END-OF-LIFE SOLUTIONS FOR SOLAR PHOTOVOLTAICS AND WIND POWER SYSTEMS IN VIET NAM

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Developing End-of-Life solutions for Solar Photovoltaics and Wind Power systems in Viet Nam

VIỆN NĂNG LƯỢNG

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Contents

List of Figures

List of Tables

Authors

Institute of Energy:	Nguyen Thi Thu Huyen Le Hoang Anh Dinh Le Phuong Anh Nguyen Ngoc Oanh Nguyen Van Truong
International consultants:	Deepali Sinha Khetriwal Kishore Ganesa Carlo Lupi
UNDP Viet Nam:	Vu Thi Thu Hang

The data on Viet Nam's electricity system and the forecast of solar and wind power capacity are extracted from the Draft Power Development Plan VIII for the period 2021 - 2030, with a vision to 2045, the 3rd version, February 2021.

Acronyms

ARF	Advanced Recycling Fee
BAU	Business as usual
BOT	Built Operate Transfer
CIT	Corporate Income Tax
DPPA	Direct Power Purchase Agreement
EEE	Electrical and Electronic Equipment
EPR	Extended Producer Responsibility
EVA	Ethylene Vinyl Acetate
EOL	End of Life
EREA	Electricity and Renewable Energy Authority
FiT	Feed in Tariff
GHG	Greenhouse gases
GW	Giga Watt (= $1x10^9$ Watt)
IRENA	International Renewable Energy Agency
IPP	Independent Power Producers
MOIT	Ministry of Industry and Trade
NDC	Nationally Determined Contribution
PDP 8	Master Plan for Power Development for 2021 - 2030
PV	Photovoltaic
PRO	Producer Responsibilty Organization
PPA	Power Purchase Agreement
PPP	Public Private Partnership
RE	Renewable Energy
RCRA	Resource Conservation and Recovery Act
R&D	Research & Development
WP	Wind Power
VAT	Value Added Tax

Executive Summary

Viet Nam is among the fastest-growing economies in the world, characterized by high energy and carbon intensity, with emissions projected to increase threefold by 2030. This has driven the Government of Viet Nam to place high importance on climate change mitigation alongside economic growth. As a part of this mitigation strategy, strong emphasis is placed on the development of renewable energy sources, especially solar photovoltaic (PV) and wind-based power (WP) generation.

Viet Nam has developed significant capacity for both solar and wind-based power aided through various policy measures and attractive Feed-in-Tariff schemes. In 2020, the electricity generated from solar and wind energy sources amounted to 12,084 GWh, accounting for nearly 5% of the nationwide power production.

Policies like the draft National Energy Development Master Plan for the period 2021-2030 with a vision till 2050 and the draft Master Plan for Power Development for 2021 - 2030 (PDP 8) with a vision till 2045 foresee an increase in installed capacity of renewable energy sources in the future as shown in the table below.

Further, the draft Power Development Plan in the period of 2021 - 2030 and with a vision till 2045 (PDP 8) gives priorities to the rational development of renewable energy sources.

Renewable energy source	2025	2030	2045
Solar	17.25 GW	18.64 GW	55 GW
Wind	11.320 GW	16 GW	39.61 GW

Table 1. Development of solar and wind power in Viet Nam as per PDP 8

This boom in installations will reflect in the waste stream in the coming years. In the next few decades, solar modules, wind turbine blades, and ancillary components will need to be refurbished, reused, recycled, or safely disposed of.

According to the scenarios in the draft PDP 8, the installed capacity of solar power will increase from 16.6 GW to maximum 20.1 GW in period of 2021 – 2030, accelerating to 71.9 GW in 2045 under the high scenario. With a panel capacity of 330 – 440W, and taking into account the technological improvements in panel capacity, with fewer panels needed for the same power, an estimated 50.9 – 62.1 million PV will be installed by 2030 and upto 150 – 220 million panels by 2045.

More than 95% of solar power plants in Viet Nam utilize crystalline silicon PV panels (70% crystalline and 25% polycrystalline solar panels), with less than 5% using thin-film panels. Following the methodology proposed by IRENA , the estimation of waste generation from EOL PV is calculated based on a Weibull distribution and selected PDP8 scenario. Figure 1 below provides a forecast for solar waste generation from 2020-2050 under early loss (2% will become waste after 10 years) and regular loss (4% will become waste after 15 years) scenarios.

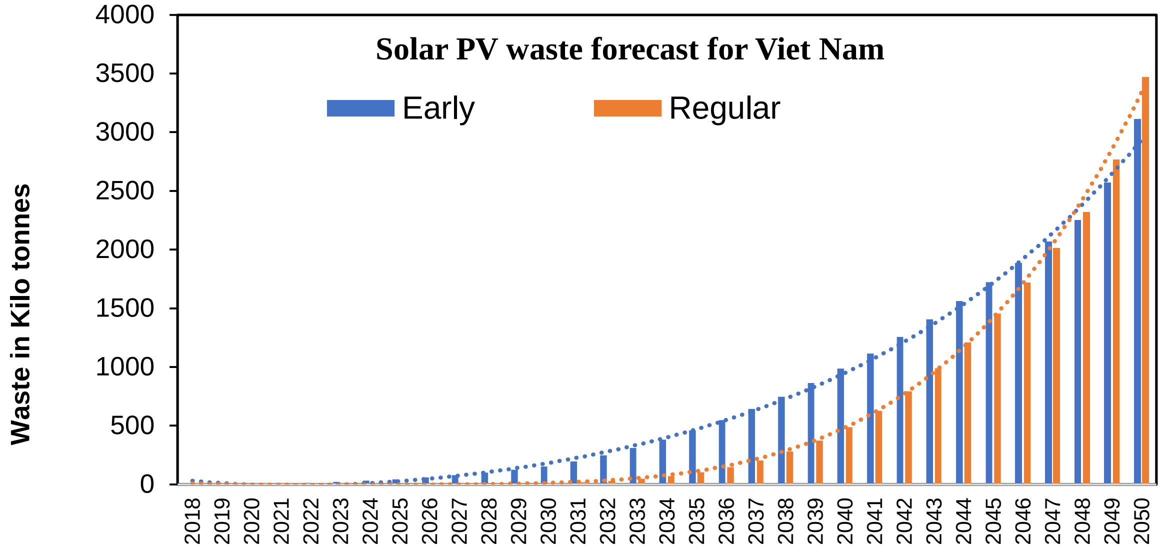

Figure 1. Solar power waste forecast in period 2020 – 2050

Wind Power

The favourable policy environment has also driven wind power installations significantly, from 30 MW in 2012 to 630 MW by 2020. According to the draft PDP 8, only onshore and near-shore wind power is expected until 2030, after which offshore wind power will start to come on stream. In total, the onshore, near-shore, and offshore installed wind power capacity is expected to increase to about 55 GW and 76 GW by 2045 under the most conservative and most ambitious scenarios respectively.

Between 19.3 and 66.9 kilo tons of EoL wind turbine waste would be generated in Viet Nam by 2030 based on the early loss and regular loss scenario, respectively. By 2040, the cumulative waste generation will rise to 112.9 to 1171 kilo tons and by 2050 to about 1484 and 5057 kilo tonnes for early loss and regular loss scenario, respectively.

The forecast of material flow from EOL wind turbines is based on the material composition and estimated EOL volumes, with the assumption that the entire wind turbine will be dismantled on failure. Figure 2 provides wind turbine waste estimation under early and regular loss scenarios.

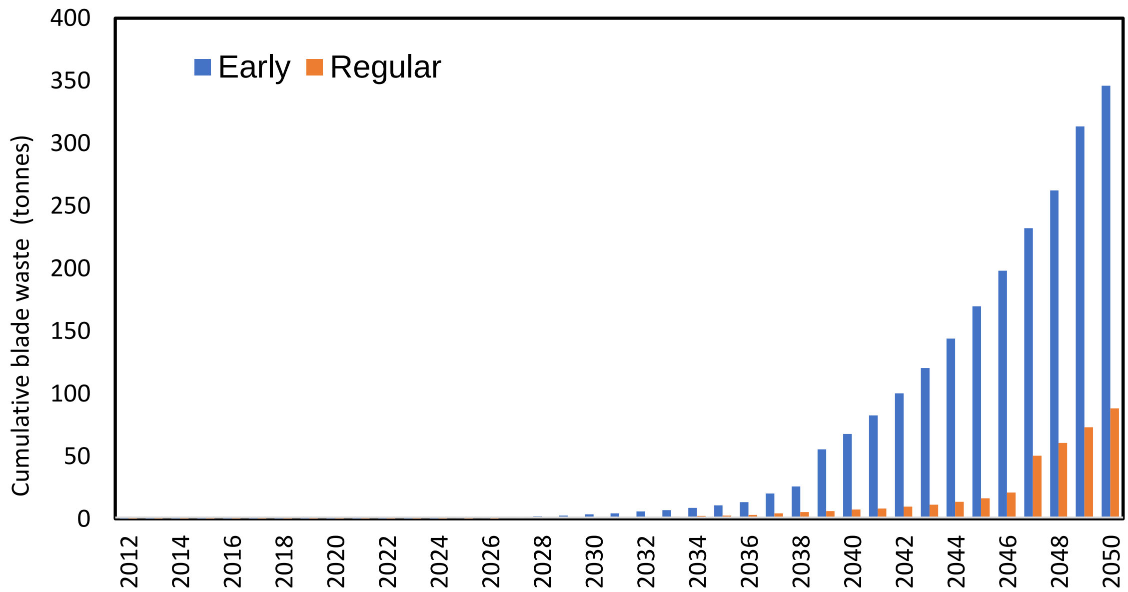

Figure 2. Wind turbine blade waste forecast (cumulative upto 2050)

International legislation - Solar PV panel waste

EoL PV panels are considered as electronic waste in all jurisdictions where it is regulated. The WEEE Directive, which came into force in 2012 in the European Union, and was recast in 2012, is one of the earliest to include EoL solar PV as a specified waste within the framework of Extended Producer Responsibility. All Member States transposed the Directive into national legislation, and therefore regulate the management of EOL PV panels. Countries like Australia, China and USA with large PV installations as yet do not have any specific regulations for EoL waste PV panels. They are managed under special directives and programmes such as the 13th five-year plan for China and National PV Recycling Program by Solar Energy Industries Association for USA.

International legislation – Wind power waste

Wind turbines owing to their size require specific regulations for dismantling and site restoration. Compared to PV panels, the dismantled components from wind turbines have established recycling chains and do not require further delamination techniques. There are no specific policies that govern the overall waste management of wind turbines. However, there exist guidelines and standards for decommissiong, dismantling and site restoration of wind turbines in different countries. Most of the decommissioning regulations for wind turbines are covered through different waste management policies like construction and demolition waste, metal waste management and e-waste management policies due to the different types of waste produced from the wind turbines like concrete, metals and electrical cables, respectively.

A few examples of specific legislative policies in different countries for decommissioning of wind turbines include Renewable Energy Sources Act, 2017 in Germany, Guidelines for the authorisation of plants powered by renewable sources in Italy and the Building Decree (2012) in Netherlands and Condition of decommissioning mentioned in building and operating permit in Denmark. Further, there are bans on landfilling of wind turbine blades in Germany and Netherlands. Financial security, dismantling/decommissioning and management of all materials produced from dismantling are some aspects considered while formulating guidelines and standards related to EoL of wind turbines.

Existing regulatory frameworks associated with EoL Management of PV and Wind Turbines in Viet Nam

Viet Nam is a Party to the Basel Convention on transboundary movement of hazardous wastes with the Circular No. 36/2015/TT-BTNMT transposing it to national law. Waste and environmental legislation in Viet Nam stems from the framework Law on Environmental protection (promote waste reduction, reuse and recycling), Decree on the management of wastes and scraps (No. 38/2015/ND-CP dated 24/4/2015) and Circular on Provision on project development and sample power purchase agreement on solar power projects (No. 18/2020/TT-BCT dated 17/07/2020), among others. Other policies like the Circular on the management of hazardous wastes define the threshold limit for hazardous materials in waste and provide management guidelines accordingly.

An EPR-based legislation for waste management in Viet Nam is being discussed. However, EoL from WP plant are not covered under this in the absence of implementing legislation. According to the draft Decree guiding the implementation of the Law on Environmental Protection (2020), an EPR-based legislation has been introduced to include the financial responsibility for manufacturers/ importers/ producers to ensure the take-back and recycling costs of collection, aggregation, transport and treatment are covered, through recycling fees. Manufacturers and importers may choose one of the following forms of recycling according to the provisions of the Law on Environmental Protection: a) Carry out the recycling by themselves; b) Hire a recycling unit to carry out the recycling; c) Fully authorize a third party to organize the recycling (hereinafter referred to as PRO). Manufacturers and importers can also choose the form of financial contribution to the Viet Nam Environmental Protection Fund. The deposit is made according to the quantity and volume of manufactured and imported products sold to the market. The deposit shall be paid and refunded at the Viet Nam Environmental Protection Fund or the provincial environmental protection fund or a financial or credit institution as prescribed by law. Where the deposit is left over, the credit institution is responsible for returning the remaining deposit to the organization or individual that has made the deposit for environmental protection.

Available Recycling Technologies – Solar PV panels

PV recycling starts with removal of junction box and aluminium frame followed by delamination of the panel to separate the solar cells, front glass and the plastic layer. Delamination techniques can be broadly classified as mechanical, thermal and chemical, with mechanical being the most commonly used due to low energy requirements and adapted to existing infrastructure. A pilot study commissioned by Sustainability Victoria found that mechanical delamination-based PV Recycling technique was the most attractive given the amount of investment and recovery rate of 85% by weight of materials (glass cullet, aluminum frame, junction box and cables). Thermal delamination methods enable purer fractions and has been shown to obtain close to 95% material recovery as shown in a pilot case study by the Korea Evaluation Institute of Industrial Technology (KEIT) funded by the Korean Ministry of Trade, Industry & Energy (MOTIE). Chemical delamination methods involve the dissolution of EVA in organic or inorganic solvents. However, these technologies are still in development and nut matured for commercial exploitation.

Available Recycling Technologies – Wind turbine blade

Recycling technologies for wind turbine blades are still in a developmental stage, at various levels of technology readiness. Cement co-processing (glass fibres are recycled as a component in cement mixes), mechanical grinding (commonly used due to effectiveness, low cost and low energy requirements) and pyrolysis (allows recovery of fibre in form of ash and polymer matrix in form of hydrocarbon products) have a higher level of maturity and closer to commercialization as compared to High Voltage Pulse Fragmentation, Solvolysis and Fluidized Bed processes.

Co-processing of wind turbine blades in cement plants is the most commercial option currently available and likely viable for end-of-life management of EOL wind turbine blades in Viet Nam. Its advantages include no separate infrastructure cost requirement, high efficiency, speed and scalability, in comparison to other available technologies. The glass fibre present in wind turbine blade waste is recycled as a component of cement mixes (clinker), while the polymer matrix is burned as fuel for the process (also called refuse-derived fuel), reducing carbon footprint of cement production.

Existing waste management infrastructure in Viet Nam for EOL Solar and Wind power installations

Currently, the collection of solar and wind power waste is not organized and is done informally, similar to e-waste, mainly performed by individuals working in scrap metalwork, equipment repairing centers and urban environmental companies (URENCO). After collection, e-waste is dismantled at big centers such as Trang Minh (Hai Phong) Bui Dau, Phan Boi (Hung Yen), Te Lo (Vinh Phuc) or private agents. Recyclable wastes such as metals, plastic and paper are sold to scrap collectors and then sent to craft villages or recycling facilities. Waste recycling technology in craft villages is mostly old and outdated, conducted in substandard infrastructures with small production scale, leading to serious environmental pollution. Most of the e-waste is manually recycled in approximately 90 craft villages scattered around the country, which use manual techniques to sort, pre-process, melt and cast the metals from e-waste ". Currently, the formal recyclers of E-waste are not competitive as they have to comply with strict environmental rules which are instead disregarded by the informal recyclers. These craft villages support around 10 million workers and have become a significant source of income for agricultural households (MONRE 2020). As of March 30, 2020, 114 hazardous waste treatment licensed companies with an overall capacity of 1.5 million tons/year operated in Viet Nam. Of these, only 15 are licensed to handle and treat e-waste, with a capacity of 0.5 - 3 tons/day each. The technology for aluminium, copper, steel, plastic and glass recycling is already available in Viet Nam, and if properly organized can already ensure the treatment of a significant amount of waste from EOL PV and WP plants.

Concerning blades, these can be first treated in existing plastic shredding and recycling facilities before they can be co-processed in cement kilns. However, the technology for the recycling of plastic in cement kiln is still not widely developed in Viet Nam, and the technology for pre-treatment of fibre-reinforced polymers (FRP) is completely missing.

Barriers for solar PV and wind power waste management

The challenges for sound management of EOL solar and wind power waste in Viet Nam quite similar to e-waste. These are:

- The lack of regulation that creates the financing mechanisms for collecting, transporting and treating waste. In the absence of regulatory obligations, there is limited interest for solar manufacturers/ developers/ installers/ importers to pay for EOL management.
- Limited inflow of products into waste stream in the initial years given that the large majority have been installed rather more recently, the waste generated from end-of-life panels and turbines is low. A report from MONRE (2020) mentions that the biggest existing problem that Viet Nam does not have an e-waste recycling industry due to the lack of stable and large enough inputs of e-waste. This makes investments in any collection and treatment unviable from a business perspective in the absence of economies of scale below a certain threshold.
- Unclear definition and classification: The point at which the solar module or wind turbine (or components/ parts thereof) becomes waste is often unclear, especially if there is an economic value still associated with it, creating ambiguity when it is a waste (generally not having any

economic value) or a product (that is bought and has a price). Moreover, whether PV panels and wind turbine blades should be classified as hazardous waste is still unclear.

- Nascent treatment technology: Recycling and treatment technologies for PV and wind power waste are still at a nascent stage around the world, and many are still in the early stages of technology readiness to move lab and pilot scale to commercial scale.

Recommendations

Since the average lifetime of renewable energy equipment varies from 20-30 years, initial waste generation will mainly be associated with equipment failure. This provides an opportunity for setting up a proper EOL management system at renewable energy plants in time to deal with the generated waste. The recommendations from the study acknowledge the identified challenges and current technological possibilities. The recommendations have been categorized into the following topics:

- Develop guidelines for waste management and categorization: A guidance document for the categorisation of solar and wind power waste and their components should be developed in collaboration with the manufacturers or importers of these plants. This will have a significant impact on the modality to be adopted for the collection, transport, and if needed, transboundary movement of these materials.

