is that the protective layer increases the light reflection and therefore decreases the efficiency.

Further improvements in technology towards a more eco-friendly design include thinner wafers for the c-Si-modules (Sander, 2007). Technology concepts where no lamination is necessary, like the “New Industrial solar Cell Encapsulation” (NICE) technology facilitate recycling of the silicon wafers (Alsema, 2007).

In the NICE technology the EVA is replaced bya vacuum. Air and humidity tight sealing around module perimeter make EVA unnecessary. The module interior is under pressure to create an electrical contact between cell contacts and metal connectors without using solder(Appleyard, 2009).

6. Discussion and future prospects

Since the "*United Nations Conference on Environment and Development*" which took place in Rio de Janeiro in 1992 sustainability became an ideal for governments to face environmental and economic matters (Luhmann, 2010). The conference emphasized the interconnectedness of economic, social and ecological processes (Bärtschi, 2012). A PV recycling process describes one relationship between society and environment. The PV recycling process is an assemblage of entities that address the need of PV recycling or the substitution of toxic materials used in PV technology. The word "assemblage" covers all real entities, including humans like PV owners, materials like silver, cadmium, lead, glass, the PV markets and nation states. Organic and inorganic entities shift freely in and out of assemblages.

Within 30 years the capacity of installed modules grew by a factor of 5000, which turned the PV industry from a niche product to an international business especially in Europe and Japan. Today most of the originally installed PV modules are still operating and the question remains when these amounts of PV systems will lose their value and turn into waste.

Utility scale owners outside the European Union do not see any value in their decommissioned devices. To find a solution that inhibits the shipping to landfills, contracts with recycling industry or glass manufacturers are interesting. Another sub purchaser can be the second market.

Until today old and broken modules are a merit to residential owners. The owner of used modules has adopted the repair, reuse and recycle hierarchy. Reusing and repairing broken modules is already a business with many repair and resell companies over the world. The motivation behind this second market is less cost compared to purchasing new items. Reusing and repairing is an effective plan of action for waste management practices. It minimizes waste as well as conserves natural resources while extracting the most out of already produced goods. The value of a PV system decreases each time it is sold: first from the manufacturer to the first user and afterwards it is traded on the second market until it no longer appeals to any buyer and becomes rubbish. If this PV waste is not destroyed but recycled, valuable materials like aluminium, cadmium and silver can be reintroduced into the manufacturing process.

How can PV waste become durable again? If the manufacturing process of a PV module would be restricted due to scarce materials used, the encapsulated materials would be goods with high value. Until today the manufacturing process is not limited by scarce materials.

To get to the encapsulated materials the state of the art recycling process needs to be ameliorated. An idea would be also to establish a PV system with eco-design so that modules can be easily dismantled.

If PV waste is not disposed properly the following negative impacts on the environment and human health can occur:

1. lead and cadmium leakage
2. loss of resources like aluminium and glass
3. loss of materials like indium, gallium, germanium and silver.

Owners were asked whether they consider the recyclability in their purchasing decision. Currently negative impacts on the environment and human health due improper waste treatments are not considered in the stakeholders' decision making.

Industry has its own strategies and practices to solve environmental problems: they reduce the ecological problem to its price and goods with no price cannot be treated (Festenberg, 1986). Manufacturers were investigated while conducting a questionnaire to get to know what profit they see in introducing a recycling strategy. According to 4 of the 20 manufacturers on the Japanese market that have been interviewed the integration of a recycling strategy could improve their image, if the recyclability is considered during the purchasing decision of PV owners. The idea to include the decommissioning time into Gantt Charts might evoke that PV modules will come to the end of their life. This could influence the purchasing decision of future PV owners.

An economic bottleneck is that recycling techniques where the silicon cell can used again cost more.

Science, according to Luhmann investigates the ecological problems without relieving the responsibilities to take the decisions and despite new technologies might have harmful side effects. The most common waste treatment methods for silicon PV recycling is the shredder process or the incineration in a municipal waste plant. During waste combustion not all materials or emissions can be saved and therefore a high ecological pressure is the result. Therefore the current recycling strategy poses harmful side effects.

Politics are responsible for the selection of environmental regulations and depend on the government and its opposition. Therefore they have to take many opinions into account and need to consider the consequences and side effects.

