



Strengthening circularity in photovoltaics

Challenges and opportunities along the lifecycle

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Overview

Every year, huge numbers of photovoltaic (PV) modules are being installed. This greatly furthers the ecological transformation of the energy system. But to solve the climate crisis every aspect has to be taken into consideration. This is why this white paper wants to shine light on challenges currently occurring or to be expected in connection with used photovoltaic modules and their disposal.

In the past decades we have seen a rise in numbers of installed modules first in the 90s and then in the early 2000s with the introduction of the Renewable Energy Act (EEG) in Germany. After 20 to 30 years, many modules are reaching their end of life - at least from an economic standpoint. In Germany alone up to 51,600 tons of used modules were expected to be disposed of by their former owners in 2020¹. By the year 2030, some projections even assume a quantity of 1,000,000 tons². Depending on further developments within the EEG, the upcoming decades could face even higher amounts, when plants are no longer eligible for feed-in-tariffs.

The current setup of collection and disposal systems for used PV modules is not yet equipped to deal with these quantities in a way that maximizes benefits to the climate and resource efficiency. For now it cannot be guaranteed, that every used module is treated the way it should. Sometimes still functioning modules are destroyed. Collection numbers are low and do not meet expectations. According to market actors, the number of (illegally) exported modules is high – but reliable statistics are lacking. To prevent harmful impacts on the environment, the destruction of working equipment or the loss of valuable resources, it is important that we act now.

Goals

To battle the climate crisis, a truly circular economy is indispensable. To reach that goal, the waste hierarchy as laid out by §6 of the German Circular Economy Act (KrWG) is an important tool. Transferred to used PV modules, it could look something like this:

- » **Prevention of waste:** PV modules are durable and handled with care in order to ensure a long product life, they are in use as long as they are working
- » **Preparation for reuse:** Discarded PV modules are checked for reuse and - if still functioning or repairable - get a 'second life', broken modules are repaired
- » **Recycling:** If modules are no longer working and repair isn't feasible with reasonable effort, valuable resources are recovered and harmful substances removed with state of the art recycling techniques

To better implement the goals of a circular economy, we will retrace the steps in the lifecycle of a photovoltaic module and analyze problems and possible solutions along these stages. After a brief description of the occurring challenges, opportunities and solutions we deem to be effective and sensible in these matters are presented.

¹ UBA (2020): „Empfehlungen des UBA für die Weiterentwicklung der Behandlungsanforderungen nach ElektroG“ Kap.: 4.3 „AG 3 – Photovoltaikmodule“, p. 115-116.

² Wagenhäuser, M. (2020): PV-Projekte nach Ende der Förderdauer in Deutschland und Frankreich – Weiterbetrieb, Rückbau und Recycling. Hintergrundpapier DFBew p. 12.

Stage zero: Design of photovoltaic modules

Challenges

The modules are made for a long durability and are firmly glued together. This impairs their recyclability. Valuable materials are used, but not easily recovered. Modules usually contain potentially harmful materials, this could pose environmental risks in later life-stages.

Opportunities

» **Eco design**

As with other electrical appliances, the design of photovoltaic modules should improve repairability and recycling. It could prove useful to include recyclers in the design process. However, design changes could impact the durability of the modules. Since a prevention of breakage actively prevents modules from becoming waste, a very balanced approach towards durability, repairability and recyclability is needed. The European Commission is in the process of developing a regulatory proposal for photovoltaic modules, inverters and PV systems, which will encompass eco design and energy label requirements. Part of the eco-design requirements will relate to hazardous substances as well as durability, repairability and recyclability as well as use of recycled materials in new products. Those aspects should be emphasised and supported going forward. Well established eco-design labelling taking those into account can provide incentives and orientation towards the public and private sector alike.

» **Reduce and eliminate the use of harmful substances**

In the past, there have been attempts to forgo lead in the production of modules, since it is replaceable by non-hazardous materials. This substitution will most likely be accelerated through the REACH prioritization of lead (Pb) and lead oxide (PbO), which will ultimately lead to restriction. As technically feasible and proven alternatives are available for leaded solder and contacting pastes, a substitution in future becomes likely. Also, research projects on how to further reduce the use of other harmful substances in PV modules should be promoted and financed via the producers.

Stage one: Placing on the market

Challenges

There have been several accusations of modules being placed on the market without registration of the producer with the responsible authority, the National Register and Clearing House – stiftung elektro-altgeräte register (stiftung ear). Online marketplaces can be especially problematic in this account. This is problematic from an environmental standpoint and puts producers who respect the law at a disadvantage.