- Establish a register of licensed waste treatment facilities: A national register, available online, of all the licensed waste treatment facilities including location and waste catergories processed allows waste generators to identify appropriate disposal options.

- Strengthen the formal collection and treatment of EOL PV and WP waste: Proper collection, dismantling and sorting in a safe and environmentally sound manner requires financial support to ensure viability of the collection system and network of dismantling centers that can depollute, pre-treat and segregate the materials into fractions for further processing in licensed facilities or secondary smelters as required.

- Channelise flow to existing infrastructure for fractions already recoverable in Viet Nam and strengthen with technical specifications for recycling and recovery. This would leverage the existing industrial infrastructure for secondary raw materials in particular steel, copper, aluminium, and certain plastics. Collaborating with glass manufacturers is recommended to identify technical capacity and technical viability and adaptations which may be needed to recycle PV glass. Similarly, for components such as blades, the technical possibility and treatment standards for co-processing in cement plants needs to be established through a pilot to specify necessary safeguards.

- Deincentivise landfilling and incineration: Experience from Europe shows that landfill bans effectively divert waste from landfill and drive towards energy recovery. In Viet Nam, the combination of the increased landfill fee and ban (alongside several other waste management policies and regulations) will therefore help to ensure that residual waste treatment will be shifted significantly away from landfilling towards proper treatment methods. Incineration should also be discouraged given the poor performance of incinerators exceeding national standards for U-POPS.

- Establish a financing mechanism through extended producer responsibility (EPR): Coupling landfill restrictions with an EPR scheme may also be an effective intervention to promote collection and recycling activities of PV and Wind turbine systems. The experience of other countries in collecting and treatment of PV panels in the past years, as well as more extensive experience from waste streams such as electronics and electrical equipment (WEEE) indicates that the intrinsic material value of waste could, for the majority of waste streams, exceed the total costs of collection, aggregation, transport and treatment. Thus, a detailed cost analysis to set an operational and financial plan for the collection, transport, and recycling of such waste, with clear identification of the financial sources in alignment with the polluter pays principle is needed.

- Develop and implement legislation: Currently, according to the draft Decree guiding the implementation of the Law on Environmental Protection (2020), an EPR-based legislation has been introduced to include the financial responsibility for manufacturers/ importers/ producers to ensure the take-back and recycling costs of collection, aggregation, transport and treatment are covered, through recycling fees. Bringing EPR based legislation would create the obligation for manufacturers/ producers or importers of PV panels and WP plants to ensure that they have systems and processes in place to take-back and send the end-of-life products for recycling. The EPR-based regulation could be introduced under existing legislation preferably as a Circular. The product scope of the EPR legislation should cover all types of solar PV and WP products, including both consumer-facing products such as solar rooftop home systems as well as large B2B utility scale installations. The stakeholder process will need to explore the options for operationalization of the EPR system in detail, and identify the most relevant and suitable structure for Viet Nam. As the stakeholder process can take several years, it is suggested to embark on it at the earliest so as to have a system ready for Viet Nam when volumes increase.
- Develop capacity and awareness: A clear, consistent, and informative education and awareness campaign that is accessible to diverse communities should form a major part of any extended producer responsibility (EPR) approach. Additionally, incentives and recycler investments are required to develop domestic capability. These should be supported through fiscal and other incentives to develop recycling and treatment capacity. Training and skills support will also be required, for regulators, recyclers, manufacturers and other stakeholders in the value chain, in order to understand specificities for EOL management of solar and wind power waste.

Conclusion

Renewable energy production in Viet Nam started at a significant level only in 2018. As the lifetime of a renewable energy equipment varies from 20 to 30 years, initially there will be only limited quantites of waste. This represents an opportunity which should not be missed for setting up a proper system for the waste manage of EOL renewable energy plants.

This study provides the first opportunity to assess the baseline and estimate the potential volumes of solar and wind power waste expected in Vietnam in the coming years. The potentially hazardous as well as resource rich nature of these waste streams necessitates proper management, both from and environmental and strategic resource perspective.

Given the existing legislative frameworks, industrial capacity in Viet Nam, and the growth of the renewable energy sector, there is positive outlook for the development of sound policies, technical infrastructure and strong financing mechanism for proper handling of end-of-life solar and wind power waste in the near future.

1. Introduction

Viet Nam is among the fastest-growing economies in the world, with its economic growth characterized by high energy and carbon intensity, with emissions projected to increase threefold by 2030 as compared to 2010. The Government of Viet Nam has therefore placed high importance on climate change mitigation alongside economic growth. Towards this, the Government of Viet Nam has ratified the Paris Agreement and also adopted the Plan for Implementation of the Paris Agreement. The updated "Nationally Determined Contribution" (NDC) was approved by the Government of Viet Nam in July 2020 with an unconditional greenhouse gas (GHG) emission reduction target of 9 percent and up to 27 percent with international support to be achieved by 2030 as compared to the BAU scenario.

The climate change mitigation strategy places a strong emphasis on the development of renewable energy sources, especially solar photovoltaic (PV) and wind-based power (WP) generation. Resolution 55 by the Central Committee of the Party on "Orientations for the Viet Nam's National Energy Development Strategy to 2030 and a vision to 2045 ("Resolution 55" of the Politburo) in 2020 envisages that renewable energy will account for 15 to 20% of the primary energy in 2030, going up to 25 to 30% in 2045. The draft National Energy Development Master Plan for the period 2021-2030 with a vision to 2050 and the draft Master Plan for Power Development for 2021 - 2030 (PDP 8) with the vision to 2045 also anticipate a strong contribution from renewable energy sources. According to the draft PDP 8, the potential for solar power is nearly 386 GW, for onshore wind power is estimated at 217 GW and 162 GW for offshore wind power.

Viet Nam also has a high potential for both solar and wind-based power, added with the above policies and as a result of the attractive Feed-in-Tariff (FiT) schemes, Viet Nam has developed in the last few years a significant capacity for both solar and wind-based power. As detailed in the report, in 2020 the renewable (solar and wind) energy represented a share of 25% of the total installed power capacity. The electricity generated from these energy sources in 2020 amounted to 12,084 GWh, accounting on average for nearly 5% of the nationwide power production. Based on the draft PDP 8, the installed capacity of solar and wind power is expected to rise.

Table 2. Renewable energy installed capacity estimated as per the draft PDP 8

Power	2025	2030	2045
Solar	17.25 GW	18.64 GW	55 GW
Wind	11.320 GW	16 GW	39.61 GW

This boom in installations will reflect in the waste stream in the coming years. In the next few decades, solar modules, wind turbine blades, and ancillary components will need to be refurbished, reused, recycled, or safely disposed of.

Alongside, the Government of Viet Nam also adopted the amended National Strategy of Integrated Solid Waste Management up to 2025, vision towards 2050 on 7 May 2018 (Decision No.491/QD-TTg). The Strategy emphasizes an integrated approach to solid waste management in line with the 3Rs approach (Reduce, Reuse, Recycle) with landfilling as limited as possible.

The Government is in the process of assessing suitable models for circular economy for the next 10-year Socio-Economic Development Strategy (SEDS) 2021 - 2030 and 5-year Socio-Economic Development Plan (SEDP) 2021-2025. A specific provision on Circular Economy (article 142) has also been included in the "Law on Environmental Protection" (Law No. 72/2020/QH14).

Yet, the transition to cleaner energy is not coupled with a circular economy approach, given the absence of technical standards or requirements for the end-of-life management of renewable energy generation equipment such as solar PV panels and wind turbines.

The overall aim of this project, proposed by the Institute of Energy (IE) and the United Nations Development Programme (UNDP), is to support the Government of Viet Nam in identifying end-of-life solutions for the solar PV and wind power industry. The study has been undertaken by a team of national and international UNDP experts and a team mobilized by the Institute of Energy.

The objective of the project is to:

i) Conduct an assessment of the flow of materials and waste generated during the operation and end-of-life stage of photovoltaic and wind power generation facilities in Viet Nam;

ii) Propose a solution for the reuse, recycling, and management of such materials and wastes, taking into account the international experiences and expected life of the Photovoltaic (PV) and Wind Power (WP) plants, the specific Vietnamese trend of renewable energy generation, and the presence and needs of infrastructure in Viet Nam for the re-processing and disposal of the material and waste generated.

The methodology applied in this study is detailed below:

- Relevant data was collected during the research time including literature review from international experiences, academic articles, references from other international organizations such as UNDP, the World Bank group, IEA, IRENA, etc. and available documents in Viet Nam. The study also utilizes updated data on power and renewable projects from reliable sources such as Ministry of Industry and Trade (MOIT), provincial Department of Industry and Trade, Department Natural Resources and Environment, Power Companies and Institute of Energy (IE).
- Field survey: After referring relevant documents and considering the current situation of solar and wind power development in Viet Nam, the research team has selected 4 provinces, where solar and wind power is strongly developed, Ninh Thuan, Binh Thuan, Dak Lak and Bac Lieu. Surveys were conducted in 8 large-scale solar power plants and one wind power plant to investigate their operation schemes, technical configurations, plant efficiency, warranty term, hazardous waste management and end-of-life waste management as well as annual reports provided by the power plants' owners.

In addition, with the support from provincial power companies and local authorities, 102 local households, 6 buildings and agricultural farms with rooftop solar systems were also investigated.

- During the site surveys, interviews were carried out in tandem with 8 large-scale solar power plants, 1 wind power plant and 108 rooftop solar project owners including households, buildings and agricultural farms by semi-structured interview questionnaires to collect technical configurations and their expectations.
- Several dialogues were performed with key stakeholders from the Ministry of Industry and Trade (MOIT) and Ministry of Natural Resources and Environment (MONRE) to understand current polices and orientations on solar and winder power development, environmental management, end-of-life solutions and risk prevention. The dialogues with provincial departments of industry and trade (DOIT) and departments of natural resources (DONRE) in Ninh Thuan, Binh Thuan, Dak Lak and Bac Lieu focused on their power development plans, incentives of renewable energy and solar power, environmental monitoring and management.

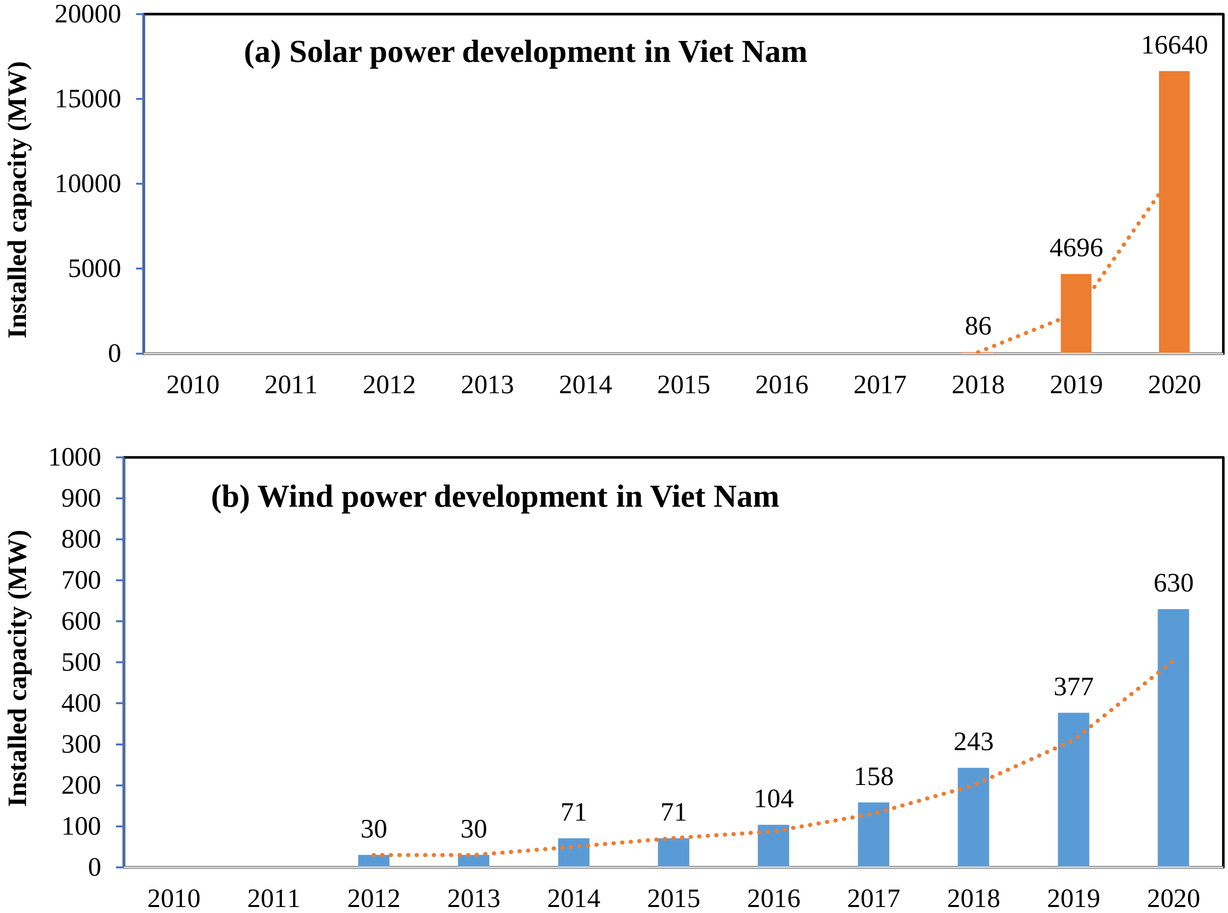

Figure 3. The development of wind and solar power in Viet Nam in the last 10 years

2. Overview of Renewable Energy Development in Viet Nam and End-of-Life Management of Solar Photovoltaic and Wind Power Systems

2.1. Viet Nam policy on renewable energy development

The development of renewable energy started from 2012. Since then, several policies and decisions have been adopted by the government. The key policies relevant in this context are:

- Decision No. 1216/QD-TTg of the Prime Minister dated 05/09/2012 on approving the National environmental protection strategy by 2020 and the orientation to 2030, intending to reduce GHG emissions in which renewable energy is encouraged.
- Decision No. 2068/QD-TTg of the Prime Minister dated 25/11/2015 on approving the Renewable Energy Development Strategy to 2030 with outlook to 2050. Based on this Decision, the proportion of electricity production generated from renewable energy (including both large and small hydropower) was expected to reach 38% by 2020, 32% in 2030, and 43% in 2050.
- Resolution No. 55 issued by the Central Committee of the Party (so-called "Resolution 55" of the Politburo) on the Viet Nam's National Energy Development orientation to 2030 with a vision to 2045 envisaged that renewable energy would account for 15 to 20% of the primary energy in 2030 and 25 to 30% in 2045. The proportion of renewable energy in the national electricity production should reach about 30% in 2030 and 40% in 2045.

- The draft National power development plan in the period of 2021 - 2030 and with a vision to 2045 (PDP 8) gives priorities to the rational development of renewable energy sources. Six development scenarios are set out, in which Scenarios No. 1, 2, 3 aim to increase the share of renewable energy at a higher level, more specifically:
  i. Scenario No.1 envisages the implementation of the National Renewable Energy Development Plan and Resolution No. 55 of the Politburo with renewable energy shares reaching 32% in 2030, 40% in 2040, and 43% in 2050.
  ii. Scenario No. 2 assumes a linear rise of renewable energy, reaching a share of 43% in 2050.
  iii. Scenario No. 3 envisages the largest development of renewable energy in the country, with a share reaching 42% in 2030, 48% in 2045 and 50% in 2050.
  iv. Scenario No. 4 adds a target of GHG reduction as mentioned in the Viet Nam's updated Nationally Determined Contribution (NDC) in 2020.
  v. Scenario No. 5 envisages that no new coal-fired power plants will be built after 2030.
  vi. Scenario No. 6 considers nuclear power development after 2035 with a capacity of 1,000 MW in 2040 and 5,000 MW in 2045.

2.2. Incentives for renewable energy investment

Viet Nam requires around US$13 billion annually between 2021 and 2030 to keep pace with the growing demand for renewable energy[1]. To meet the high capital requirements, the Government is making the sector attractive for foreign investors by allowing 100% foreign ownership of companies in the energy sector. In addition, under the Law on Investment, renewable energy projects are eligible for special investment incentives, as follows:

- Corporate income tax preferences: Income from new investment projects for renewable energy production will be subject to corporate income tax (CIT) at the rate of 10% for the first 15 years (Decree No. 218/2013/ND-CP) or corporate income tax exemption for 4 years, and a reduction of 50% for the following 9 years. Enterprises producing electricity from renewable energy able to meet several criteria according to Decision 693/QD-TTg can benefit from a preferential CIT rate of 10%.
- Import duty preferences: There is an exemption from import duty in respect of goods imported to construct or form fixed assets, such as raw materials, manufactured materials, and components. In addition, the renewable energy projects have import tax exemption within 5 years from the COD for raw materials, supplies, and components that cannot be produced domestically.
- Land related incentives: Investors can be entitled to exemption from the land use fee that would usually apply for 11 years or, in cases where the investment project is in a region facing extreme socio-economic difficulties, 15 years.