Governmental incentives assemble from diverse elements like institutions, consultants and social groups. This brings together diverse actors like labours, entrepreneurs, scientists and activists. Further diverse objectives, like profit, property, efficiency and sustainability need to be considered. Currently, the main driver for the recycling of photovoltaic waste in the EU is the pressure of regulatory factors.

A social bottleneck is that the WEEE directive responds to different national situations and philosophies. Therefore there are two different management systems within the EU: the clearing house management scheme and a collective management scheme. There are pros and cons with both systems. National collective schemes are considered to be simple and most effective route to collecting and recycling WEEE. Producers who support collective models identify the additional costs of managing a national clearing house, separate collection containers, extra logistics etc. and point to economies of scale of the collective approach, especially in small countries where volumes cannot create a viable market for multiple systems.

Collective systems are “tried and tested” and represent the only approach that has so far been shown to work in practice. The collective scheme does not encourage cost reduction (Savage, 2006).

Another bottleneck is that the WEEE directive frames the recycling targets in terms of the product's weight. Cadmium and telluride have high impacts on the environment but show a low contribution to the products weight. The Government as subsystem does not provide any incentive to fully subsidize toxic materials. Therefore another approach in terms of the environmental impact is more ecological.

The main difference within the Japanese and the German e-waste policy is the pre-treatment and transportation fee in Japan. Through this fee, reusing but also illegal dumping is increased (Savage, 2006).

Convenience of a waste collection and recycling program is one of the most important non-socioeconomic determinants in whether an individual will recycle. Laws covering the collection costs increase the convenience as the consumer does not have to look for the cheapest acceptor.

European Member States collect more e-waste than elsewhere. National WEEE legislation, differ in terms of the scope of products covered and the range of instruments used.

That society forms and changes nature is the concept of sustainable development. According to Luhmann the main failure to achieve sustainability is caused by autonomously acting subsystems.

While referring Lehmann's system theory to the ideal of sustainability, it is the ecological fear that disturbs the system rather than humans mitigating and preventing climate change. Looking at PV, a rather new technology with few amounts of waste there has been not much pressure to deal with its waste. Further the state of the art manufacturing process is not limited by scarce materials.

Instead, there are physical objects like materials used in the PV module, events like conferences, but also signs like the crossed out wheel bin, utterances like the one that PV modules harm the environment if they are landfilled without proper treatment and bodies like the European Commission. Therefore human beings are not one of the subsystems of society but instead a special agent that defines and controls sustainability.

Waste management is a process set within a wider framework of social, political and legislative structures and, therefore, needs to be considered in these contexts.
Any successful waste strategy must be inclusive, fully integrated with economic and social practices, and incorporate all sectors of society. This means that a wide range of social groups and actors must be actively involved.

In conclusion through establishing a recycling process for Photovoltaic modules actors like Users, Governments and Manufacturers, but also things like materials used for PV modules, utterances from scientists and activists assemble in order to reduce the negative effects of PV waste disposal. Actors within the PV recycling process are closely interwoven and do not act autonomously.

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Bibliography

Fischer et al. (2012). *Photovoltaikmodule – Umweltfreundlichkeit und.* Stuttgart: Ministerium für Umwelt, Klima und Energiewirtschaft Baden Württemberg.

Tao et al. (2011). *Natural Resource Limitations to Terawatt Solar Cell Deployment.* Arlington: University of Texas.

Ackermann, F. (1997). *Why do we recycle.* Washington: Island Press.

Alsema. (2007). REDUCTION OF THE ENVIRONMENTAL IMPACTS IN CRYSTALLINE SILICON MODULE MANUFACTURING. *22nd European Photovoltaic Solar Energy Conference* (S. 829-836). Milano: Energy research Centre of the Netherlands ECN.

Appadurai. (1986). *The Social Life of Things: Commodities in Cultural Perspective.*

Appleyard, D. (22. 4 2009). *Renewable Energy World*. Abgerufen am 24. 4 2014 von Light Cycle: http://www.renewableenergyworld.com/rea/news/article/2009/04/light-cycle-recycling-pv-materials

Arranz, P. A. (2013). PV SYSTEMS WITH LOWER ENVIRONMENTAL IMPACT: NEW STRATEGIES AND ANALYSIS TOOL . *6BV.8.2.* Paris, France: 28th European Photovoltaic Solar Energy Conference and Exhibition.