Opportunities

» **Law enforcement and market supervision**

There should be a stronger enforcement of existing laws by responsible authorities and an intensified market supervision. While hints from market actors can help in identifying panel imports by unregistered producers, it is indispensable that authorities adopt an active role in market supervision. In order to simplify market supervision, it could be helpful to make the specification of the registration number received via the 'stiftung ear' mandatory when registering new PV systems with the Federal Network Agency's (BNetzAG) maindata registry (MaStR). When selling PV panels, it should be obligatory to provide the 'ear'-registration number to the buyer.

» **Making online marketplaces accountable**

It is not sufficient to oblige online marketplaces to check whether the producers are correctly registered for proper disposal. If producers and distributors are not accessible for customers, the online marketplace must take over their duties, including those on information, disposal and safety requirements.

Stage two: Collection

Global Challenges

The collection of used and waste panels represents the biggest challenge regarding the overall improvement of the situation. As of now the collection processes of used and waste PV-modules are not optimal. Critics paint them as intransparent, complicated and too expensive. Also, the proper handling of modules isn't always ensured, which can prevent (preparation of) reuse and repair. Improper collection and subsequently disposal can lead to negative environmental effects due to loss of resources and possible contamination with harmful substances.

The entirety of the current collection processes could lead to undesirable disposal outcomes and hence should be addressed in several ways – some solutions are more general in nature, while others apply only to household or business-to-consumer (B2C) transactions and non-private household or business-to-business (B2B) transactions.

Global Opportunities

» **Information of relevant stakeholders and the general public**

Across the board, a lack of information on processes, responsibilities and possibilities in recycling and disposal of used photovoltaics is noted. The Federal Ministry of Environment and municipalities should make information on this topic widely available and start specific information campaigns with a focus on PV panels especially within associations involved, such as the association of municipal enterprises (VKU), the chambers of industry and commerce, the solar industry and the leading municipal associations.

Challenges for B2C modules

If the amount and type of modules is 'typical for a private household' (B2C), used modules can be disposed of at recycling depots of the municipal waste management authorities, no matter at what point they have been brought to the market. This take-back and subsequent treatment of B2C modules is partly financed via the municipalities and the module producers (shared product responsibility). The quality of the collection differs strongly between municipalities. Several municipalities offer reasonable and appropriate take-back possibilities. But with many, the take-back is not very consumer-friendly and knowledge about handling and responsibilities of panel take-back is lacking - according to some users, sometimes it is outright refused. In LAGA notice M31A the environment ministers of the federal states have agreed on a return quantity of 20-50 modules as typical for households. This is not implemented in every municipality. Furthermore it does not always correspond with reality, where a private plant easily exceeds this number. Unless there is another take-back possibility, like a voluntary collection via the producers or a 1:1-exchange due to repowering with new panels, this does and will lead to private owners looking for alternative and not always environmentally friendly disposal routes.

Opportunities for B2C modules

» Improve public collection systems

Collection processes should be defined and standardized in all municipalities and made consumer-friendly. For some, this includes increasing the number of collection points, training on-site workers and other municipal staff and the provision of information on take-back modalities on- and offline. This should be regulated via LAGA notices to establish a nationwide uniform standard and made binding on a state-level. To prevent the destruction of still functioning modules, employee training and protective requirements (such as reusable mounting straps and nets) and a revision of the collection containers available to municipalities are needed. The guidelines on amounts to be considered as typical for a private household have to be revised and a *minimum* take-back of 30 modules per person and day should be established in the ElektroG. Owners inquiring for a disposal opportunity exceeding municipal take-back possibilities have to be pointed towards other accessible options.

Challenges for B2B modules

Since the 24.10.2015, due to the Extended Producer Responsibility implemented via §19 ElektroG, producers of PV panels have to provide a reasonable possibility of return and recycling of modules from users other than private households. So far, due to the longevity of solar panels the amount of modules that has been given up for disposal via this channel is rather small. But, as seen with other types of products within the scope of the ElektroG, not all producers excel in the provision of take-back possibilities. Since the collection and recycling of modules is cost-intensive under the current conditions, similar developments can be expected for the PV sector. Exemplary companies, who follow the rules, are thereby disadvantaged compared to companies that do not comply with the laws.