[1] Draft PDP8 in February, 2021 - https://moit.gov.vn/thong-bao-moi/bo-cong-thuong-xin-y-kien-gop-y-du-thao-de-an-quy-hoach-phat2.html

2.3. Solar power

2.3.1. Policy for Solar power development

Towards achieving ambitious targets described above, the Government of Viet Nam has set in force several mechanisms to promote the development of renewable energy. Key policy drivers boosting solar power are:

- Decision No.11/2017[2] that establishes rules on the tariff, loan, land clearance, transmission and distribution networks. The incentive structures giving preferential prices (feed-in-tariffs - FiT) and purchase guarantees help minimize the risks associated with varying natural conditions. All generated solar power is purchased by the state-owned Electricity of Viet Nam (EVN).
- Decision No. 02/2019/QD-TTg on amendments and supplements to certain articles of Decision No. No.11/2017/QD-TTg[3] establishing that the calculation of the energy generated by rooftop solar plants and sold to the network is based on the measurement taken by 2-way meters, with separate delivery and receiving directions. This decision also promulgates technical regulations on solar power, regulations on connection, metering, connection procedures, and meter installation of rooftop solar power projects.
- Decision No. 2023/QD-BCT dated 05/07/2019 by (MOIT)[4] approving the promotion program on rooftop solar PV power with the target of 100,000 rooftop solar panels, equivalent to 1000 MWp in 2025.
- MOIT circular from January 2020[5] establishing rooftop solar power systems of construction projects with a capacity of less than 01 MWp are directly and indirectly connected to the low-power grid (less than 35 kV). The temporary price from rooftop solar power projects after 30/06/2019 has been set to VND 1,916 per kWh equivalent to US cent 8.38 per kWh.
- Proposal by MOIT[6], outlining a pilot program on direct power purchase agreement (DPPA) mechanisms. The DPPA program will allow energy producers to sell and buy electricity to corporate consumers instead of going through the state-owned electric utility companies. The proposal sets a two-year timeframe for implementing the pilot programs and lays down criteria for participating developers and private power consumers.
- Decision No.13/2020/QD-TTg to replace Decision No.11/2017/QD-TTg[7] on the incentive mechanism for solar power in Viet Nam. This new decision, effective from 22/5/2020, specifies the new tariffs for grid-connected solar power plants (see Table 3). Although the new tariffs are 10 to 24% lower, they are still competitive and remunerative for the investors. A special purchase price has been established for Ninh Thuan province, provided that the total cumulative capacity does not exceed 2,000 MW (see Table 3.).

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[2] Decision No.11/2017/QD-TTg dated 11/04/2017 on encouraging mechanisms for solar power development in Viet Nam.

[3] Decision No. 02/2019/QD-TTg on amendments and supplements to certain articles of the Decision No. No.11/2017/QD-TTg

[4] Decision No. 2023/QD-BCT dated 05/07/2019 by the Ministry of Industry and Trade (MOIT)

[5] Document No. 89/BCT-DL dated 06/01/2020 to notify the EVN on the encouraging mechanism for rooftop solar power development.

[6] Proposal No.544/TTr-BCT on 21/01/2020

[7] Decision No.13/2020/QD-TTg to replace Decision No.11/2017/QD-TTg that expired in June 2019

Table 3. FiT mechanisms for solar energy projects in Viet Nam

No.	Regulatory documents	Type of project			Validity
		Ground-mounted	Floating	Rooftop	
1	Decision No.11/2017/QD-TTg dated 11/4/2017	2086 VND/kWh 9.35 US cent/kWh			30/6/2019
2	Decision No.13/2020/QD-TTg dated 6/4/2020	1644 VND/kWh 7.09 US cent/kWh	1783 VND/kWh 7.69 US cent/kWh	1943 VND/kWh 8.38 US cent/kWh	31/12/2020
	Ninh Thuan province	2086 VND/kWh 9.35 US cent/kWh			

- MOIT Circular No. 18/2020/TT- BCT dated 17/07/2020 stipulates the development of solar power projects, sample power purchase agreements (PPA) and regulates the land use rate of solar power projects not exceeding 1.2 ha/MW.
- In the near future, Viet Nam intends to implement an auction mechanism. All projects, which do not qualify for the new FiT rates established by Decision No. 13/2020/QD-TTg, will go through a competitive bidding process. By giving the Government the ability to issue a call for tenders and select the most price-competitive firms, the scheme will help to better manage the development of renewable energy across the country. Recently, under the support from the World Bank group, the Government of Viet Nam has issued the solar competitive bidding strategy and framework (World Bank, 2019)[8], in which Viet Nam could pilot competitive bidding through two different schemes: (i) substation-based competitive bidding and (ii) solar park competitive bidding (ground-mounted and floating). Both schemes aim to reduce the development risks perceived by independent power producers (IPP), thus reducing the risk premium in the cost of capital.

[8] https://documents1.worldbank.org/curated/en/949491579274083006/pdf/Vietnam-Solar-Competitive-Bidding-Strategy-and-Framework.pdf

2.3.2. *Current and projected photovoltaic installation*

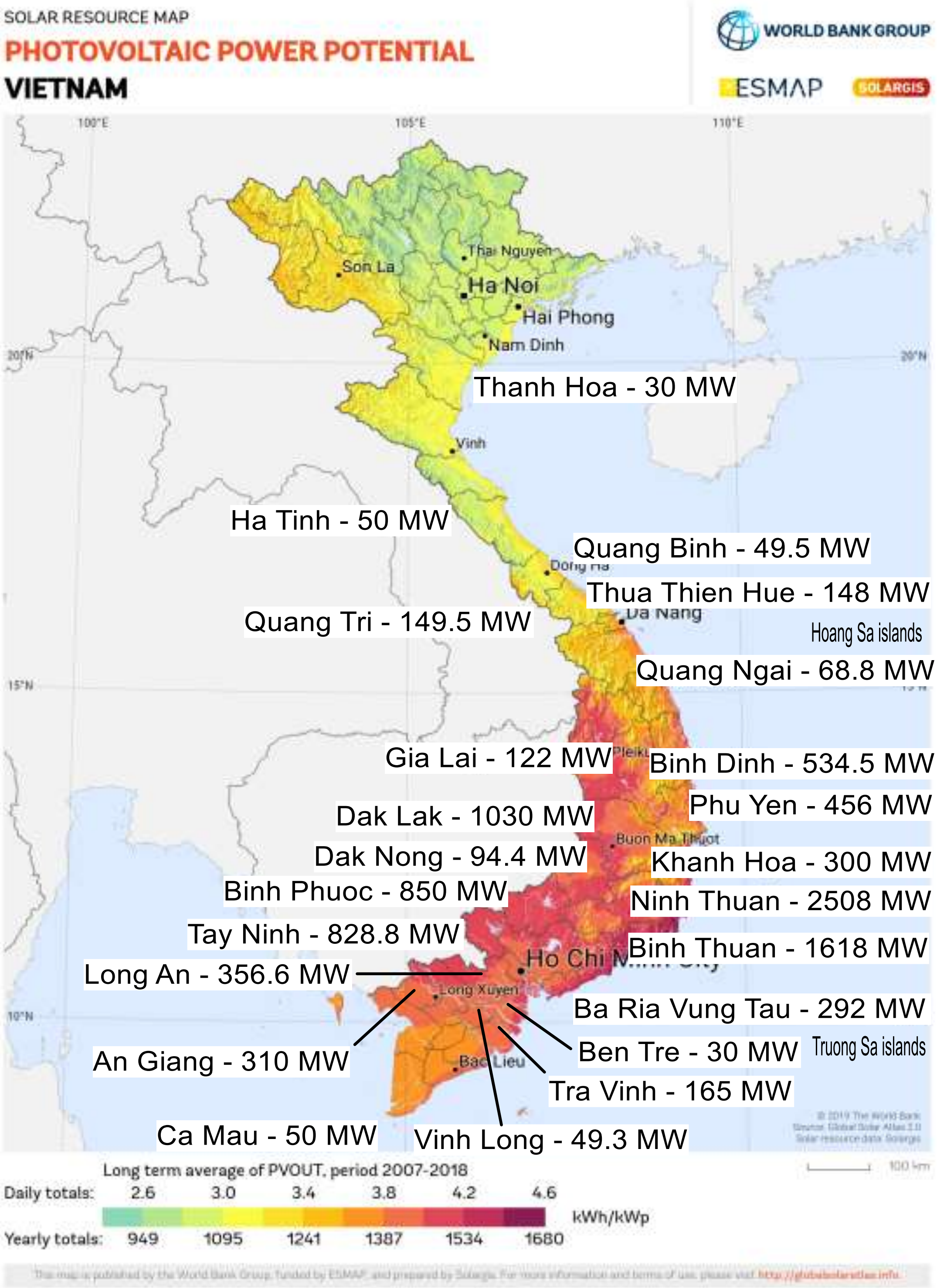

Figure 4. Existing utility solar power capacity in Viet Nam by provinces overlapped on the photovoltaic power potential map published by the World Bank group

Until as recently as 2017, installed renewable energy capacity in Viet Nam remained limited. As of August 2017, the total installed solar PV capacity was only about 28 MW, mainly small-scale off-grid systems and some pilot low-voltage projects on buildings and offices. Since then, government policy has significantly driven investment in renewable power. The first solar power plant in Viet Nam, the TTC Phong Dien 1 located in Dien Loc commune, Phong Dien district, Thua Thien – Hue province, started production on 5 October 2018 after 6 months of construction[9], with a total capacity of 35 MW.

By the end of 2020, the total solar power capacity put into operation reached 16.640 GW with an electricity output of 12,084 GWh as of 2020 (see Figure 3), with most projects concentrated in the central and southern regions where solar radiation is higher than other regions (see Figure 4). The grid-connected solar power sources, put into operation, raised about 9,000 MW. Together with utility-scale projects (including ground-mounted and floating projects), the rooftop solar PVs also experienced a sharp growth. Until the end of 2019, the installed capacity of PV roofs nationwide was only 340 MWp (272 MW), but by the end of 2020, the total installed capacity reached 7,780 MW. The majority of solar power systems are located in the Central and the South regions where the solar irradiation is higher (see Figure 4). In 2021, about 130 utility-scale solar projects are operational in Viet Nam.

The Xuan Thien group set up the largest solar power plant in Viet Nam and Southeast Asia. The Xuan Thien – Ea Sup plant has a capacity of 600 MW(ac)/831 MWp[10], with phase 1 operational from 15 November 2020 (see Figure 5). Phase 2, with a planned capacity of 1,400 MW is under construction in Ia Rve commune, Ea Sup district as of 2020. The provinces in the Southeast region (including Ho Chi Minh City) are the leader in rooftop solar PV installations with both the number of projects and the total installed capacity (see Figure 4).

A bottleneck is represented by the transmission grid being unable to match the pace of solar power development. The construction time of solar projects is very fast, only about 6-12 months, mainly in a number of potential provinces such as Ninh Thuan, Binh Thuan, Dak Lak, etc. are putting great pressure on the power transmission system (Because the transmission grid cannot be built synchronously. The construction period for 220 kV grid is at least 3 years, 500 kV grid is from 4-5 years). Therefore, at present, the National Dispatch Center always has to calculate and request daily reduction of the generating capacity of solar power plants in concentrated development areas (Ninh Thuan, Binh Thuan, An Giang, etc.) to avoid overloading the regional grid.

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[9] https://baodautu.vn/khanh-thanh-nha-may-dien-mat-troi-35-mw-dau-tien-tai-viet-nam-d88820.html

[10] https://doanhnghiephoinhap.vn/nha-may-dien-mat-troi-xuan-thien-ea-sup-lon-nhat-dong-nam-a-dong-dien-thanh-cong-hoa-luoi-dien-quoc.html

Figure 5. Solar power panels in Xuan Thien – Ea Sup[11]

According to our surveys with 8 large-scale solar power plants and interviews with 7 project developers, the majority of solar power plants in Viet Nam came on stream in 2019. They are therefore currently under the manufacture's guarantee period - typically 12 - 20 years for PV panels and 5 years for inverters. Same as utility-scale solar power plants, most of PV panels in rooftop facilities have come from well-known bands, i.e. Canadian Solar, Longi, Q Cell, Jinko Solar, etc. via local suppliers and installers. According to the annual reports provided by solar power plants, catalogs, the efficiency degradation rates of solar PVs are about 0.5 to 1.1% per year, in line with manufacturer claims. Most reputable manufacturers guarantee their solar cells with a maximum performance degradation rate of 10% for the first 10 to 12 years and a maximum of 20% after 25 years.

An estimated 28 million solar panels are currently installed in utility-scale plants. Our research shows that more than 95% of solar power plants in Viet Nam utilize crystalline silicon PV panels, with less than 5% using thin-film panels. Of the crystalline silicon PV panels, more than 70% are monocrystalline, about 25% polycrystalline solar panels, and the balance is of the mono half-cell type. The efficiency of solar PVs varies from 17 to 21.3 %. On average, the panel capacity increased yearly from 265 W in 2019 to 330 W and 365 W in early 2020 and 470 W at the end of 2020.

As per our survey, there are still very few faulty PVs currently in large-scale solar power plants - only 0.002 - 0.04% of the total number of panels in a plant (8/123,200 panels in Hong Phong 4, 3/153,600 panels in Gelex, 60/151,520 panels in Sinenergy Ninh Thuan and 22/700,000 panels in Trung Nam - Ninh Thuan power plant). We estimate approximately 560 - 11,000 faulty panels in total 30 million solar PVs at present, weighing between 13 - 251 tons, considering an average mass of a panel of 22.5 kg. In the absence of regulation for end-of-life (EOL) management of solar panels, many plants keep the faulty panels with other electric waste on their sites. Some plants such as Sinenergy and Trung Nam - Ninh Thuan have given their faulty panels to licensed waste management units to treat as hazardous waste. The current installed capacity of rooftop solar power is approximately 7.7 GW, with most plants ranging from 330 W to 440 W, translating into an estimated 17.5 – 23.5 million rooftop PV panels. Thus, the number of faulty solar PVs in rooftop systems is small, accounted approx. 0.04% of total installed panels.

[11] http://nangluongvietnam.vn/news/vn/dien-hat-nhan-nang-luong-tai-tao/dong-dien-nha-may-dien-mat-troi-xuan-thien-ea-sup-giai-doan-1.html

Based on the current classification of electric and electronic waste, EOL PV panels should be considered hazardous waste unless the components containing hazardous materials are removed and properly disposed of. However, sometimes faulty or broken panels, instead of being properly disposed of, are used as fences, rooftops of livestock barns, or sold to unofficial waste collectors. Although at this stage, the number of broken PVs is very limited, if this informal management of PV panels is not stopped now, once the amount of EOL PV will become significant, the prohibition of this informal management could face social issues.

2.3.3. *Year wise estimation of material flows from End-of-life PV systems*

According to the scenarios in the draft PDP 8, the installed capacity of solar power will increase from 16.6 GW to maximum 20.1 GW in period of 2021 – 2030, accelerating to 71.9 GW in 2045 under the high scenario (see Table 4). With a panel capacity of 330 – 440W, and taking into account the technological improvements in panel capacity, with fewer panels needed for the same power, an estimated 50.9 – 62.1 million PV will be installed by 2030 and upto 150 – 220 million panels by 2045.

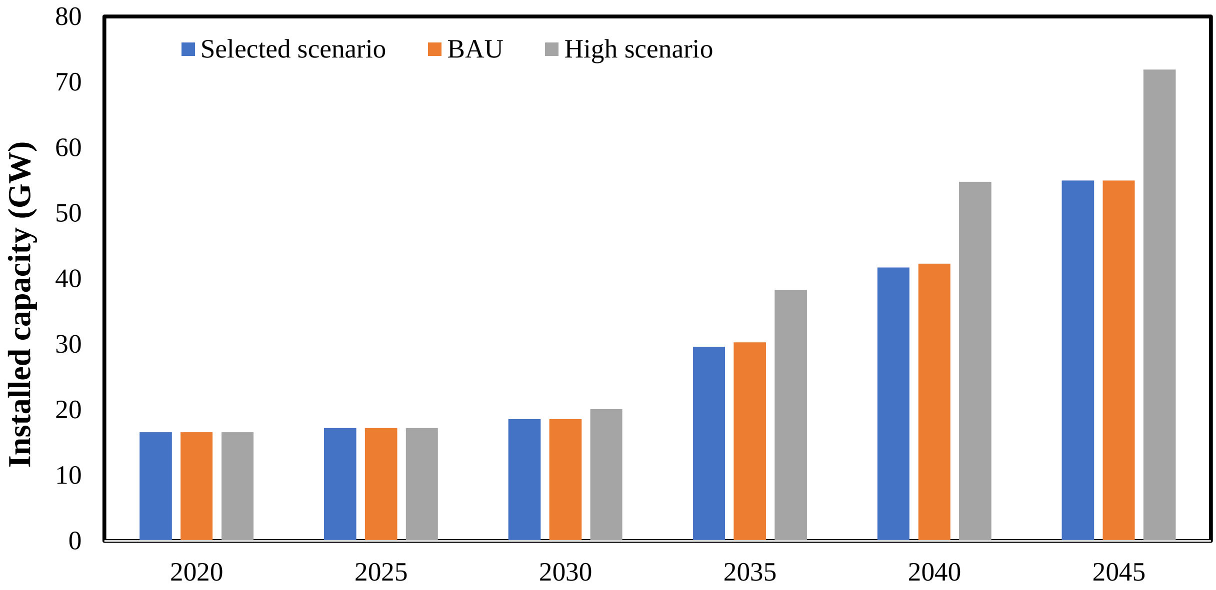

Figure 6. Solar power development progress in period 2020 – 2045
(Source: The draft PDP 8)

Table 4. Solar power development in the draft PDP 8 in different scenarios (in GW)

No.	Scenarios	2020	2025	2030	2035	2040	2045
1	Selected scenario	16.6	17.2	18.6	29.6	41.7	55.0
2	BAU	16.6	17.2	18.6	30.3	42.3	55.0
3	High load scenario	16.6	17.2	20.1	38.3	54.8	71.9

Following the methodology proposed by IRENA[12], the estimation of waste generation from EOL PV is calculated based on a Weibull distribution and the selected PDP8 scenario, as shown in the equation below:

$$F(t) = 1 - e^{-(\frac{t}{T})^{\alpha}}$$

Where:

F(t): Probability of failure during life cycle

t: time in year

T: average lifetime

α: shape factor, which controls the typical S shape of the Weibull curve

The shape factor α is divided in to 2 scenarios of “early loss” and “regular loss”. In the early loss scenario, 2% will become waste after ten years and 4% will become waste after 15 years due to technical failures. Table 5 lists out the assumptions used in this forecasting model.