Augistine, S. M. (20. July 2014). Living in a Post-Coding World: Analysis as Assemblage. *Qualitative Inquiry* , S. 747-753.

Baecker, D. (2006). Zu viel Kausalität, zu wenig Resonanz? Becks Risikogesellschaft undLuhmanns Ökologische Kommunikation. In *politische oekologie 100* (S. 41–45). oekom.

Bailey et al. (2002). *Space Solar Cells and Arrays.* Rochester: NASA.

Barber, D. (15. 3 2013). *The Emerging PV Module Recycling Market*. Abgerufen am 20. 2 2014 von Energy Trend: http://pv.energytrend.com/research/EnergyTrend_PV_20120315.html

Barles. (2006). *History of wastemanagement and the social and the cultural representations of waste.* Champs-sur-Marne: Institut Francais d'Urbanisme.

Bärtschi, R. (2012). *Nachhaltige Entwicklung in der Schweiz.* Bern: Interdepartementaler Ausschuss Nachhaltige Entwicklung (IDANE).

BBC. (2014). *BBC*. Abgerufen am 14. 5 2014 von Primary History Second World War: http://www.bbc.co.uk/schools/primaryhistory/world_war2/the_war_effort/

Beck, U. (1986). *Risikogesellschaft. Auf dem Weg in eine andere Moderne.* Frankfurt a.M.: Suhrkamp.

Belectric. (2011). *Decommissioning Plan.* Sacramento: Sacramento County Department of Planning and Community Development.

BLANCO, R. M. (11. November 2009). Environmental Awareness and paper recycling. *CELLULOSE CHEMISTRY AND TECHNOLOGY*, S. 431-449.

Burgess, C. (2009). The illusion of homogenous Japan. *The Asia Pacific Journal*.

Chung, S.-W. (2008). *A Comparative Study of E-waste Recycling Systems.* Tokyo.

Clover, I. (2014). Regulations in recycling. *PV magazine*, 38-41.

Cooper, T. (11 2008). Challenging the 'refuse revolution': war, waste and the rediscovery of recycling, 1900–50*. *Historical Research*, S. 710–731.

DeLanda, M. (2006). *A New Philosophy of Society: Assemblage Theory and Social Complexity.* Hampshire: Ashford Colour Press.

Diermann, R. (1 2013). *PV magazine-Deutschland*. Abgerufen am 8. 4 2014 von Senioren unter Strom: http://www.pv-magazine.de/index.php?id=85&tx_ttnews%5Btt_news%5D=9966&tx_ttnews%5BbackCat%5D=226&tx_ttnews%5BbackPid%5D=86&cHash=8e582fccf5709ab449436119bded0064#ixzz2yBjUS9LI

Dreimann, M. (2010). *Solar Power: Managing Uncertainty of Emerging Technologies.* Pennsylvania : The Wharton School.

Enerdata. (10. November 2014). *Share of renewables in electricity production*. Von Global Energy Statistic: http://yearbook.enerdata.net/#renewable-in-electricity-production-share-by-region.html abgerufen

Festenberg, N. v. (1986). EinTheoretiker der neuen Göttin Angst. *Der Spiegel*, 111-117.

Fiedler, F. (15. 4 2014). second sol. (A. Auer, Interviewer)

focus. (7 2009). End-of-life PV. *renewable energy focus*, S. 48-53.

Foddy, W. (1993). *Constructing Questions for Interviews and Questionnaires.* Cambridge: Cambridge University Press.

Fraunhofer CSP. (2013). *TECHNOLOGIEN | BEWERTUNG | DIAGNOSTIK | CHARAKTERISIERUNG.* Fraunhofer Institut .

Fraunhofer Institut IBP. (2012). *LCA screening of a recycling process for silicon based PV modules.* stuttgart: Fraunhofer Institut.

Fthenakis, V. (2008). *Lead-Free Solder Technology Transfer from ASE Americas.* Upton: The National Photovoltaic Environmental Assistance Center.

Gómez et al. (2011). *SUSTAINABLE INDUSTRY SOLUTION FOR THE END-OF-LIFE PV MODULES.* Hamburg, Germant: 26th European Photovoltaic Solar Energy Conference and Exhibition.

Green, M. A. (2002). Photovoltaic principles. *Physica E*, S. 11-17.