With modules that have been placed on the market before the 24.10 2015, there is no such regulation. Unless voluntary extended producer responsibility systems for end-of-life module collection and recycling were in place, such as in the case of thin-film CdTe PV modules sold in Germany and the EU, they are often problematic, since all obligations for a proper disposal fall on the owner. When calculating and setting up PV systems, the costs for their disposal are usually not included in the price. There is an expectation of free disposal, which is neither met through the public collection nor fee based private collection. So these owners will try to find ways to rid themselves of the modules at the lowest possible price, which leads to rather creative ways of disposal (e.g. in barns and attics; smaller installers are particularly problematic here) or resale abroad, where old modules possibly pose an environmental risk and the last owner is no longer accountable. The disposal of these panels poses the biggest challenge in regard to the immediate future.

Opportunities for B2B modules

» **Improving producer take-back for B2B modules sold after 24.10.2015**

The implementation of reasonable return options on the part of the producer must be enforced via the responsible authorities. To further ensure that the producers fulfill their duties, they should be obliged to join a collection system or to set up similar take-back possibilities. One important requirement that has to be set legally: at least one take-back possibility in every Postcode Area (at best in every ZIP code area, but at least in every two-digit area) or alternatively offering onsite collection. To ensure proper collection structures for large industrial plants, even if a bankruptcy occurs, solid financial guarantees have to be devised by the German legislator. The obligation to offer take-back and associated information requirements when repowering a solar plant has to be further enforced via the responsible authorities.

» **Incentivizing take-back for B2B modules sold before 24.10.2015**

Law enforcement must carry out more inspections to hold the owners of the so-called ‘historical’ panels accountable. Unlike with other electrical equipment, the Federal Network Agency knows the location and launch date of nearly every PV plant in Germany. Even the shutdown of a plant has to be registered within their maindata registry (MaStR). To further incentivize the proper disposal by the current holder, a letter or mail, detailing their duties in regards to proper further treatment and the possible consequences of improper disposal should be sent out nearing the end of receiving feed-in-tariffs via the EEG and again when the owner registers its plant for decommissioning. At the time of deregistration the last owner should be obliged to provide information and submit a proof of the further disposition, for example sale or disposal, within the electronic interface of the maindata registry. In addition to enforcing the obligations of the owners of historical modules, these measures aim at creating a better database and traceability on the panels’ whereabouts.

Stage three: Repair and Reuse

Challenges

Germany reported a collection of 7,865 tons of waste panels in total in 2018 in its WEEE reporting³. This amount is at the lower end of previous predictions. This can be due to several reasons: the life expectancy of modules is longer than expected, the collection processes do not function reliably (as detailed above) or significant numbers of panels are exported and do not show up in the reported data.

Since newer PV panels have much higher efficiency levels, exchanging old modules that are still functional can make economic sense, especially if it coincides with the expiration of an EEG subsidy or in a guarantee case, when a whole plant is exchanged. This is why there is - in theory - a high potential for reuse and repair in used photovoltaic modules. However, this does not show up in German reports of the Federal Statistical Office (Destatis) for 2018, where only 900 tons, so 11,4 % were registered for preparation of reuse.⁴ Albeit this may also be related to the fact that modules that are resold as second-hand do not reach official waste status and therefore do not appear in the reporting.

Apart from niche markets, such as the replacement of individual panels in a whole plant, selling or repairing secondhand modules is not worthwhile (yet) for the German market. Market actors do report high percentages of exported modules. There are allegations of illegal exports. First reports⁵ should be counted as a warning sign. Target regions frequently mentioned by market actors include Syria, Lebanon, North Africa or Afghanistan. These are countries with a relatively undeveloped waste management industry. While a prolonged life of PV-modules is beneficial to the environment, improper disposal is not. This poses elevated risks due to the presence of hazardous materials in PV panels.