Table 5. Weibull shape factors for forecasting model (Source: IRENA[13]),

Scenario	Early loss	Regular loss
Shape factor α	2.4928	5.3759
Average panel lifetime	30-year	30-year
Probability of loss after 40 years	99.99 %	99.99 %
Waste due to damage during transport and installation phases	0.5 % of PV panels	0.5% of PV panels
Waste within two years due to bad installation	0.5 % of PV panels	0.5% of PV panels

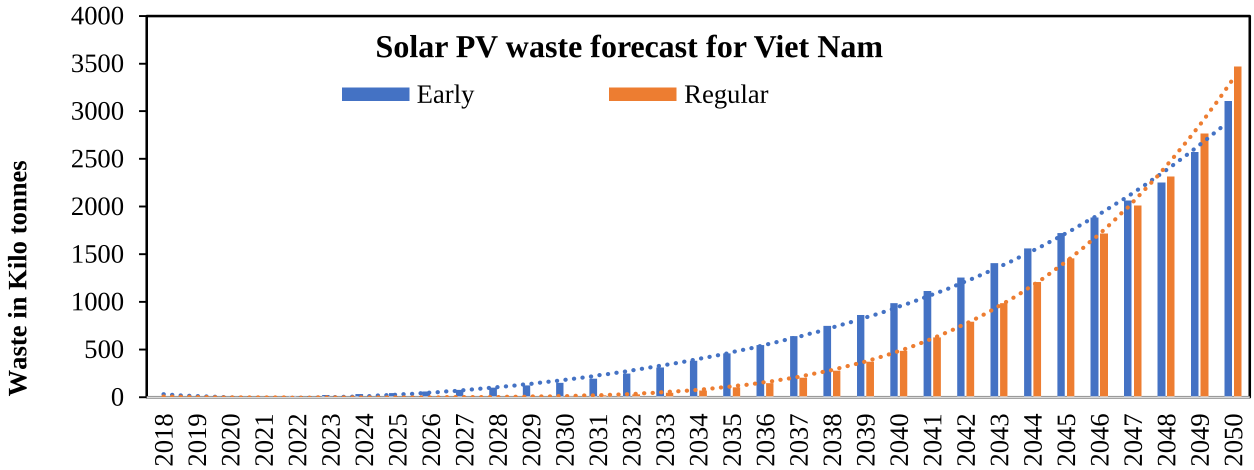

Figure 7. Solar power waste forecast in period 2020 – 2050

[12] IRENA-EoL management of Solar PV

[13] IRENA-EoL management of Solar PV

Based on this methodology, the cumulative PV waste for 2030 are 235 kilo tonnes and 18 kilo tonnes for early and regular scenarios respectively. By 2045, the cumulative PV waste rises to 1.959 million tonnes and 1.777 million tonnes for ealy and regular scenarios and subsequently the cumulative solar PV waste in 2050 is estimated as 3.110 million tons in the early loss scenario and 3.468 million tons in the regular loss scenario. The forecasted PV waste volumes are as a result of loss profiles as indicated in Table 6. It is to be noted that waste volume for a particular year, is a result of earlier installations and should not be compared with the installation target for that year of interest.

Based on material composition data from Fraunhofer-Photovoltaics Report 2020, solar power installations comprise of a mix of glass, metals and plastics[14]. The detailed composition breakdown can be found in Table 6.

Considering the share of panel types installed in Viet Nam, the material flow forecast from EOL solar power plants up to the year 2050 in the 2 scenarios is given in Table 6.

Table 6. Material flow forecast for EOL solar power plants in Viet Nam

Year	Scenario	2025	2030	2035	2040	2045	2050
Cumulative waste forecast up to 2050 (Kilo Tons)	**Early loss**	**44**	**151**	**460**	**984**	**1,721**	**3,110**
	Regular loss	**1**	**11**	**103**	**487**	**1,455**	**3,469**
Glass (in Kilo Tons)	Early loss	30	105	318	680	1,190	2,149
	Regular loss	0	8	71	337	1,006	2,398
Aluminum frame (in Kilo Tons)	Early loss	8	27	82	175	306	553
	Regular loss	0	2	18	87	259	616
Junction Box (in Kilo Tons)	Early loss	0	0	1	6	18	44
	Regular loss	1	2	6	12	22	39
Cable (in Kilo Tons)	Early loss	0	1	5	10	17	31
	Regular loss	0	0	1	5	14	34
Plastics (EVA + Backsheet) (in Kilo Tons)	Early loss	3	10	30	64	112	203
	Regular loss	0	1	7	32	95	226
Silicon (in Kilo Tons)	Early loss	2	5	17	35	62	112
	Regular loss	0	0	4	18	52	125
Silver (in Tons)	Early loss	22	76	230	492	861	1,555
	Regular loss	0	5	52	244	728	1,734
Copper (in Tons)	Early loss	48	167	506	1082	1894	3,420
	Regular loss	1	12	113	536	1601	3,816
Aluminum (in Tons)	Early loss	229	787	2391	5114	8952	16,169
	Regular loss	3	57	536	2533	7566	18,038
Lead (in Tons)	Early loss	15	51	154	329	577	1,042

[14] https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Photovoltaics-Report.pdf

Year	Scenario	2025	2030	2035	2040	2045	2050
	Regular loss	0	4	35	163	487	1,162
Tin (in Tons)	Early loss	5	17	53	113	198	358
	Regular loss	0	1	12	56	167	399

Based on the inventory as above, glass volume is accounted for 69% of total solar EoL waste weight, 28% is shared by metals (Silver, Copper, Aluminum, Lead and Tin). The remaining (approx. 3%) is from plastics, silicon, etc. This shows good potential for recycling this valuable resource and promoting the Circular Economy model. As explained in section 4.5, however, some end-of-life materials – like glass – may be still classified as hazardous if they contain concentration of hazardous chemicals above the regulatory thresholds established by the regulation. The identification of hazardous waste is therefore a key capacity for the proper management of EOL PV in the perspective of Circular Economy.

For Solar PV systems, assuming battery storage is included in PV systems installed from 2021 and assuming lead-acid battery is used in initial installations upto 2030 weighing around 75 kg per kWh of usable capacity and lithium-ion battery usage in installations beyond 2030 typically weighing around 12.5 kg per kWh, the following estimation has been carried out. The lifespan of a battery system is assumed as 5 years[15] with 25% capacity factor for solar PV systems and assuming 30% of energy generated in stored in batteries.

Table 7 depicts the forecasted cumulative battery waste for Viet Nam based on the above assumptions. 27.5 million tonnes of battery waste is expected in the next 10 years with a exponential increase to 395 million tonnes by 2050. The reason for such high volumes is the lower lifetime of batteries (5 years). Regarding the type of battery waste, majority of waste is expected to be of lead acid battery waste untill 2035 with lithium ion waste expected to increase after 2035. This can be attributed to the technology shift that is taking place in the battery sector from lead acid to lithium ion. It must also be noted that the high waste volume of batteries is made with a assumption that Solar PV plants will be accompanied by battery storage. Future research needs to be done to undsertand the percentage of standalone PV plants compared to PV plants with battery storage in order to obtain detailed insights on waste generation.

Table 7. Cumulative battery waste estimated for Solar PV installation in Viet Nam

Year	2030	2035	2040	2045	2050
Cumulative Battery waste (Million Tonnes)	27.5	96.5	186	286	395

[15] https://www.fluxpower.com/blog/lithium-ion-vs.-lead-acid-battery-life

2.4. Wind power

2.4.1. *Policy for Wind power*

Similar to policy drivers for solar power, wind power generation is also supported through key policy interventions. Key policy drivers boosting wind power are:

- Decision No. 37/2011/QD-TTg[16] dated 29 June 2011 by the Prime Minister on "A mechanism to support the development of wind power projects in Viet Nam". This decision stipulates that "electricity buyers (EVN or its authorized subsidiaries) were responsible for purchasing the entire electricity output from wind power projects with the price of VND 1,614 VND per kWh (excluding value-added tax, equivalent to US cents 7.8 per kWh). The state also subsidized VND 207 per kWh for wind power electricity buyers through the Viet Nam Environmental Protection Fund. Wind power projects are not connected to the national electricity grid (on islands), in addition to incentives in terms of investment capital, taxes, fees and land infrastructures, also received special incentives on power purchase prices.
- Decision 39/QD-TTg[17] from September 2018 concerning the FiT for wind power plants. The "wind FiT" (excluding VAT) will be VND 1,928 per kWh (equivalent to US cents 8.5 per kWh) for onshore wind power projects and VND 2,223 per kWh (equivalent to US cents 9.8 per kWh) for offshore wind power projects. This replaces the previous wind FiT of US cents 7.8 per kWh. This new FIT will be applicable to wind power projects that achieve commercial operations before 1 November 2021 and will be valid for 20 years from the commercial operations date (COD). This new FIT is also applicable to wind power projects operating before the issuance of Decision 39, for the remaining term of their signed PPAs.
- MOIT Circular 02[18] effective on 28 February 2019, aims to attract further investment into Viet Nam's wind energy market. Replacing previous regulations, the circular updates the review and approval process of wind power project applications. The circular streamlines, and in some cases, tightens conditions such as land-use rate that is now limited to 0.35 ha per MW, as compared to the previous threshold of 0.5 ha per MW. It also stipulates a revised PPA sample that is a mandatory requirement and prohibits parties from making revisions that are contrary to the provisions of the PPA sample.

2.4.2. *Current and projected WP installation*

Wind power installations have also gone up significantly, from 30 MW in 2012 to 630 MW by 2020 (see Figure 3) and several projects are under construction. The total capacity of wind power plants with signed PPAs with EVN has already reached 3,000 MW as of end of 2020. By December 2020, more than 12,000 MW were approved by competent authorities, both nationally and regionally. These projects are concentrated mainly in the Central region, the Central Highlands, and the Mekong River Delta (see Figure 8). The Xuan Thien group has invested in an offshore wind power plant with capacity of 5,000 MW in Binh Thuan province[19].

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[16] Decision No. 37/2011/QD-TTg on A mechanism to support the development of wind power projects in Viet Nam

[17] Decision No. 39/2018/QD-TTg on amending several articles of the Decision No. 37/2011/QD-TTg

[18] Circular No. 02/2019/BCT on wind power project development and power purchase agreement

[19] http://www.pecc1.com.vn/d4/news/Dong-dien-Nha-may-dien-mat-troi-Xuan-Thien-Ea-Sup-giai-doan-1-8-1650.aspx

Figure 8. Existing wind power plants in Viet Nam

According to the draft PDP 8, there are 16 wind power plants in Viet Nam with capacity ranging from 4 to 64 MW, with 249 installed turbines, each with a capacity of between 1.6 – 4 MW. According to our survey, as most are only recently installed, the plants are still in their guarantee periods, thus no EoL from wind power plants was found.

2.4.3. *Year wise estimation of material flows from End-of-Life WP systems*

According to the draft PDP 8, only onshore and near-shore wind power is expected until 2030, after which offshore wind power will start to come on stream. In total, the onshore, near-shore, and offshore installed wind power capacity is expected to increase to between 55 - 76 GW by 2045 under the most conservative and most ambitious scenarios respectively.

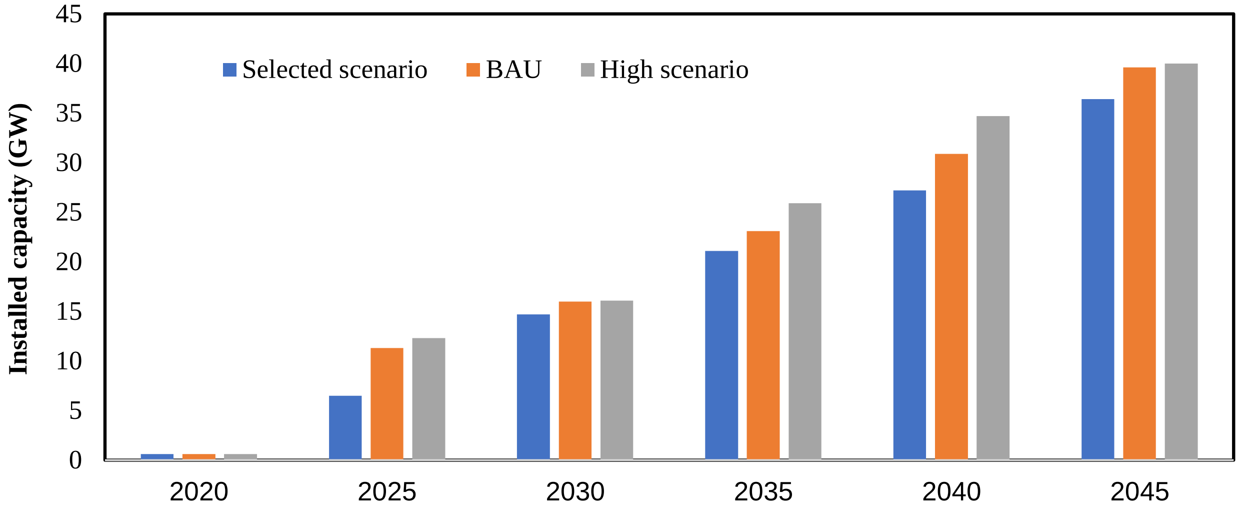

Figure 9. Onshore and nearshore wind power capacity

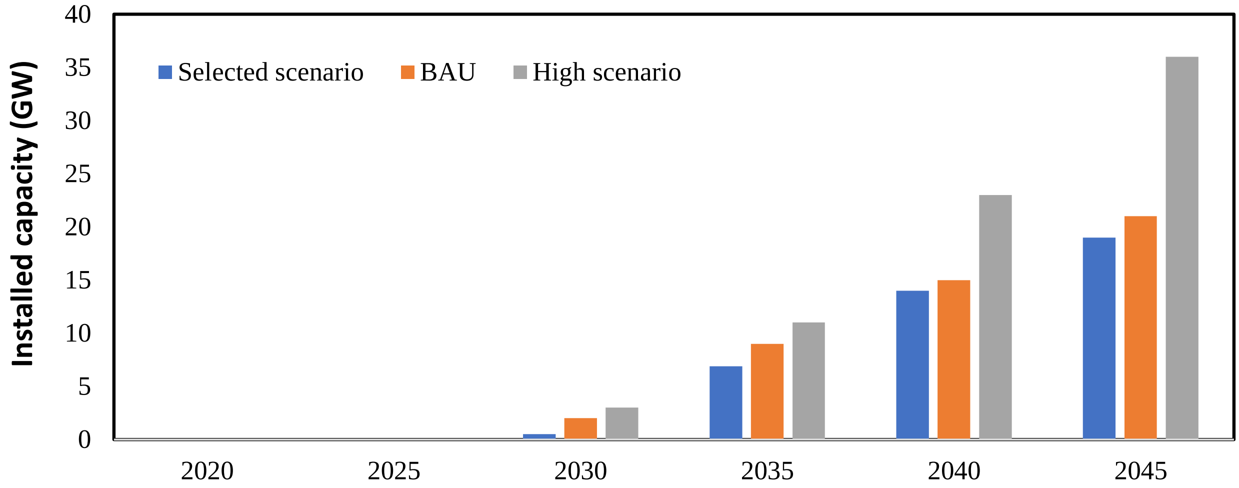

Figure 10. Offshore wind power capacity

Table 8. Wind power development in the draft PDP 8 in different scenarios (Unit: GW)

No.	Scenarios	2020	2025	2030	2035	2040	2045
Onshore and nearshore wind power							
1	Selected scenario	0.6	6.5	14.7	21.1	27.2	36.4
2	BAU	0.6	11.3	16.0	23.1	30.9	39.6
3	High load scenario	0.6	12.3	16.1	25.9	34.7	40.0
Offshore wind power							
1	Selected scenario	0	0	0.5	6.9	14.0	19.0
2	BAU	0	0	2.0	9.0	15.0	21.0
3	High load scenario	0	0	3.0	11.0	23.0	36.0
Total wind power							
1	Selected scenario	0.6	6.5	15.2	28	41.2	55.4
2	BAU	0.6	11.3	18	32.1	45.9	60.6
3	High load scenario	0.6	12.3	19.1	36.9	57.7	76

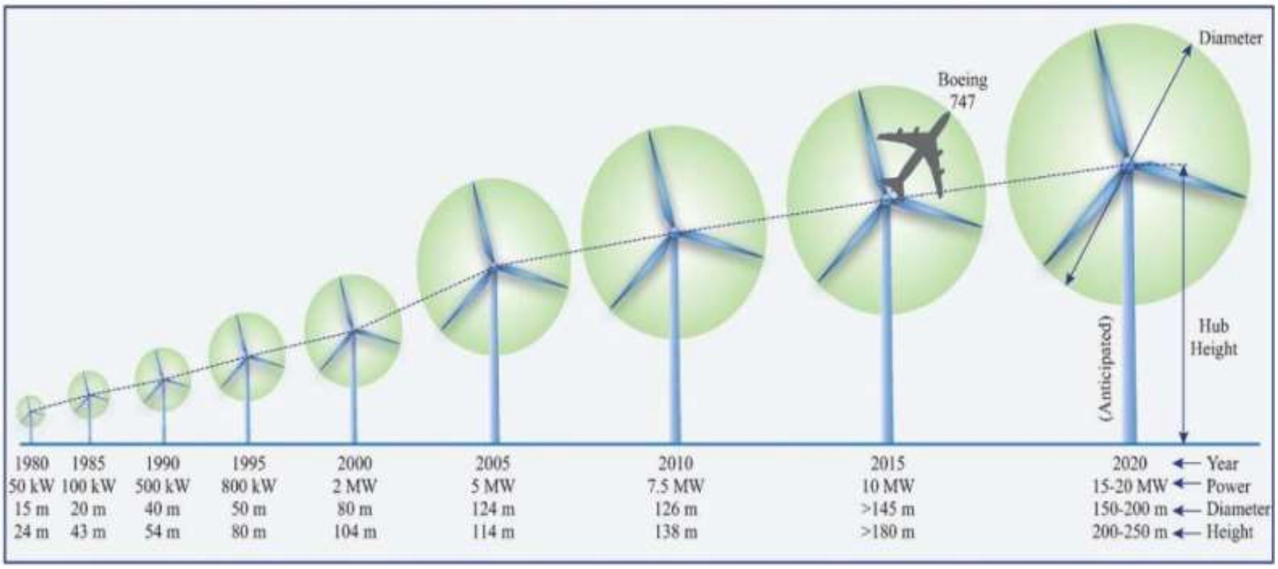

Figure 11. The development of wind turbines and blades (Source: draft PDP 8)

Although current turbines have a capacity of 4 - 5 MW, the expected advances in technology will mean that new wind power plants may have a range of 5 - 15 MW turbines. The parameters of this turbine technology will be 124 - 150 m of diameter, 114 - 200 m height (see Fig. 9 above). Thus, an estimated 1010 - 3820 thousand in 2030 and 3,700 – 15,200 thousand in 2045. Stafell and Green, 2014[20] stated that wind turbines are found to lose 1.6 ± 0.2 % of their output per year.