Häberli, R. (2002). *Vision Lebensqualität: Nachhaltige Entwicklung.* Zürich: vdf Hochschulverlag.

Hahne et al. (2 2010). *BINE.* Karlsruhe: FIZ. Abgerufen am 24. 2 2014 von Recycling von Photovoltaik Modulen: http://www.bine.info/fileadmin/content/Publikationen/Projekt-Infos/2010/Projektinfo_02-2010/projekt_0210_internetx.pdf

Hartleitner, B. (21. 4 2011). End of Life Management: Recycling von Solarmodulen. (B. Mueller, Interviewer)

Hayashi, T. (24. 2 2014). DOWA PV recycling company in Japan. (A. Auer, Interviewer)

Hischier, R. (July 2005). Does WEEE recycling make sense from an environmental perspective?: The environmental impacts of the Swiss take-back and recycling systems for waste electrical and electronic equipment (WEEE). *Environmental Impact Assessment Review*, S. 525–539.

International Organization for Standardization. (2014). Abgerufen am 24. 4 2014 von ISO 14000 - Environmental management: http://www.iso.org/iso/home/standards/management-standards/iso14000.htm

Jordan, D. C. (2012). *Photovoltaic Degradation Rates — An Analytical Review.* Oak Ridge: National Renewable Laboratory.

Kaesler, S. (2013). Wohin mit der ausgedienten PV-Anlage? In *Erneuerbare Energien* (S. 40-44). elektro.net.

Kaizuka et al. (2014). Policy review. *PV magazine*, 22-24.

Kaizuka, I. (2012). Project boom. *PV Magazine*, 22.

Koller, I. (2009). *Das Kommunikationsverhalten in der Forstwirtschaft.* Wien: Universität Wien.

Krause, F. (13. 2 2013). *Friday Focus*. Abgerufen am 7. 4 2014 von The growth of the secondary photovoltaic market-PV Tech: http://www.pv-tech.org/friday_focus/friday_focus_the_growth_of_the_secondary_photovoltaic_market

Krebs, G. (2009). *Das moderne Japan, 1868-1952: von der Meiji-Restauration bis zum Friedensvertrag von San Francisco.* Berlin: Ouldenburg Wissenschaftsvelag.

Kumar, R. (October 2006). Economic analysis of paper recycling vis-à-vis wood as raw material. *International Journey of Production Economoics*, S. 489–508.

Labelident. (2010). *industrieetiketten*. Abgerufen am 13. 2 2014 von WEEE-ElektroG: http://www.industrieetiketten.net/bleifrei-etiketten_weee-elektrog.htm

Lenardič, D. (2009). *Large Photovoltaic Power Plants.* Jesenice: Denis Lenardič.

Lewis, A. (4. 8 2010). *BBC*. Abgerufen am 13. 2 2014 von Europe breaking electronic waste export ban: http://www.bbc.co.uk/news/world-europe-10846395

Luhmann, H.-J. (1. 10 2010). Auf welche Wissenschaft beruft sich die Politik beim Zwei-Grad-Ziel? *GAIA - Ecological Perspectives for Science and Society*, S. 175-177.

Luhmann, N. (2004). *Ökologische Kommunikation.* Wiesbaden: Springer VS.

Lund, H. (June 2007). Renewable energy strategies for sustainable development. *Energy*, S. 912–919.

Mani, G. T. (2009). Testing the reliability and safety of photovoltaic modules: failure rates and temperature effects. *8th Photovoltaics International*, 146-152.

McConnell, A. (9 2012). *Noxious Earth*. Abgerufen am 19. 5 2014 von A journal of Politics and Culture: http://www.caravanmagazine.in/photo-essay/noxious-earth

Mehta, S. (2013). PV Technology and Cost Outlook, 2013-2017. *PV technology*.

Meza, E. (2014). The Land of PV. *PV magazine*, 18-21.

Miller, D. (1987). *Material Culture and Mass Consumption.* Oxford: Basil Blackwell.

Monier et al. (2011). *Study on Photovoltaic panelssupplementing the impact assessment for a recast of the WEEE directive.* Paris: Bio Intelligence Service.

Müller et al. (2006). *LIFE CYCLE ANALYSIS OF A SOLAR MODULE RECYCLING PROCESS.* Utrecht: 20th European Solar Energy Conference and Exhibition.