Opportunities

» Preparation for reuse

Second hand panels have a better overall carbon footprint and reuse possibilities should be enhanced. To ensure proper handling when used modules are dismantled, a training and certification process for craftsmen should be developed. Also, the proper sorting of modules, by type and functionality, has to be implemented, e.g. within specialized organisations or primary treatment and recycling facilities. Every used PV panel should undergo a functionality control, so that no functioning modules are destroyed, whether it is destined for reuse in Germany or exported. Municipalities, collection systems, producers and distributors should be required to cooperate with reuse companies and initiatives. One possibility of reuse within Germany could be the provision of relatively inexpensive used modules to universities,

³ BMU 2020: Daten zu Elektro- und Elektronikgeräten in Deutschland [2018]
https://www.bmu.de/fileadmin/Daten_BMU/Download_PDF/Abfallwirtschaft/elektrogeraete_daten_2018_bf.pdf

⁴ Destatis 2020: Zur Erstbehandlung angenommene Elektro- und Elektronikaltgeräte 2018,
<https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Umwelt/Abfallwirtschaft/Tabellen/liste-erstbehandlung.html>

⁵ INTERPOL 2020: STRATEGIC ANALYSIS REPORT: Emerging criminal trends in the global plastic waste market since January 2018, S.34

schools or non-profit organizations that could not otherwise afford to equip any. To ensure that all data collected for the German WEEE-reporting, verification of the data delivered to the responsible bodies should be intensified.

» **Stopping illegal exports and improving circularity on a global scale**

In general, the export of E-Waste without notification is illegal, while the export of functioning second hand devices is allowed. However, the responsible authorities are too hesitant at this point and there are not enough (unannounced) checks, to determine whether exported goods do actually fulfill this requirement. The burden of proof when it comes to demonstrating the functionality of the equipment lies with the exporter. Suitable documentation on the functionality of the equipment has to be provided and checked by customs.

The technical testing of the functionality of PV modules is comparatively easy to do. In order to guarantee that exported modules still function safely, standardized test methods must be developed and mandated. Exporters should have to provide evidence of such successful testing. Furthermore, the (statistical) traceability of used modules must be made possible with the help of suitable identification numbers and categories.

To prevent negative effects on the environment due to exported panels, the establishment of collection and recycling structures abroad have to be supported, e.g. within the framework of development cooperation. Also Germany should take a lead in global treaties on waste shipment.

Stage four: Recycling

Challenges

The minimum recovery targets specified for those PV panels collected within the frame of the WEEE directive (>85% recovery and >80% preparation for reuse and recycling) are met. However in most facilities, only glass and metals (aluminum, copper) are recovered. Glass typically is subject to downcycling. The techniques to extract further materials exist (at least in research or as prototypes), but without high requirements set by law and security regarding available quantities, further necessary investments are not probable. Only if recyclers can count on a predictable stream of a minimum number of non-functioning modules and if there are sufficiently high revenues for the recycled materials, investments into innovative recycling methods will prove fruitful.

Opportunities

» Develop recycling requirements

In order to raise recycling to a high level in terms of quality and to level the playing field between all recyclers, the technical recycling possibilities and their implementation should be taken into account and converted into laws. This includes the removal of harmful substances and the recovery of valuable materials, such as silicon, for which realistic and ambitious recycling quotas need to be set.

Therefore, in the frame of the next revision of the treatment ordinance for electrical and electronic equipment, further recycling requirements regarding valuable or critical raw materials, like metals and silicon, have to be set. The regulations set out in the EN 50625 series of standards (CENELEC standards) should act as a reference point when developing future recycling standards.

The recovery of glass with a high degree of purity should be aimed for, with the goal of high-quality applications. Further incentives for a use of the recovered materials in new modules should include an addition to Green Public Procurement requirements. Comparable products with recycled materials on the market should be preferred in public procurement. The long-term goal must be to create closed loops as far as possible, so that recycled material can be used again in new modules.

Conclusion

Right now, there is a window of opportunity to truly make PV modules part of the circular economy and to make Germany a front-runner in high-end collection, repair, reuse and recycling of solar panels. This could further strengthen the energy transition, help in the battle against climate change and provide possibilities for innovation, investment and job creation. If we miss the chance to act now, there is a strong probability that solar modules will become a problematic waste stream. This is not only undesirable but also unnecessary.

To prevent this, the systemic nature has to be taken into account: if we want to improve recycling of PV panels, recyclers need an incentive to provide means for high end recycling, e.g. recycling requirements and a predictable and secure stream of material. Therefore the collection of EoL modules needs to be ensured. If we want repair and reuse of modules, proper handling and testing for functionality need to be a given. If reliable producers shouldn't be at a disadvantage, 'bad apples' that do not respect laws, e.g. when placing modules on the market, need to be removed. **All actors have to contribute their fair share: producers, owners, recyclers and public bodies.** Via extensive research in literature, many in-depth interviews with stake-holders and surveys with relevant actor groups, we identified the most urgent challenges and opportunities to strengthen the circularity of photovoltaics in Germany.