Wind blade waste volume is calculated based on Liu et al. 2017[21] and the selected scenario of draft PDP8. For Viet Nam, manufacturing waste is excluded as most wind turbine installations are imported. Compared to Solar PV panel, wind turbines are a assembly of different components and hence Weibull distribution cannot be used for forecasting the whole of wind turbines. Wind turbine blades are the most prone to failure given their continuous motion. Liu et al have collected empirical data on the failure rate of wind turbine blades across categories like routine O&M waste, accidental O&M waste and repowering (upgrading) waste. The research suggests that wind turbine blades can suffer a routine O&M failure at rate of 1-2% in 6th year of operation and can fail at rate of 1-3% due to accidents around the 6th year for regular and early scenarios respectively. The End- of- Life of wind turbine blade is reached in 18th - 26th year in early and regular scenario. These failure rates are used to calculate and forecast wind turbine blade waste.

Table 9. Wind blade failure assumption as per Liu et al.

Life cycle	Service/O&M related waste (% of annual tonnage of wind blade introduced)				EoL waste
	Routine O&M waste (6th year)	Accidental O&M waste (6th)	Total waste generated in 6th year	Upgrading waste (16th)	
Early	2 %	3 %	5 %	10 %	18th year
Regular	1 %	1 %	2 %	2 %	26th year

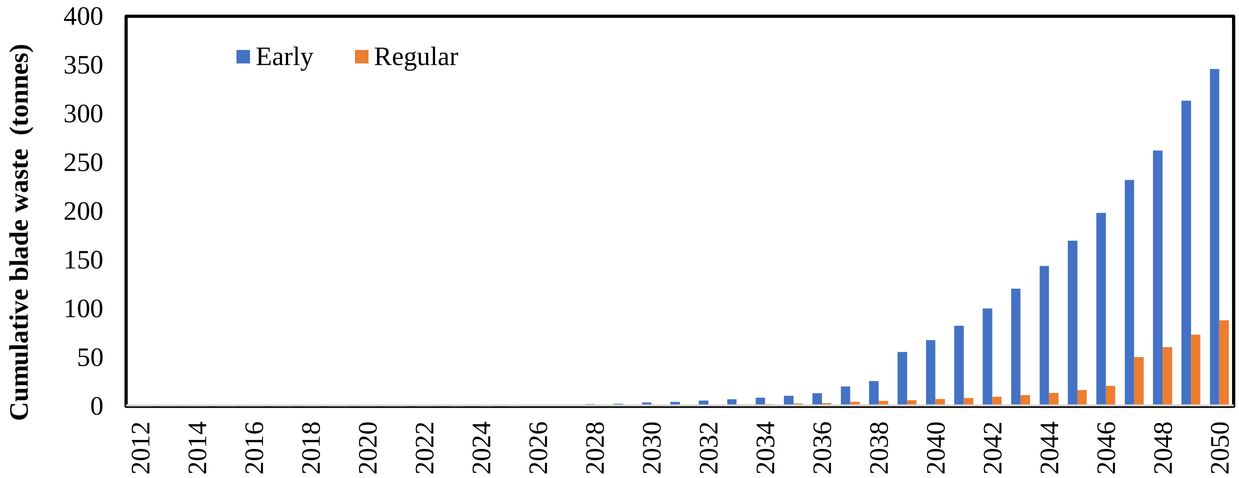

Figure 12. Wind turbine blade waste only -forecast (cumulative upto 2050)

The forecast of material flow from EOL wind turbines is based on the material composition and estimated EOL volumes, with the assumption that the entire wind turbine will be dismantled on

[20] Staffell, I., & Green, R. (2014). How does wind farm performance decline with age?. *Renewable energy*, *66*, 775-786.

[21] Liu, P., & Barlow, C. Y. (2017). Wind turbine blade waste in 2050. *Waste Management*, *62*, 229-240.

failure. The Table 10 gives the detailed material breakdown in both the early loss and regular loss scenarios described above. The material composition of wind turbines is taken from *Jensen, 2019*[22].

It is estimated that between 19.3 and 66.9 kilo tons of end of life wind turbine waste would be generated in VietNam by 2030 based on the early loss and regular loss scenario respectively. By 2040, the cumulative waste generation rises to 112.9 to 1171 kilo tons for and by 2050 the wind turbine waste volume reaches between 1484 and 5057 kilo tonnes for early loss and regular loss scenario respectively.

From the table below, is rather evident that the bulk of the waste stream associated with the dismantling of wind turbines may be recycled in conventional facilities. This is the case for instance of ferrous metal, aluminum, and copper, which may be recycled in secondary metal plants, whilst wood may be recycled either as material or in waste-to-energy plants. The most important waste stream requiring specialized treatment, as explained in other part of this report, are the composite materials which are mostly utilized for the manufacturing of wind blades and for the casing of the nacelles. The best option for this material would be the recycling - as material and energy at the same time – in cement kiln plants, although this would require the development of pre-treatment capacity and development of suitable production processes in the cement industry which are currently not available in Viet Nam. Minor waste streams including electronic components, batteries, fluorescent lamps, require specialized waste treatment facilities which are not specific for wind-power plants but instead represent a need for other waste treatment sectors. Last but not least, a specific waste stream is represented by the NdFeB magnets contained in the turbines, which are a very strategic component as they are a limited resource, for which however the available technological options are limited. These material should be stored pending the development of available technologies for their recycled.

Table 10. Cumulative waste forecast of material flow for EOL of wind turbines up to 2050

Year	Scenario	2025	2030	2035	2040	2045	2050
Cumulative wind turbine waste forecast upto 2050 (in Kilo Tons) (Sum of A to N)	**Early loss**	**4.1**	**66.9**	**185.9**	**1171**	**2812**	**5,057**
	Regular loss	**1.3**	**19.3**	**47.3**	**112.9**	**241.7**	**1,484**
A. Blade waste (in Kilo Tons) – Also depicted in Figure 10	Early loss	0.2	3.8	10.6	66.5	159.8	287.4
	Regular loss	0.1	1.1	2.7	6.4	13.7	84.4
B. Ferrous metal (in Kilo Tons)	Early loss	3	55	154	970	2328	4187
	Regular loss	1	16	39	93	200	1229
C. Aluminum (in Kilo Tons)	Early loss	0.054	0.878	2.441	15.4	36.9	66.4
	Regular loss	0.017	0.253	0.621	1.5	3.2	19.5
D. Composite materials (in Kilo Tons)	Early loss	0.342	5.573	15.485	97.5	234.2	421.2
	Regular loss	0.108	1.608	3.940	9.4	20.1	123.6
E. Lubricating oil (in Kilo Tons)	Early loss	0.016	0.254	0.705	4.4	10.7	19.2
	Regular loss	0.005	0.073	0.179	0.4	0.9	5.6
	Early loss	0.064	1.047	2.909	18.3	44.0	79.1

[22] Jensen, J. P. (2019). Evaluating the environmental impacts of recycling wind turbines. *Wind Energy*, *22*(2), 316-326.

Year	Scenario	2025	2030	2035	2040	2045	2050
F. Electronics (in Kilo Tons)	Regular loss	0.020	0.302	0.740	1.8	3.8	23.2
G. Batteries (in Kilo Tons)	Early loss	0.019	0.304	0.844	5.3	12.8	23.0
	Regular loss	0.006	0.088	0.215	0.5	1.1	6.7
H. Fluorescent lamps (in Kilo Tons)	Early loss	0.002	0.032	0.089	0.6	1.3	2.4
	Regular loss	0.001	0.009	0.023	0.1	0.1	0.7
I. NdFeB magnet (in Kilo Tons)	Early loss	0.021	0.338	0.939	5.9	14.2	25.5
	Regular loss	0.007	0.097	0.239	0.6	1.2	7.5
J. Copper (in Kilo Tons)	Early loss	0.151	2.465	6.850	43.2	103.6	186.4
	Regular loss	0.048	0.711	1.743	4.2	8.9	54.7
K. Balsa wood (in Kilo Tons)	Early loss	0.015	0.245	0.680	4.3	10.3	18.5
	Regular loss	0.005	0.071	0.173	0.4	0.9	5.4
L. Polyethylene (in Kilo Tons)	Early loss	0.017	0.270	0.751	4.7	11.4	20.4
	Regular loss	0.005	0.078	0.191	0.5	1.0	6.0
M. Polypropylene (in Kilo Tons)	Early loss	0.003	0.056	0.154	1.0	2.3	4.2
	Regular loss	0.001	0.016	0.039	0.1	0.2	1.2
N. Polyvinylchloride (in Kilo Tons)	Early loss	0.003	0.051	0.141	0.9	2.1	3.8
	Regular loss	0.001	0.015	0.036	0.1	0.2	1.1

Battery estimation for forecasted wind turbine systems in Viet Nam is based on study by *Jensen, 2019*[23]. The difference in battery waste volume from solar PV to wind turbines can be attributed to the installation volumes of both the technologies and the size of battery installation. It can be noted that 23 kilo tonnes of battery waste is expected by 2050 in the early loss scenario whereas 6.7 kilo tonnes of battery waste can be expected by 2050 in the regular loss scenario.

3. International overview of the management End-of-Life Photovoltaic and Wind Power Systems

3.1. Summary of worldwide trends for EoL photovoltaic plants

There has been an exponential increase in solar PV installations across the globe over the last two decades, with an installed capacity of over 700 GW worldwide by 2020 (see Figure 13). This trend is expected to continue and indeed accelerate in IRENA’s climate-resilient pathway (REmap Case) shown in Figure 14.

[23] Jensen, J. P. (2019). Evaluating the environmental impacts of recycling wind turbines. *Wind Energy*, *22*(2), 316-326.

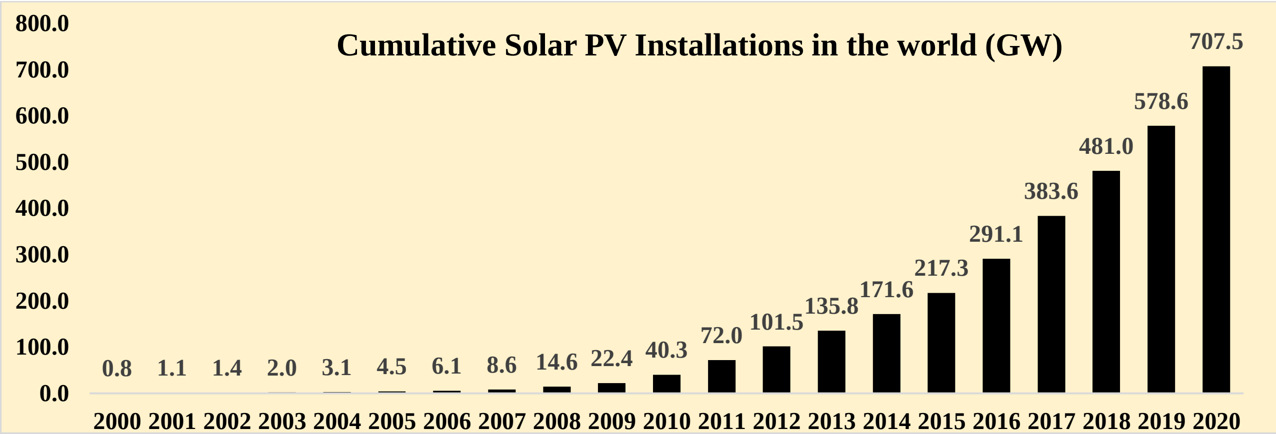

Figure 13. Cumulative installed capacity of Solar PV installations in the world[24]

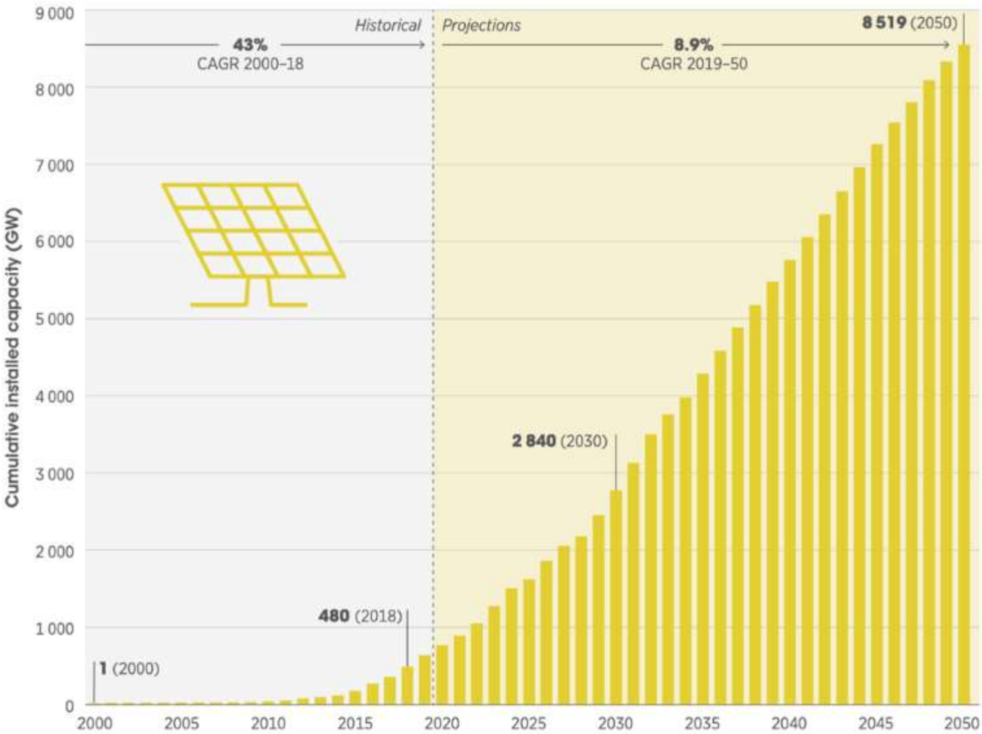

Figure 14 Cumulative Global PV Installations upto 2050 (According to REmap Case)

In 2000, with a global capacity of 0.8 GW, early adopters of solar power included Japan, USA, and Germany. By 2019, the total installed capacity of solar power globally stood at 578.6 GW, with China in the lead, alone with over 200 GW of installations. China also dominates the PV module manufacturing market, followed by Taiwan and Malaysia. China is first also on the installation of PV modules.

The current Solar PV Installed Capacity in the World is estimated at 578.6 GW at end of 2019. In order to identify the early adopters and the current leaders in Solar PV installations, the top 10 countries (representing more than 80 – 85% of global installations) for years 2000, 2010 and 2019 were identified and listed as shown in Figure 15. The countries with the earliest installations from

[24] IRENA- World Renewable Energy Statistics

nearly 20 years ago are relevant examples as case studies on policies, standards and technologies to analyse the overall end-of-life management of solar PV systems.

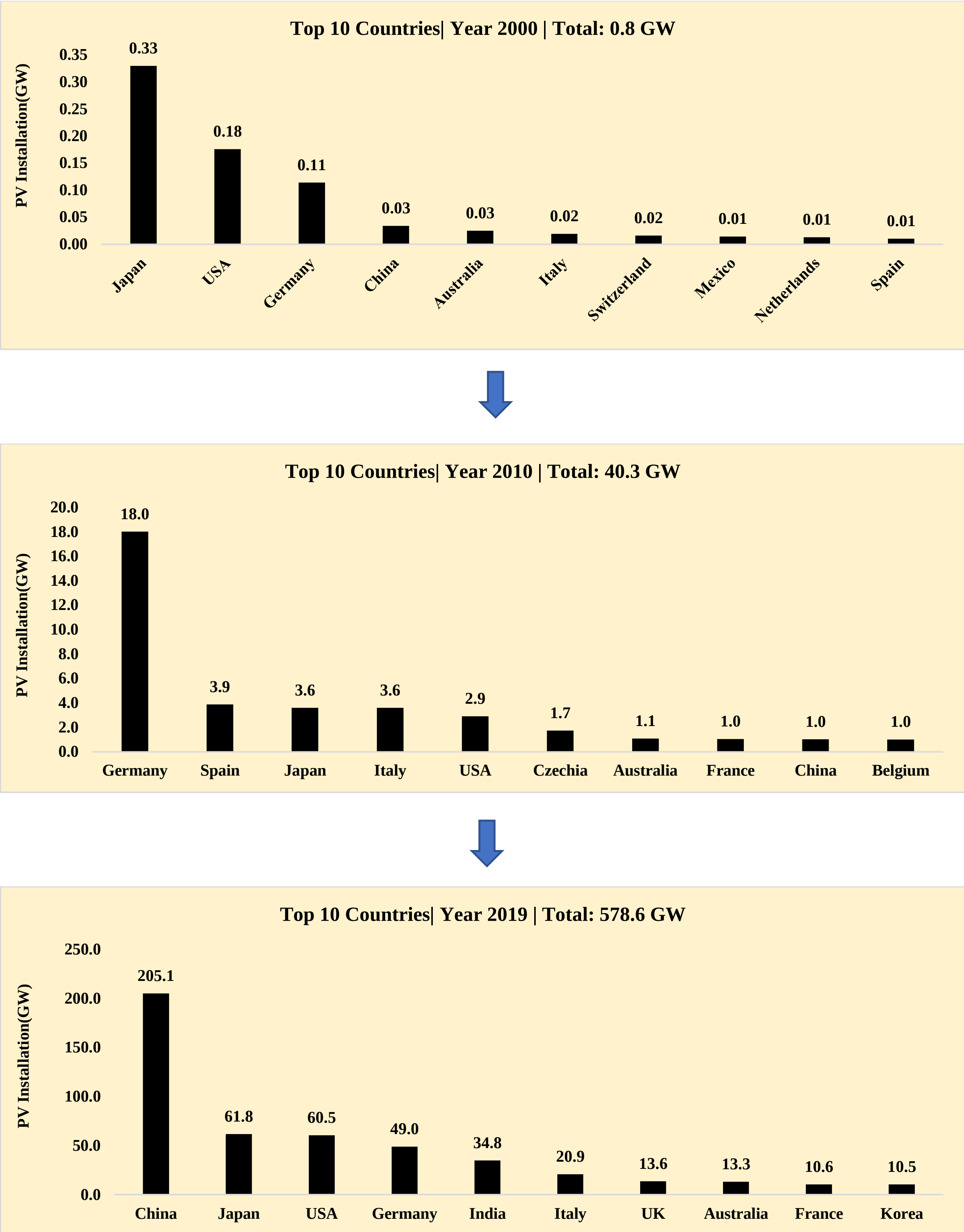

Figure 15. Top 10 countries in Solar PV Capacity in Years 2000,2010 and 2019 (latest)

3.1.1. *Generation of materials and waste from EOL solar power plants*

Globally, 60 - 78 million tons are projected to be generated by 2050 from EOL PV modules as per a study conducted by IRENA[25] as shown in Figure 16. Such an exponential increase of waste volumes can be attributed to individual countries as well.