Omer, A. (December 2008). Energy, environment and sustainable development. *Renewable and Sustainable Energy Reviews*, S. 2265–2300.

Patel, M. (2006). *Wind and Solar Power Systems: Design, Analysis, and Operation.* Raton, Florida: CRC press.

Patton. (2012). *An overview of potential environmental, cultural, and socioeconomic impacts and mitigation measures for Utility-scale solar energy development.* Argonne: Argonne National Laboratory.

Photovoltaic Austria Federal Association. (2014). *Photovoltaic Austria*. Abgerufen am 3. 2 2014 von Grafiken: http://www.pvaustria.at/daten-fakten/grafiken/

PV Cycle. (2009). *Recast of the WEEE directive.* Brussels: PV Cycle.

PV Cycle. (2011). *Annual Report 2011.* PV Cycle.

Reed Exhibitions. (10. October 2014). *pvexpo.jp*. Von International photovoltaic power generation: http://www.pvexpo.jp/en/ abgerufen

REFERGY . (2012). *DECOMMISSIONING PLAN REPORT.* Cambridge: Ontario Solar PV Fields.

Reiling. (2012). *Reiling*. Abgerufen am 13. 2 2014 von Recycling bring Zukunft. Reiling: http://www.reiling.de/

RITEK . (2014). *RITEK Energy Division*. Abgerufen am 23. 5 2014 von Crystalline Solar Modules: http://www.riteksolar.com.tw/eng/p2-solar_modules.asp

SAN DIEGO GAS & ELECTRIC. (2012). *Decommissioning & Reclamation Plan.* California: UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF LAND MANAGEMENT.

Sandberg, J. (2014). Europeans plan giant PV factory to take on China. *Recharge*, 6-7.

Sander, K. (2007). *STUDIE ZUR ENTWICKLUNG.* Hamburg: Bundesministeriums für Umwelt, Naturschutz und Reaktorsicherheit.

Savage, M. (2006). *IMPLEMENTATION OF WASTE ELECTRIC AND ELECTRONIC.* Brussels: European Commission.

Schaffar, W. (2000). Die Informationsstruktur der japanischen Sprache. In W. Schaffar, *Die Informationsstruktur der japanischen Sprache* (S. 53-60). Tübingen: Literaturverlag Münster HaMBURG lONDON.

Schweizerische Eidgenossenschaft. (2014). *Bundesverfassung.* Switzerland: Ulan Press.

Schwentker, W. (1998). Strukturanalyse asiatischer Gesellschaften. In W. Schwentker, *Max Weber in Japan: eine Untersuchung zur Wirkungsgeschichte 1905-1995* (S. 154-168). Tübingen: Mohr Siebeck.

Siemens. (10. October 2014). *Sektor Energy.* Von Siemens konzentriert sich bei erneuerbaren Energien künftig auf Wind- und Wasserkraft:

http://www.siemens.com/press/de/pressemitteilungen/?press=/de/pressemitteilungen/2012/energy/e201210007.htm abgerufen

Silicon Valley Toxics Coalition. (2013). *2013 SOLAR SCORECARD.* San Francisco,: Silicon Valley Toxics Coalition. Abgerufen am 23. 4 2014 von Solar Score Card.

Taetow, W. (2013). *Status, Zukunftsperspektiven und Chancen des Sammelns von PV-Modulen.* PV Cycle.

Tayler et al. (2011). *Garbology: What does our trash tell us?* Indiana: Indiana State University.

Thompson, M. (1979). *Rubbish Theory .* Oxford: Oxford University Press.

Tilly. (1975). *The Formation of National States in Western Europe.* Princeton: Princeton University Press.

Trommsdorff, G. (1993). Besonderheiten sozialen Handelns in japan. In K. Gisela Trommsdorff, *Deutsch-japanische Begegnung iin den Sozialwissenschaften* (S. 227-255). Konstanz: Universitätsverlag Konstanz.

TUV Rheinland. (10. October 2014). *TUV Rheinland-genau richtig*. Von Philosophie und Marke: http://www.tuv.com/de/deutschland/ueber_uns/philosophie_marke/leitbild.html abgerufen

Tyagia et al. (2012). Advancement in solar photovoltaic/thermal (PV/T) hybrid collector technology. *Renewable and Sustainable Energy Reviews*, S. 1383–1398.