Key issue 1: due to costs and efforts existing collection processes often are not attractive for owners of used PV panels, so they look for alternatives like illegal export, which leads to negative environmental impacts

- oblige the public sector as a collection point of private modules to uniform standards of taking back at least 30 modules
- oblige producers to join a collection system or to create similarly good return options with sufficient collection points
- monitor markets and penalize producers who try to evade their obligations, for example by placing modules on the market illegally
- owners who report their PV systems to the Federal Network Agency as decommissioned will be made aware of their disposal obligations
- Illegal exports of modules that are no longer in working order must be prevented through standardized testing, frequent controls and uniform waste identification numbers

Key issue 2: Used modules are often still functional, but are destroyed by inadequate treatment and cannot be reused.

- Mandatory training for employees and usage of suitable collection containers and safeguarding measures in transport (in private and public collection infrastructures)
- Development of a specialized training and certification process for craftsmen handling used modules
- Implementation of functionality controls and sorting by type for each module
- actors along the collection process, such as municipalities, collection systems, producers and distributors should be required to cooperate with reuse companies and initiatives

Key issue 3: Modules are difficult to recycle and the recycling of modules often leads to a loss of valuable materials and downcycling, although better technical options can be developed

- Future modules should be made easier to recycle, thanks to eco-design regulations
- Increased collection volumes will lead to higher investment security for recyclers
- Specific recycling requirements, e.g. for silicon and glass, should provide incentives for the use of best possible technology

About the partners and our study

We, organisations working all along the life cycle of PV modules and towards a cleaner and more sustainable future, came together, to tackle a common goal: improving the circularity in the photovoltaic sector in Germany. While we are convinced that solar is the way to go, we collectively recognized a need for change and innovation with modules reaching the end of their (first) life.

So we got involved with actors from all over the country, to identify the most important problems and solutions in this regard. To arrive at the conclusions given in this paper, we used a mixed approach of qualitative and quantitative methods. We had experts in the field explain their views and conducted surveys with several stakeholder groups.

Expert interviews

Apart from an assessment of the general situation, we asked the experts about their insights and opinions regarding all the life stages of a PV Panel. This included for instance questions about the relevance of different actors, the informal sector, the reuse potential and the biggest challenges in their eyes.

Among the organisations with which we led expert interviews were the following:


- German Solar Industry Association - BSW
- Federal ministry of the environment - BMU
- Association of municipal waste management companies - VKU
- German Environment Agency – UBA
- National Register and Clearing House – stiftung elektro-altgeräte register (stiftung ear)


Stakeholder surveys


To gain a broader overview of the whole PV sector, we conducted surveys with those stakeholders, who deal with secondhand or End of Life modules. For some of the survey participants, this was followed up by more in-depth interviews. Groups we talked to included:


- Commercial buyers of used modules
- PV Module collections systems
- recyclers
- installers and maintenance service providers
- (municipal) public waste disposal providers


About the partners

 **Deutsche Umwelthilfe** The Environmental Action Germany (DUH) has been campaigning to preserve the natural foundations of life for more than 40 years. In doing so, it brings together protecting the environment with consumer protection like no other organisation in Germany. The organisation is politically independent and it campaigns mainly on a national and European level.

 **First Solar** First Solar is a leading global provider of comprehensive photovoltaic (PV) solar energy solutions with more than 25GW sold worldwide. We are the world's largest thin film PV solar module manufacturer. We design, manufacture, sell and sell PV solar modules with an advanced thin film semiconductor technology. From raw material sourcing through end-of-life module recycling, First Solar's PV modules and systems protect and enhance the environment.

 **ROSI** ROSI Solar is a company offering innovative solutions for recycling and revalorization of raw materials in the PV industry. The technologies allow to recover highly pure silicon and other metals currently lost during the production of photovoltaic cells and at the end-of-life of solar panels.

 **take-e-way** Take-e-way GmbH is an internationally operating compliance service provider and offers comprehensive solutions for all product responsibility issues of manufacturers and distributors of electrical and electronic equipment - including PV modules. More details at: www.take-e-way.de.

 **VEOLIA** The Veolia group is the global leader in optimized resource management and designs and provides water, waste and energy management solutions which contribute to the sustainable development of communities and industries. Through its three complementary business activities, Veolia helps to develop access to resources, preserve available resources, and to replenish them. More details at: www.veolia.de.

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