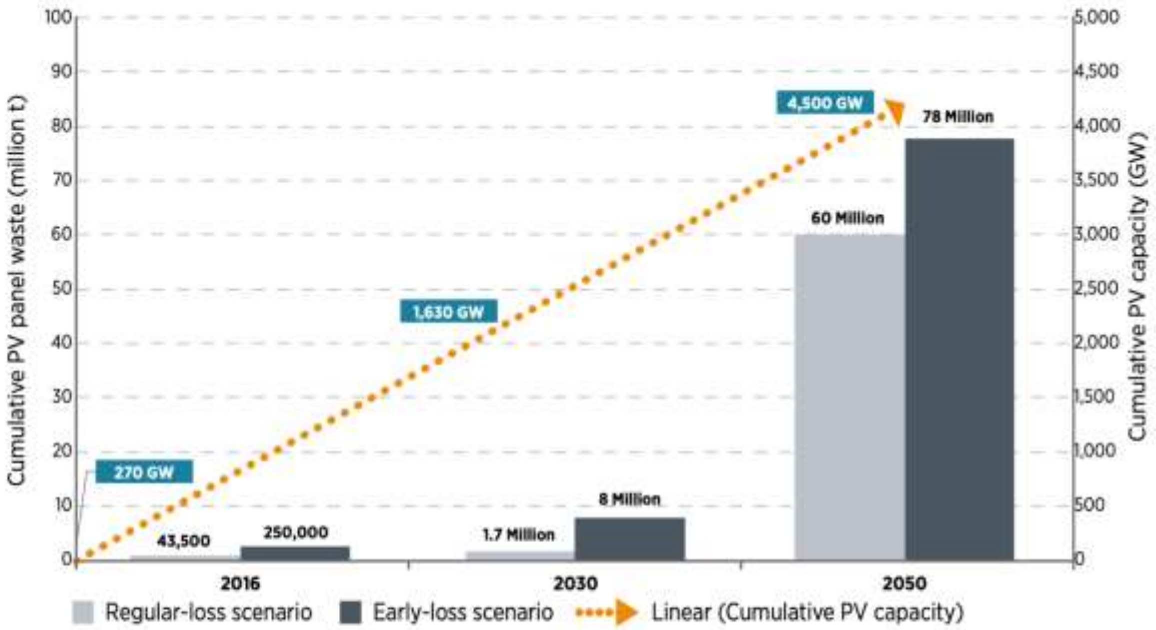

Figure 16. Global PV waste projected until 2050

As seen in the previous section, Viet Nam is expected to generate PV waste at an exponential trend reaching 3.1-3.4 Million tonnes by 2050. A depiction of global PV waste volumes compared to forecast made for Viet Nam is shown in Table 11.

Table 11. Cumulative Global PV waste forecast volume (IRENA[26]) compared to the forecasted PV waste volume for Viet Nam in Million Tonnes

	Year 2030		Year 2045		Year 2050	
Forecast Scenario	Early	Regular	Early	Regular	Early	Regular
Viet Nam	0.151	0.011	1.721	1.455	3.110	3.469
World	1.7	8	35	55	60	78

Most countries are yet to record significant volumes of PV waste with the exception of some Member States from the European Union.

[25] End of life management of Solar PV report – 2016- IRENA

[26] End of life management of Solar PV report – 2016- IRENA

Table 12 shows the PV waste volumes (in tons) reported by EU member countries according to Waste Electrical and Electronic Equipment (WEEE) directive. The blank spaces indicate the unavailability of data. Previously, data for PV waste were reported under the consumer equipment category, and only recent changes[27] require member countries to separately identify PV panels as category 4b. PV CYCLE[28], a producer responsibility organization for takeback and recycling of PV panels in Europe reports collection and treatment of 11,514 tons of PV waste in 2019. The volume collected in 2019 includes 4,859 tons from France where 81.4% of the waste panels were silicon-based.

Table 12. Reported PV waste volumes in Europe in tons[29]

Country	2015	2016	2017	2018
Belgium		242	117	168
Czechia	39	129	7	16
Denmark	2	3	5	6
Germany		2,032	3,595	7,865
Greece		70		0
Spain		27	155	462
France	366	223	1,885	1,555
Italy				1,350
Hungary				2,289
Netherlands	0	100	90	131
Austria		12	22	8
Slovakia		0	0	14
United Kingdom	147	104	106	87

3.1.2. *Overview of the regulatory framework for PV waste in the world*

Figure 17 depicts countries with specific regulations for managing EoL waste PV panels with Green depicting countries with existing regulations and Red indicating countries with policies under consideration. The majority Grey regions specify that PV panels in those countries are either regulated under common waste regulations or do not have specified regulations currently for handling PV waste. The information for creating this map was consolidated from various literature. The details of the existing and upcoming policies/regulation will be detailed in the concerned country sections in Annex 0.

[27] Commission Implementing Decision (EU) 2019/2193 of 17 December 2019

[28] Activity Report 2019-PV CYCLE

[29] EUROSTAT- ENV_WASELEE

Figure 17. Map depicting countries with existing regulations for EoL management of PV panels (Green) and countries with polices under consideration (Red)- Created using mapchart software

An overview of policies and standards established on end-of-life management of Solar PV panels is provided in Table 13. For detailed explanations on each of the policies, a in-depth international overview report has been prepared as a part of this assignment which can be reffered.

Table 13: Overview of polices in international context on end-of-life management of PV panels

Policy specific to End of Life Management of PV panels	Country	Infrastructure for recycling End of Life PV panels	Classification of PV waste
WEEE directive	European Union	Standards: EN 50625-2-4 standard for collection, logistics and treatment of WEEE and TS 50625-3-5 containing specifications for de-pollution of PV panels, respectively. Producer Responsibility organization (PRO): PV CYCLE	E-waste (non hazardous)
UK WEEE legislation[30]	United Kingdom	Implemented through PROs like PV CYCLE	E-waste (Non hazardous)
French WEEE law (Decree 2014-928)	France	Veolia has built the first commercial PV panel recycling plant which processes 1400 tonnes of material per year in 2017 and have planned to process up to 4000 tonnes by 2021 in France.	E-waste (Non hazardous)
Switzerland Government has established SENS foundation which is responsible for collection, handling, and guaranteed disposal of white goods. SENS and SWICO RECYCLING made a commitment for adhering to the European Standards for WEEE	Switzerland	SENS and SWICO recycling have processed photovoltaic equipment with volume of 300 tons in 2017 and the same volume per year continues until 2019[31].	PV module waste is included under ARF tariff code 600110. PV module waste come with an advance recycling fee of CHF 0.04 per kg. E-waste (comes under special waste category) which is different from hazardous waste or municipal waste.

[30] https://www.irena.org/publications/2016/Jun/End-of-life-management-Solar-Photovoltaic-Panels

[31] Technical Report 2020- SENS

Policy specific to End of Life Management of PV panels	Country	Infrastructure for recycling End of Life PV panels	Classification of PV waste
collection, logistics and safe disposal through EN 50625 at the end of 2014.			
Electrical and Electronic Equipment Act (ElektroG[32]).	Germany	National Register for Waste Electrical Equipment (Stiftung Elektro-Altgeräte Register or Stiftung EAR[33]) is the implementation agency for EPR in Germany	E-waste (Non hazardous)
Legislative Decree 14 March 2014, n. 49: Implements WEEE Directive 2012/19/EU	Italy	Gestore dei Servizi Energetici/Guarantor of Electric Services (GSE[34]) develops and manages the guidelines for proper end of life management of PV panels along with the certification and returning of upheld feed in tariff incentives to producer on successful disposal of PV waste.	E-waste (Non hazardous)
There are currently no regulations for management of waste PV panels at the federal level. Some state governments like Victoria, South Australia have taken pilot studies and have imposed landfill ban on PV waste.	Australia	Reclaim PV Recycling[35] is an Australian owned and operated solar panel recycling company utilizing a robust recycling process through Pyrolysis - a well-known thermal deconstruction technique - to delaminate PV panels into their component parts by passing them through a high-temperature furnace	-

32 ElektroG

33 Stiftung EAR clearing house

34 https://www.gse.it/servizi-per-te/fotovoltaico/conto-energia/gestione-moduli

35 https://www.pv-magazine.com/2021/02/08/australias-first-large-scale-pv-recycling-operation-amps-up-waste-collection/

Policy specific to End of Life Management of PV panels	Country	Infrastructure for recycling End of Life PV panels	Classification of PV waste
China has no PV-specific waste regulations but has sponsored R&D on PV recycling technologies through the National High-tech R&D Programme for PV Recycling and Safety Disposal Research under the 12th five-year plan36.	China	Directives for accelerating the end-of life management of waste PV modules are described in the 13th five-year plan for 2016-2020. The National High-tech R&D Programme for PV Recycling and Safety Disposal Research has provided recommendations for developing policy guidelines to address PV waste challenges[37].	-
There are no specific regulations for taking back of solar photovoltaic panels at the federal level in United States of America. The disposal of waste PV panels are currently governed by Resource Conservation and Recovery Act (RCRA). Few states described below have specific regulations to manage End-of-Life PV panels. State of Washington: HB 2645	United States	Solar Energy Industries Association is running a National PV Recycling Program which focuses on partnering with companies that have prior expertise in recycling glass, silicon, aluminium, scrap metal, and electronics. The aim of the program is to make SEIA partners capable to recycle solar panels and inverters.	California classifies PV panels as hazardous waste eligible to be handled as universal waste. Universal waste – same as e-waste, batteries and lightbulbs. South Carolina advisory is that they may or may not be hazardous based on their composition. Some types and brands are considered hazardous while others are not[38].

[36] http://www.firstsolar.com/en-IN/-/media/First-Solar/Sustainability-Documents/PVTP_6pp_First-Solar-recycling-hi.ashx

[37] Global review of policies & guidelines for recycling of solar PV modules

[38] https://scdhec.gov/sites/default/files/Library/OR-1695.pdf

Policy specific to End of Life Management of PV panels	Country	Infrastructure for recycling End of Life PV panels	Classification of PV waste
California: SB 489 North Carolina: House Bill 329 New York: Senate Bill S2837B			

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3.1.3. *WEEE directive:*

From the summary of policies associated with end of life management of solar PV panels, WEEE directive of the European Union has been successfully implemented and practiced. A detailed description of the policy framework is provided below. Independent of developed/ developing country context, the WEEE policy involving extended producer responsibility can be implemented.

Since 2012, the WEEE directive in Europe has established provisions for regulating the implementation of extended producer responsibility (EPR) for PV panel producers and importers. EoL PV panels are considered as WEEE and for this reason their collection, recycling and/ or disposal has to be ensured by the producer at no additional cost for the consumers. Based on the WEEE directive, the following qualify as producers:

- Manufacturers established in an EU Member State;
- Distributors or resellers established in an EU Member State;
- Importers established in an EU Member State;
- Distance/ online sellers those selling PV modules through internet to private households or to users established in and EU Member State.

Producers must comply with obligations including the registration in the national WEEE register, inform end customers, exchange data with the disposal facilities, finance the take back and disposal, disbursement of a financial guarantee, and must achieve the collection and recycling target required by the legislation. The WEEE directive is transposed into the national regulation of each Member State for the implementation of the directive.

The WEEE Directive aims to improve the collection, re-use and recycling of used electronic devices (including PV panels) to contribute to the reduction of waste and to ensure resource efficiency. It also aims to limit illegal exports of such waste from the EU and to improve the environmental performance of all stakeholders involved in the product life cycle. The Directive establishes Extended Producer Responsibility (EPR) as a means of encouraging design for environment, design for recycling and sustainable production of products (PV panels in this case), in order to facilitate repair, refurbishment, re-use, disassembly and recycling. Specific collection targets have been set for PV panels in WEEE directive. The recovery target is indicated as percentage of weight of total PV waste generated within the Member States. The targets are expressed by dividing the weight of the PV waste that enters the recovery or recycling/preparing for re-use facility by the weight of all separately collected PV waste, expressed as a percentage. As of 2019, the annual minimum collection rate is 65% of Electric and Electronic Equipment (EEE) put on the market, calculated on the basis of the total weight of WEEE collected; and the average weight of EEE put on the market in the three preceding years; or 85% of WEEE generated on the territory of that Member State. Member States will be able to choose which one of these two equivalent ways to measure the target they wish to report.

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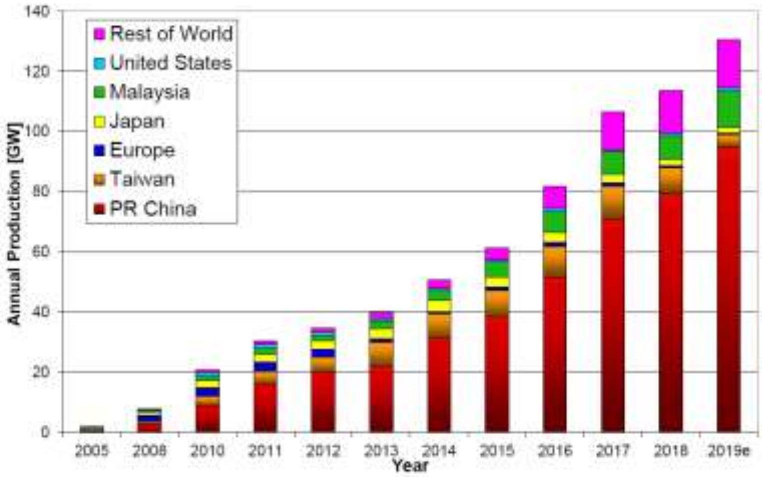

Figure 18. Worldwide distribution of PV production from 2005 to 2019 (EC-JRC 2019)

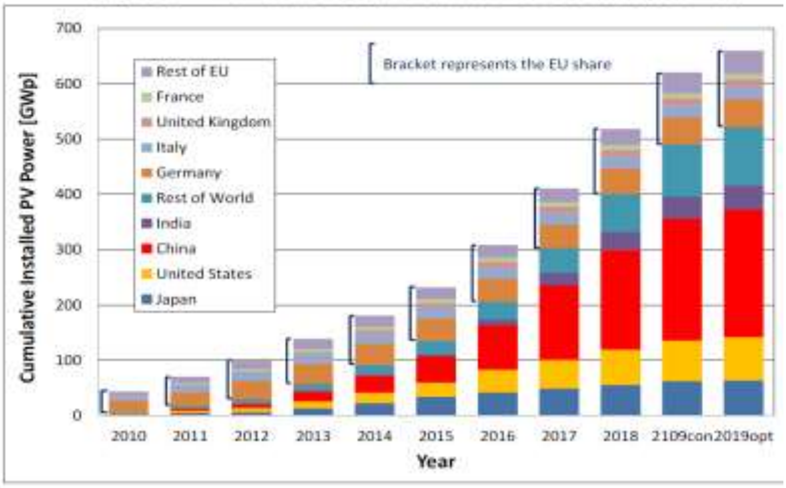

Figure 19. Cumulative PV installation from 2010 to 2019 (EC -JRC 2019)

Solar photovoltaic panels have been classified under the non-hazardous e-waste category in the WEEE regulation by European Union. There hasn't been a precedence of countries classifying solar PV panel waste as hazardous. The reason is the absence of major hazardous material constituents in PV panel. Even material like Cadmium, lead, Selenium is present in the form of a compound in PV module which makes them non – hazardous.

Urban mining or sustainable material recovery from PV panel waste can relieve the supply constraints in the future. It must also be noted that secondary raw material production is less energy intensive than primary production for most of the materials associated with PV panels. The contribution/usage of secondary raw materials in production of associated PV panel materials is illustrated in Table 14. The European data can be considered as upper limit across the world, given the absence of circular approach in most of other countries.

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Table 14. Contribution of recovered materials on the demand for raw materials in Europe: (EOL – RIR)[39] and Economic value of the materials recovered €/ t

Material Type	Material	% of Recovery	Economic Value (€ / kg)
High Value	**Silver**	94	490
Toxic	**Cadmium**	95	2.6
	Lead	93	1.9
	Selenium	80	39.84
Critical	**Gallium**	99	318.5
	Indium	75	282.1
	Silicon(sand and metal)	95	0.8
Other	**Aluminium**	99	1.6
	Copper	96	5.3
	Tin	99	15
	Zinc	90	2.4
	Tellurium	95	72
	Glass cullet	98	1.6
	Polymer	80	

3.1.4. *Policy Status in developing countries in Asia*

In spite of its massive production and installation, in China there are no state-wide plans for the recycling of solar panel. In November 2016, the Ministry of Environment of Japan estimated that the generation of solar panel waste per year could reach 800,000 tons by 2040, whilst there were no plan to dispose safely this waste. Apparently only EU, through the WEEE directive, has established a framework to ensure the safe disposal of PV since they are placed in the market, although infrastructures for implementing the WEEE directive are still incomplete.

China has no PV-specific waste regulations but has sponsored R&D on PV recycling technologies through the National High-tech R&D Programme for PV Recycling and Safety Disposal Research under the 12th five-year plan[40]. Directives for accelerating the end-of life management of waste PV modules are described in the 13th five-year plan for 2016-2020. The National High-tech R&D Programme for PV Recycling and Safety Disposal Research has provided recommendations for developing policy guidelines to address PV waste challenges[41].

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[39] ENEA-Socio Economic Study (In Italian)

[40] http://www.firstsolar.com/en-IN/-/media/First-Solar/Sustainability-Documents/PVTP_6pp_First-Solar-recycling-hi.ashx

[41] Global review of policies & guidelines for recycling of solar PV modules

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The Ministry of Economic Affairs of China is currently studying the bulk purchase contract to require manufacturers of solar photovoltaic panels to be responsible for recycling; in the future, the recycling mechanism of the Environmental Protection Agency will be compared with that of the manufacturers. The deposit will be used as the recovery fund for the future solar photovoltaic module. At present, the Ministry of Economic Affairs, the Environmental Protection Agency, and solar photovoltaic related companies are also jointly developing future implementation plans to ensure that discarded solar panels can be properly disposed of and minimize their impact on the environment.