Wassenhove, V. (Dezember 1996). An environmental life cycle optimization model for the European pulp and paper industry. *Omega*, S. 615–629.

Weinberger, E. (1998). *Waldnutzung und Waldgewerbe in Altbayern und im beginnenden 19. Jahrhundert.* Stuttgart: Franz Steiner Verlag.

Weiss, P. (1993). *Nachhaltigkeit -Alter Grundsatz als Lösung für Krisen der Neuzeit.* Wien: Österreichischer Forstverein.

Williams. (April 2011). How are WEEE doing? A global review of the management of electrical and electronic wastes. *Waste Management*, S. 714–730.

Y. Matsufuji et al. (2005). *Japan's Experience in Promotion of the 3Rs.* Tokyo: The Ministry of Environment.

Yamamoto, D. K. (2. June 2014). PV Recycling. (A. Auer, Interviewer)

Young, R. D. (1986). Encouraging Environmentally Appropriate Behavior: The Role of Intrinsic Motivation. *Journal of Environmental Systems*, S. 281 - 292 .

Appendices

1. Appendix: Questionnaire sample

During the PV Expo held in Tokyo the 26th to 28th of February 2014 I handed out a questionnaire to 20 manufacturers. The idea behind this questionnaire was to get in touch with manufacturers and to see whether PV recycling is on the agenda of the PV industry. Five manufacturers answered the questionnaire.

Swedish University
Of Agricultural Science,
Uppsala

SLU

TÜVRheinland®

UNIVERSITÄT HOHENHEIM 1818

Questionnaire: How to deal with PV waste?

PV Expo Tokyo, 26th to 28th February 2014
Agathe Auer

Name ___________________ E-mail ___________________ Position ___________________
Name of PV manufacturer ___________________

1. Do you consider the recycling of PV modules as necessary? Yes ◯ No ◯
   - Why do you consider recycling as necessary / unnecessary?

____

____

____

2. What benefits/disadvantages would you see from implementing an internal module recycling program in your company?

____

3. Is your company a member of a recycling programme? Yes ◯ No ◯
   Please name the company ______________________________

4. Do you believe that performing an LCA (Life Cycle Analysis) could help improve your company's efficiency and profitability? Yes ◯ No ◯

5. What products are recycled?

Metal Frame ◯ Glass Plate ◯ Balance-of-System ◯ Si- Wafer ◯

What capacity has been recycled in 2013 (kWh)? ______________________

What is the lifetime of the recycled modules? ______________________

6. Do you think that a “cradle-to-cradle” (complete re-use of all materials and “up-cycling”) life cycle for PV modules is feasible in the near term? Yes ◯ No ◯

7. Do you think that the design of PV Modules and their input materials should be improved for greater recyclability? Yes ◯ No ◯

8. Is your warranty covering the recycling method? Yes ◯ No ◯

9. Is your company interested in certified recycling methods? Yes ◯ No ◯

10. To what ecological standard is your company referring? ______________________

11. Do you think that module recycling should be the responsibility of the manufacturer? Does it make more sense to perform recycling in-house or for it to be done by specialized companies? Yes ◯ No ◯
    Please explain why.

____

Thank you for your contribution.

2. Appendix: Answered questionnaires

Agricultural Science, Uppsala

SLU

Questionnaire

1. Does your company consider recycling technic
   - Why do you consider recycling as necessa

Wiederverwendung als Rohstoff

2. What benefits/disadvantages would you see from implementing an internal module recycling program in your company?

Image, Rohstoffgewinnung, wirtschaftl. Reiz

3. Is your company a member of a recycling programme? Yes ⊗ No ○
   Please name the programme PV-Cycle

4. Do you believe that performing an LCA (Life Cycle Analysis) could help improve your company's efficiency and profitability? Yes ⊗ No ○

5. Which of your products or components are being recycled?

Metal Frame ⊗ Glass Plate ○ Balance-of-System ⊗ Silicon Wafers ○

What capacity has been recycled in 2013 (kW or units)? ________

What is the decomissioning time (lifetime) of the recycled modules? 30 Jahre

6. Do you think that a complete re-use of all materials of current PV modules is feasible in the next 10 to 20 years? Yes ○ No ⊗

7. Do you think that the design of PV Modules and their used materials should be improved for greater recyclability? Yes ⊗ No ○