India has released a blueprint[42] providing guidelines on waste management of antimony present in silicon PV panels. The Indian Government has also released a policy draft titled National resource efficiency policy[43] which aims to create dedicated PV recycling centres by 2035. However no policy/guidelines have come in place to manage waste PV panels in India.

3.1.5. *PV panel Recycling technologies*

PV recycling technologies have been researched since 1990s with the first patent being filed in 1995 for crystalline silicon PV panels. However through the years, the emphasis on R&D in recycling has been on cadmium telluride (CdTe) PV modules due to the hazardous and rare earth material content. It is interesting to note this because more than 95% of the market of PV panels is held by crystalline silicon PV panels.

Currently First solar is the only company which has a inhouse recycling center along with PV production facility for their CdTe modules. For the crystalline silicon PV modules, there is currently only one commercial recycling facility. It is operated by Veolia in France[44].

In general PV recycling starts with removal of junction box and aluminium frame present in a panel. The most important step in PV recycling is the delamination of the panel to separate the solar cells, front glass and the plastic layer (encapsulant, backsheet). The delamination techniques can be broadly classified as Mechanical, Thermal and chemical.

Mechanical delamination with Aluminium frame and junction box removal has been the most used technology commercially for PV recycling. Such processes exhibit low energy demand and easy integration with existing glass/metal/e-waste recycling infrastructure. Mechanical delamination is comparatively cheaper compared to the other technologies but lack in recovery of high value materials like silver, silicon, cadmium, lead etc which are present inside the solar cells.

Thermal delamination methods enable pure material stream recovery of glass and PV core containing silicon and metals as the polymer sheets undergo complete pyrolysis or burn off. The advantage therefore is higher material recovery from a PV panel compared to mechanical delamination. However exhaust gas treatments are required which increases the investment cost. The backsheets of most PV panel contains fluorine which demands exhaust gas treatments owing to the combustion involved in thermal delamination.

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[42] http://164.100.94.214/sites/default/files/webform/notices/DraftBluePrintAntimony.pdf

[43] http://moef.gov.in/wp-content/uploads/2019/07/Draft-National-Resourc.pdf

[44] https://iea-pvps.org/key-topics/end-of-life-management-of-photovoltaic-panels-trends-in-pv-module-recycling-technologies-by-task-12/

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Chemical delamination methods involve the dissolution of EVA in organic or inorganic solvents. The treatment time initially ranged in days, but dissolution under ultrasonic irradiance has enabled short dissolution times. Chemical delamination is still under the laboratory stage, and there is a need to understand the additional environmental impact due to the inclusion of chemical solvents.

The table below summarizes the current state of the art in recycling technologies and their status towards commercial deployment[45].

Process	Advantages	Disadvantages	Status
Organic solvent dissolution	• Easy access to the EVA • Less cell damage • Recovery of glass	• Delamination time depends on area • Harmful emissions and wastes	Research
Organic solvent and ultrasonic irradiation	• More efficient than solvent dissolution process • Easy access to the EVA	• Expensive equipment • Harmful emissions and wastes	Research
Electro-thermal heating	• Easy removal of glass	• Slow process	Research
Mechanical separation by hotwire cutting	• Low cell damage • Recovery of glass	• Other separation processes required for full removal of EVA	Research
Pyrolysis (conveyer belt furnace and fluidised bed reactor)	• Separate 80% of wafers and almost 100% of the glass sheets • Cost-effective industrial recycling process	• Slightly worse texturisation (damage to cell surface)	Research (pilot)
Solvent (Nitric acid) dissolution	• Complete removal of EVA and metal coating on the wafer • It is possible to recover intact cells	• It can cause cell defects due to inorganic acid • Generates harmful emissions and wastes	Research (pilot)
Physical disintegration	• Capable of treating waste	• Other separation processes required for full EVA removal • Dusts containing heavy metals • Breakage of solar cells • Equipment corrosion	Commercial
Dry and wet mechanical process	• No process chemicals • Equipment widely available	• No removal of dissolved solids	Commercial

[45] https://www.intechopen.com/chapters/59381

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Process	Advantages	Disadvantages	Status
	• Low energy requirements		
Thermal treatment (Two steps heating)	• Full removal of EVA • Possible recovery of intact cell • Economically feasible process	• Harmful emissions • High energy requirements • Cell defects and degradation due to high temperature	Commercial
Chemical etching	• Recover high purity materials • Simple and efficient process	• Use of chemicals	Commercial

3.1.6. *Mechanical Delamination – Suitable for replication in Viet Nam*

In 2018 Sustainability Victoria commissioned a research project surveying relevant stakeholders to assess product stewardship over the life cycle of PV panels. The pilot study focused on mechanical delamination-based PV Recycling technique as detailed in Figure 20. With minimum investment, this technology can be replicated in other countries and by other e-waste recyclers to process solar waste and recover more than 85% by weight of materials (glass cullet, aluminum frame, junction box and cables).

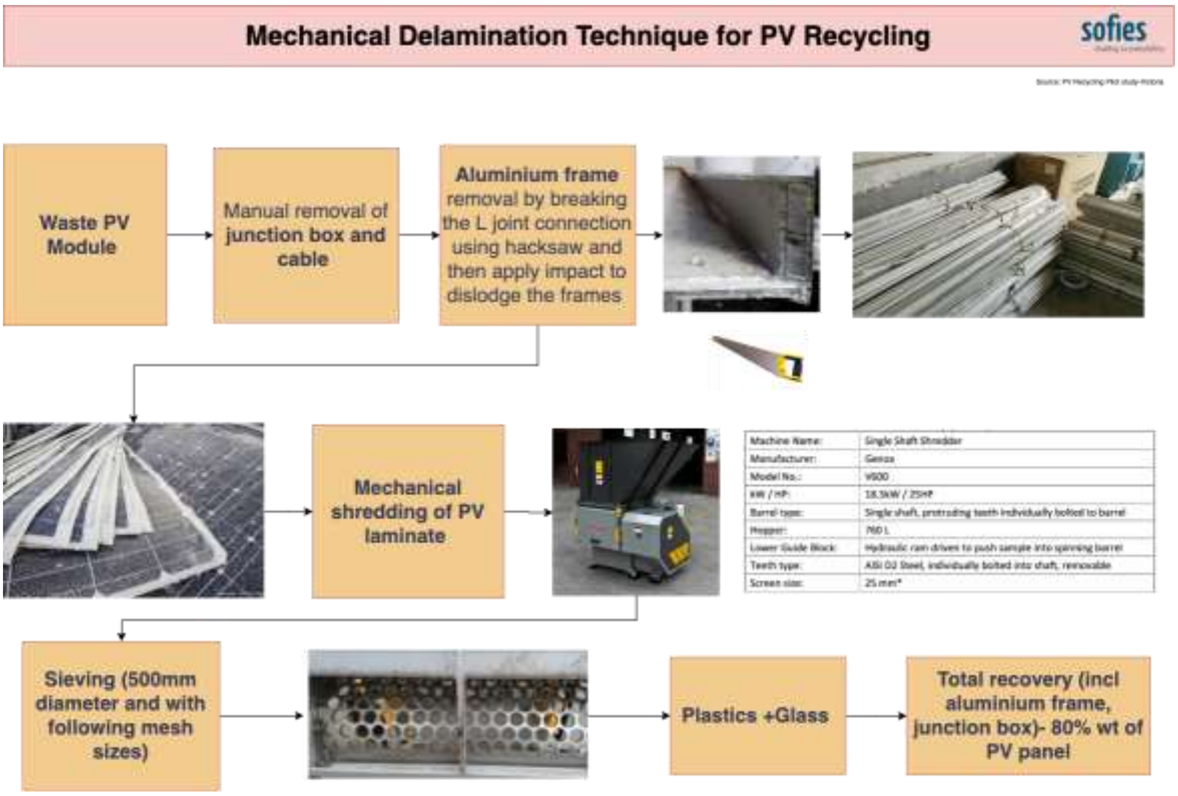

Figure 20. Mechanical delamination of PV panels- Victoria PV Pilot case study[46]

[46] https://www.sustainability.vic.gov.au/About-us/Research/Solar-energy-system-lifecycles

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3.1.7. *Case Study: Thermal Delamination – Best practice for obtaining close to 95% material recovery*

Korea Evaluation Institute of Industrial Technology (KEIT) established a high value PV recycling technique funded by the Ministry of Trade, Industry & Energy (MOTIE), Republic of Korea. As a result of this technique 95% by weight or more material recovery from PV panels is deemed possible. The detailed process parameters along with the steps to extract silicon and aluminium present inside the solar cell are illustrated in Figure 21.

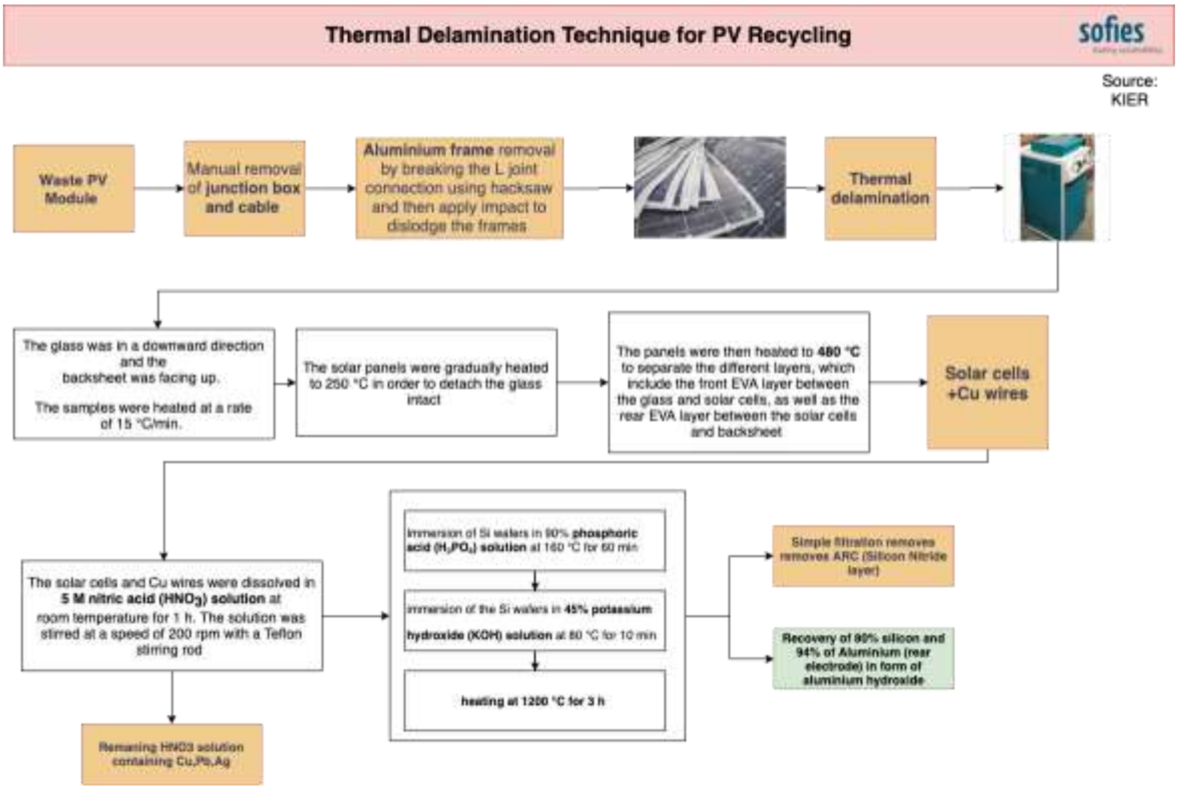

Figure 21. Complete material extraction from PV panels

The extraction process involved in silver, lead and copper extraction is described in Figure 22. This thermal delamination process can achieve recovery of 95% by weight of materials present inside PV panels.

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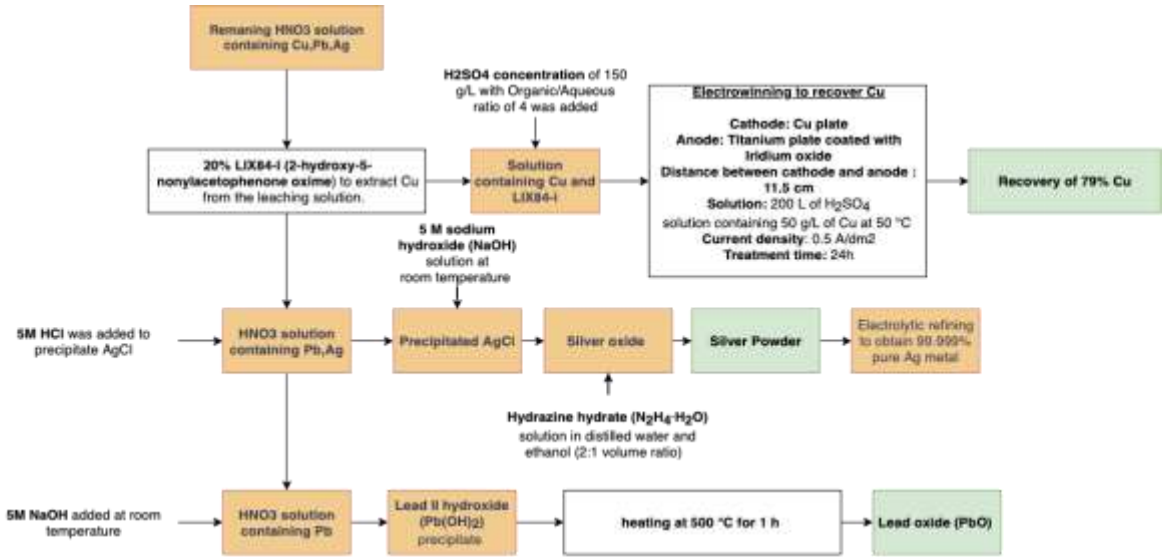

Figure 22. Extractions steps for copper, silver and lead from PV panels

3.1.8. Economic analysis on PV Recycling

The economic analysis on PV recycling is based on data obtained from **Recupero integrale pannelli fotovoltaici /Full Recovery End of Life Photovoltaic (FRELP) – PV Recycling Process Study[47].**

FRELP project was carried out by SASIL S.p.A through funding from the European LIFE+ program. The project concentrated on developing technology for full recovery of mono and polycrystalline silicon PV panels. The project ran between 2013 and 2016. FRELP stands for Full Recovery End of Life Photovoltaic panel. The phases of the project were as follows:

I- Robotic mechanical detachment of aluminum profiles, glass connectors and PV sandwich

II- Thermal combustion of the Eva to recover metallic silicon and other metals

III- Acid leaching to separate silicon from other metals by filtration

IV- Electrolysis to recover copper and silver and acid water neutralization treatment.

The project successfully demonstrated the overall treatment technology envisaged in phases I, II, III and IV and proved that the adopted technology is economically and environmentally sustainable. The FRELP project was discontinued in April 2016 as the availability of photovoltaic panels at the end of their life was insufficient to ensure the sustainability of the prototype. Phase I allows the recovery and enhancement of 88% of the total weight of the mono and / or poly crystalline silicon photovoltaic panels with a negative impact of the sandwich alone, which represents 12% of the weight. The economic return of phase I could be achieved with a quantity of only 2,000 t /year of panels, equal to one work shift. The economic return of phases II, III, IV, on the other hand, requires a minimum of 7,000 t / year of panels as the processing cycle is foreseen continuously, 24 hours a day.

[47] ENEA-Socio Economic Study (In Italian)

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Table 15. Overview of cost-benefits with respect to PV recycling from FRELP project (As example)

Cost (Mentioned as €/ton of PV waste)			
Investment cost (Land & Machinery): 53 to 62 €/ton			
Assuming Incidence of a ten-year mortgage, at an interest rate of 4%. For Veolia: Machinery Investment cost for 4000 t/year plant was 1 Million euros whereas for FRELP with projected capacity 7000 t/year, the cost came up to 2 Million euros. Cost of land is assumed to be 1 Million euros.			
Production/Operation cost: 116 €/ton			
Input/Output	**Quantity**	**Cost (€/ton)**	**Total cost €**
Electricity	113.55	0.2	22
Fuel	1.14	1.05	1
Water	309.71	0.002	1
Nitric Acid	7.1	1.6	11
Calcium hydroxide	36.5	0.9	33
NOx	2		
Landfill waste	320	0.11	35
Special landfill waste(hazardous)	52.25	0.24	13
Labour costs: 100 to 190 €/ton			
Veolia estimates 10 to 19 employees in its pilot plant. Using the Veolia data and assuming an average gross salary of € 40,000 a year, we get an incidence of labor costs between 100 and 190 € / t.			
Transport cost: 42 €/ton Assuming 7000 tons/year plant; 438 loads per year; 2 crew members for transport and corresponding fuel prices			
Revenues:620 €/ton (Potential: 1240 €/ton)			

Material	**Theoretical potential (kg)**	**FRELP (Sasil) (kg)**	**Economic value of recovered material (€/kg)**	**Total Revenue €**
Glass	730	686.0	0.006	4.116
EVA	36.8	Combusted	0.7	0
PET Back sheet	2.7	Combusted	0.7	0
Aluminium	182	182.0	1.6	291.2
Silicon	40.3	34.7	0.8	27.76
Silver	1.7	0.5	490	245
Copper	6.7	4.4	5.3	23.32

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Tin	0.8	Not recovered	15	0
Lead	0.4	Not recovered	1.9	0
Electric Energy (kWh)		69.1	0.2	13.82
Thermal Energy (litres of diesel equivalent)		13.7	1.05	14.385

3.2. Summary of Worldwide trends for EOL wind power

Cumulative wind power installations across the world is depicted in Figure 23. An exponential trend can be seen over the past decade with increase of installations from 180.8 GW in 2010 to 733.2 GW in 2020 .