8. Is your warranty covering the recycling method and decommissioning costs? Yes ⊗ No ○

9. Is your company interested in certified recycling methods? Yes ○ No ⊗

10. To what environmental standard is your company using? WEEE

11. Do you think that module recycling should be the responsibility of the manufacturer? Does it make more sense to perform recycling in-house or for it to be done by specialized companies? Yes ⊗ No ○
    Please explain what would be ideal for you.

externe Firma weil darauf spezialisiert

Swedish University of
Agricultural Science,
Uppsala

Questionnaire

1. Does your company consider recycling technics for P
   - Why do you consider recycling as necessary / unr

2. What benefits/disadvantages would you see from implementing an internal module recycling program in your company?
   No benefits due to site/market conditions (rules

3. Is your company a member of a recycling programme? Yes ☒ No ◯
   Please name the programme PV Cycle

4. Do you believe that performing an LCA (Life Cycle Analysis) could help improve your company's efficiency and profitability? Yes ◯ No ☒

5. Which of your products or components are being recycled?

Metal Frame ◯ Glass Plate ◯ Balance-of-System ◯ Silicon Wafers ◯

What capacity has been recycled in 2013 (kW or units)? very

What is the decomissioning time (lifetime) of the recycled modules? 35 years

6. Do you think that a complete re-use of all materials of current PV modules is feasible in the next 10 to 20 years? Yes ☒ No ◯

7. Do you think that the design of PV Modules and their used materials should be improved for greater recyclability? Yes ◯ No ☒ Hersteller

8. Is your warranty covering the recycling method and decommissioning costs? Yes ◯ No ☒

9. Is your company interested in certified recycling methods? Yes ◯ No ☒

10. To what environmental standard is your company using?

11. Do you think that module recycling should be the responsibility of the manufacturer? Does it make more sense to perform recycling in-house or for it to be done by specialized companies? Yes ◯ No ☒

Agricultural Science,
Uppsala

Questionnaire

1. Does your company consider recycling technics for PV
   - Why do you consider recycling as necessary / unn

   necessary

2. What benefits/disadvantages would you see from implementing an internal module recycling program in your company?

3. Is your company a member of a recycling programme? Yes ☑ No ○
   Please name the programme PV Cycle

4. Do you believe that performing an LCA (Life Cycle Analysis) could help improve your company's efficiency and profitability? Yes ☑ No ○

5. Which of your products or components are being recycled?

Metal Frame ☑ Glass Plate ☑ Balance-of-System ○ Silicon Wafers ☑

What capacity has been recycled in 2013 (kW or units)? 400,000.00 Units

What is the decomissioning time (lifetime) of the recycled modules? 25 Years

6. Do you think that a complete re-use of all materials of current PV modules is feasible in the next 10 to 20 years? Yes ☑ No ○

7. Do you think that the design of PV Modules and their used materials should be improved for greater recyclability? Yes ☑ No ○

8. Is your warranty covering the recycling method and decommissioning costs? Yes ○ No ☑

9. Is your company interested in certified recycling methods? Yes ☑ No ○

10. To what environmental standard is your company using?

11. Do you think that module recycling should be the responsibility of the manufacturer? Does it make more sense to perform recycling in-house or for it to be done by specialized companies? Yes ☑ No ○
    Please explain what would be ideal for you.

TÜVRheinland

アンケート：PV モジュールのリサイクルについて

PV Expo Tokyo, 26th to 28th February 2014
Agathe Auer

お名前 荒木 健二　E-mail kenji.araki@west-gr.co.jp　役職 執行役員
会社名 ウエストホールディングス

1. PV モジュールのリサイクルは必要と考えますか?　(はい) ○　いいえ ○
   - その理由を教えてください。

使える部材が多いと思うので。

2. 御社内でリサイクルプログラムを導入した場合、どのようなメリット/デメリットがあると考えますか?

メリット. 再利用品などのビジネスチャンス　デメリット：手間がかかる

3. 御社はリサイクルプログラムのメンバーですか?　はい ○　(いいえ) ○
   プログラム名 ____________

4. ライフサイクルアセスメント（LAC）を行った場合、御社の効率性や利益改の改善に繋がると感じますか?　はい ○　(いいえ) ○

5. 御社でリサイクルされている製品、コンポーネンツは？
フレーム ○　ガラス板 ○　BOS ○　シリコンウエハ ○

2013 年にリサイクルされた容量はいくらですか (kWh)? N/A

リサイクルされたモジュールの耐用年数は何年ですか? わからない

6. PV モジュールの完全な再利用は 10～20 年後に実現可能だと思いますか?　(はい) ○　いいえ ○

7. リサイクル性の向上のため、PV モジュールのデザインや使用する部材の改善が必要と考えますか?　(はい) ○　いいえ ○

8. 御社の保証はリサイクルや廃棄費用もカバーされていますか?　はい ○　(いいえ) ○

9. リサイクル方法の認証に関心はありますか?　(はい) ○　いいえ ○

10. どの環境基準を使用していますか?

11. モジュールのリサイクルはモジュールメーカーの責任だと考えますか?　はい◯　いいえ◯
リサイクルは自社、又は専門の業者が行うべきだと考えますか?

はい。自社でリサイクル会社へ。

ご協力ありがとうございました。

... モジュールのリサイクルについて

PV Expo Tokyo, 26th to 28th February 2014
Agathe Auer

お名前 Katsuhisa Sasaki　E-mail katsuhisa.sasaki@etsolar.com　役職 Country Manager
会社名 ET Solar Japan K.K.

1. PV モジュールのリサイクルは必要と考えますか?　はい ☑　いいえ ○
   - その理由を教えてください。

If we don't recycle it, it would be the waste of energy and resources

2. 御社内でリサイクルプログラムを導入した場合、どのようなメリット/デメリットがあると考えますか?

Cost might be the issue and we need to corporate with other locations of ET Solar group.

3. 御社はリサイクルプログラムのメンバーですか?　はい ☑　いいえ ○
   プログラム名 ____________

4. ライフサイクルアセスメント（LAC）を行った場合、御社の効率性や利益政の改善に繋がると感じますか?　はい ☑　いいえ ○

5. 御社でリサイクルされている製品、コンポーネンツは？
   フレーム ○　ガラス板 ○　BOS ○　シリコンウエハ ○

2013 年にリサイクルされた容量はいくらですか (kWh)? ____________

リサイクルされたモジュールの耐用年数は何年ですか? ____________

6. PV モジュールの完全な再利用は 10～20 年後に実現可能だと思いますか?　はい ○　いいえ ○

7. リサイクル性の向上のため、PV モジュールのデザインや使用する部材の改善が必要と考えますか?　はい ☑　いいえ ○

8. 御社の保証はリサイクルや廃棄費用もカバーされていますか?　はい ○　いいえ ○

9. リサイクル方法の認証に関心はありますか?　はい ☑　いいえ ○

10. どの環境基準を使用していますか?

11. モジュールのリサイクルはモジュールメーカーの責任だと考えますか? はい ◯ いいえ ◯
リサイクルは自社、又は専門の業者が行うべきだと考えますか?

To some extent, we have the responsibility
But I think that we need to corporate with
the end users.

ご協力ありがとうございました。

TÜV Rheinland Japan Ltd.
Board of Management

TÜV Rheinland®
Genau. Richtig.

LETTER OF RECOMMENDATION

To whom it may concern

Ms. Agathe Auer, born January 22nd 1990 in Müllheim, Germany, joined our company from February 1st, 2014 until July 31th, 2014 and worked in our Photovoltaics Laboratory as an intern.

Her job carried the following responsibilities:

- Testing photovoltaic modules according to international safety, quality and performance standards IEC 61215, 61730 and 61646
- Writing a Master Thesis on recycling methods for photovoltaic modules.
  Title: "Photovoltaic recycling and decommissioning in globally and in Japan."
- Master thesis conclusions based on interviews with Solar PV key stakeholders as manufacturers and owners. Design and implementation of questionnaires, as literature review and online research.
- Assisting engineers during project handling with market research activities for large scale PV Power Plants in relation to the above mentioned master thesis

Ms. Auer worked in a responsible and co-operative manner within our team and with customers alike. She consistently achieved excellent results and was always very reliable. Ms. Auer was proactive in taking responsibility for matters requiring urgent attention and has acquired experiences in a wide range of duties.

For the future, we wish Ms. Auer much success in business and all the best personally.

Yokohama, December 5th, 2014

H. Kunz
President & CEO
TÜV Rheinland Japan Ltd.

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