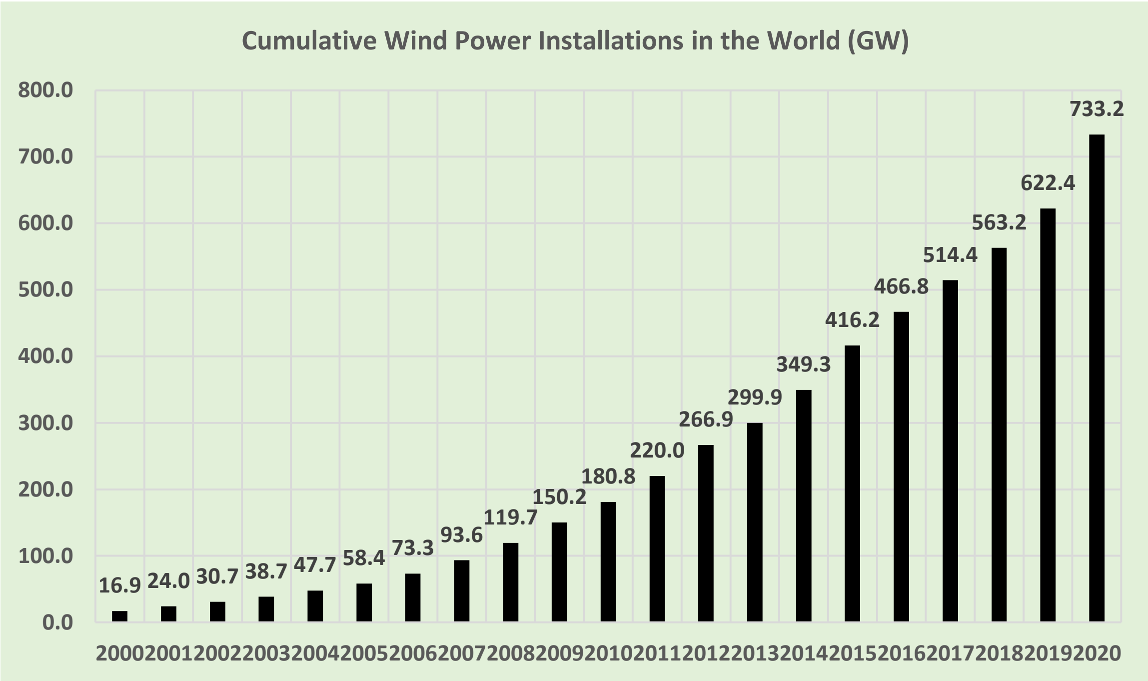

Figure 23. Cumulative wind turbine installed capacity in the world

According to IRENA's climate-resilient pathway (REmap Case), which projects scenario where global temperature rise remains below 2°C and closer to the 1.5°C carbon budget levels, provided in the IPCC Special Report on Global Warming of 1.5°C (SR1.5), the following Global Wind power installations projections have been made as shown in Figure 24.

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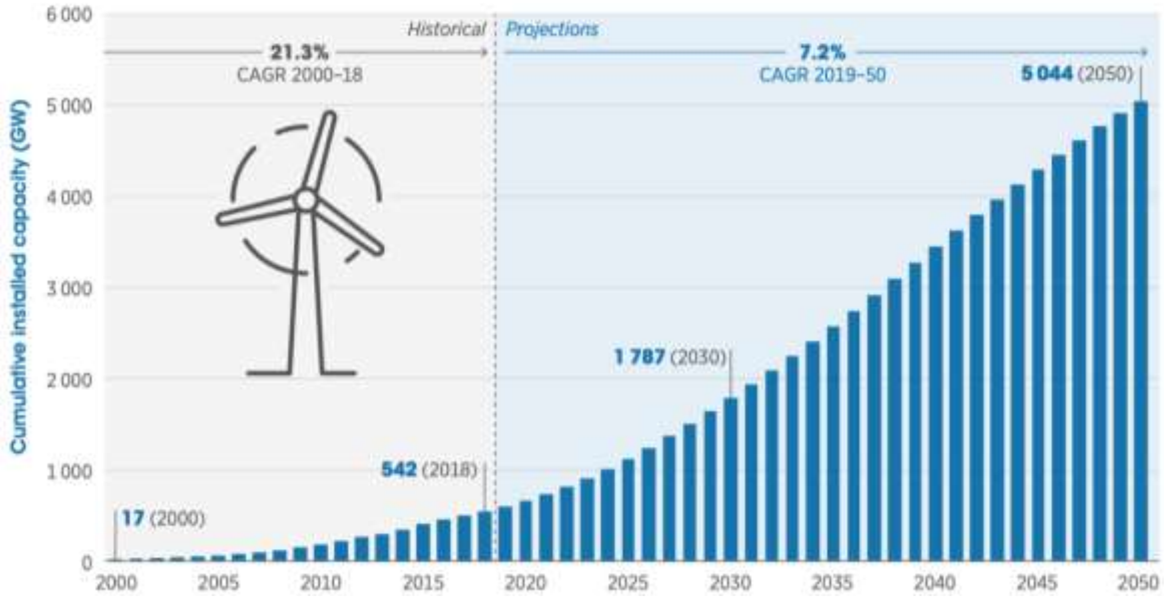

Figure 24. Cumulative Global Wind Power Installations upto 2050 (According to REmap Case)[48]

3.2.1. *Generation of materials and waste from EOL Wind power plants*

Germany decommissioned 97 MW, Austria 32 MW, Denmark 32 MW, the UK 17 MW and France 0.2 MW in 2019. Out of the total decommissioned capacity in EU in 2019, 174 MW were onshore and 4MW were Offshore. This can be seen in Figure 25 where decommissioned capacity in Europe has been depicted.

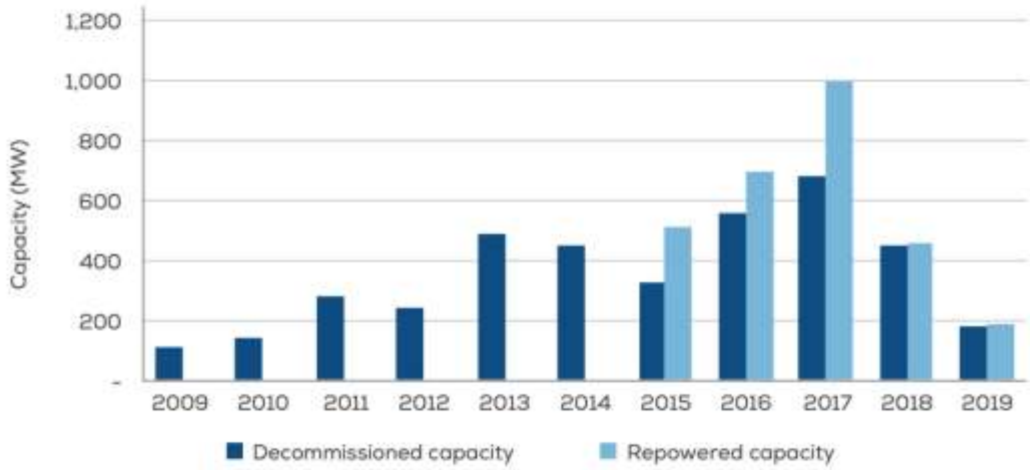

Figure 25. Decommissioned wind turbine capacity from 2009-2019 in Europe[49]

[48] IRENA- Future Outlook for Wind power systems

[49] Wind Power Europe

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A Research study[50] indicates that there will be 43 million tons of cumulative wind turbine blade waste worldwide by 2050 with China possessing 40% of the waste, Europe 25%, the United States 16% and the rest of the world 19% as shown in Figure 26.

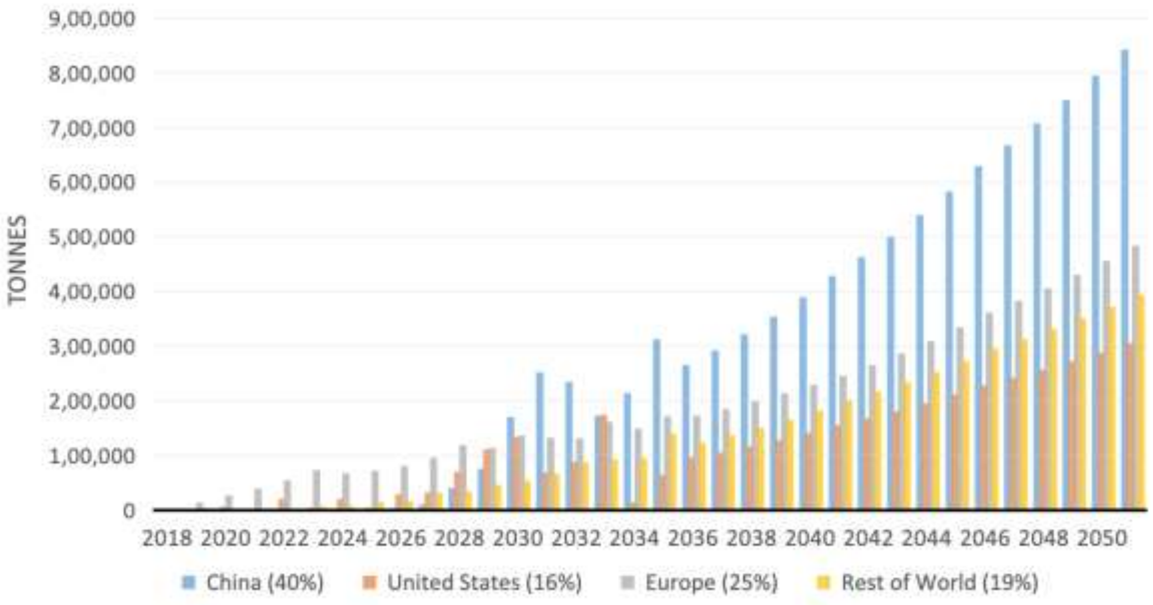

Figure 26. Forecasted Wind turbine blade waste – Country wise

The research also suggests that End-of-Life waste stream will annually generate more than 2 Mt annually in 2050 as shown in Figure 26 and cumulative blade waste in 2050 will lie between 21.4 Mt and 69.4 Mt with the most probable waste level being 43.4 Mt. Although China is expected to tackle huge volumes of wind turbine blade waste, European countries would face major amount of waste in near future given that they have been the early adopters of the wind power systems.

[50] Pu Liu et al.- Wind turbine blade waste in 2050

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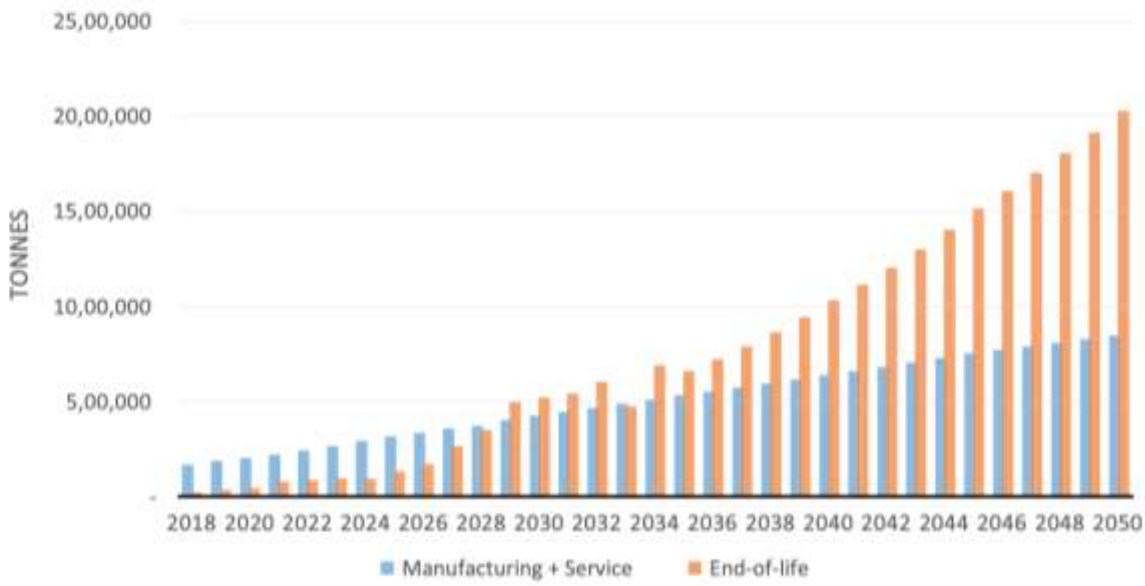


Figure 27. Annual wind turbine blade waste (Manufacturing, Service and End-of-life) projected globally

3.2.2. *Overview of Policy related to end of life management of wind turbines*

Wind turbines owing to their size require specific regulations for dismantling and site restoration. On the other hand, compared to PV panels, the dismantled components from wind turbines have established recycling chains and do not require further delamination techniques. Table 16 denotes a checklist for specific policy availability in relevant countries for end-of-life management of wind power systems categorized as rules for decommissioning, legislation for resource management and site restoration guidelines. Details of the policies are discussed in the corresponding sections addressing the countries.

Table 16. Policy checklist for end-of-life management of wind turbines[51]

Countries	Decommissioning Regulation for wind turbines	Specific legislation framework for resource management				Site Restoration
		Concrete	Metals	Electrical cable	Composite waste (Wind turbine blades)	
Germany	Renewable Energy Sources Act, 2017	Comes under demolition and construction waste	Comes under existing metal waste management policies	Comes under existing e-waste management policies	Ban on landfilling wind turbine blades	Responsibility: The Federal States Committee for Soil Protection Requirement: operator has to issue a declaration of commitment to dismantle the installation and remove all soil sealing when permanently abandoning the sit
Italy	Ministerial Decree of 10 September 2010 titled "Guidelines for the authorisation of plants powered by renewable sources".					The Ministerial Decree of 10 September 2010 requires producers to return the site to its original conditions.
Spain					-	
France	Regulation mentioned in 'arrêté du 22 juin 2020'				France has set sets recycling targets for wind turbines as	Requirement: excavated foundations are replaced by earth with

[51] Decommissioning of onshore wind turbines- Wind Power Europe

Countries	Decommissioning Regulation for wind turbines	Specific legislation framework for resource management				Site Restoration
		Concrete	Metals	Electrical cable	Composite waste (Wind turbine blades)	
					whole, and rotor blades in particular	characteristics comparable to the land in place near the installation
Netherlands	Building Decree 2012				Under the 3rd edition of the National Waste Management Plan, landfilling of composite waste is banned but there is an exception for landfilling if cost of treatment is higher than the benchmark value of €200/t	
Denmark	Condition of decommissioning mentioned in building and operating permit				-	Responsible organization: Municipality Requirement: to remove all equipment, including the foundation, as deep as 1m below the surface and rehabilitate the area.
United Kingdom	Projects will have agreed a ‘decommissioning bond’ regulated by	Comes under demolition and	Comes under existing metal waste	Comes under existing e-waste	-	Local planning authority specifies the site soil quality that needs to be

Countries	Decommissioning Regulation for wind turbines	Specific legislation framework for resource management				Site Restoration
		Concrete	Metals	Electrical cable	Composite waste (Wind turbine blades)	
	local planning authority	construction waste	management policies	management policies		restored after decommissioning
USA	There is a challenge with the lack of policy[52] in the U.S. regarding end-of-use considerations for turbine blades, further contributing to the status quo of storage or disposal as solid waste in landfills.	Comes under demolition and construction waste	Comes under existing metal waste management policies	Comes under existing e-waste management policies	-	-
China	No specifc regulations	Comes under demolition and construction waste	Comes under existing metal waste management policies	Comes under existing e-waste management policies	No specifc regulations	No specifc regulations

[52] https://blog.ucsusa.org/james-gignac/wind-turbine-blades-recycling

As seen in Table 16, there are no specific policies that govern the overall waste management of wind turbines. There are guidelines and standards for decommissiong, dismantling and site restoration of wind turbines as seen in the European Union countries listed in Table 16. Detailed explanantion on each of the policy can be seen on Annex 7.

The following are the aspects or lessons that can be followed from the guidelines and standards related to end of life management of wind turbines depicted in the countries listed in Table 16.

Financial Security

1. Permits for wind power operations needs to be combined with requirements for financial security. The purpose of providing financial security is to create security for the cost of dismantling and site restoring a wind farm in the event that the operating company goes bankrupt or for other reasons cannot complete the decommissioning.
2. The amount of the security should be calculated in the individual case where the height of the tower, rotor diameter, geographical location and how much of the foundation the business the practitioner is required to remove are important parameters. The financial security should be set aside before construction work for the respective wind turbines are started
   - The financial security can be calculated based on hub height

     Hub height of the wind turbine (m) x 1000 = amount of security deposit
   - Another calculation method is based on the installed electrical power.

     € 30,000 per megawatt of installed electrical output (Germany case)
   - Another approach is to focus on the production or investment amount and based on a flat percentage as dismantling costs eg. 6.5% is assumed of investment amount in Germany
3. After the final inspection is approved by the supervisory authority, the financial security is returned to the operator.

Dismantling/Decommissioning

1. Owing to the diversity of plant modules, co-operation with manufactures becomes utmost necessary for wind power systems. It is not possible to develop a single dismantling procedure which can be applied to the diverse wind farms. However technical guidelines and standards can be developed as seen in the case of Germany. Technical guidelines would be a flexible instrument and could provide non-binding but effective instructions for the actors involved and contain references to existing laws and standards, e.g., for sawing/shredding rotor blades, design of rotor blades suitable for recycling, material requirements for resulting material flows, specifications for interim storage, etc.
2. There is a need for regulations defining requirements regarding safety and occupational safety aspects, evidence of training certifications (e.g., height training, switching authorization) or test badges (e.g. for work equipment); the same standards should apply for construction and dismantling and be applied in practice;

Waste Management

1. Although elements recovered from dismantling of wind turbines fall under common waste regulations in most countries, there is a need to develop specific waste management strategies for certain critical elements of the turbine in order to drive

circularity such as for Concrete flows from wind turbine (tower and foundations) due to lack of use and acceptance of recycled building materials and for Rare Earth magnets from wind turbines (synchronous generators), due to lack of quantities for economic recycling and finally for Waste containing glass fibre reinforced plastics and carbon fibre reinforced plastics from wind turbines (rotor blades), due to lack of specifications for professional processing/decomposition of rotor blades on site.

2. Regulations for bundling of waste with a similar composition of economically strategic and environmentally relevant metals, e.g. Rare earth elements (REE)-containing materials such as wind turbine gearboxes, and the development of suitable concepts for the recycling of neodymium or other REE, which is generated decentralized in different sectors.

Extended Producer Responsibility for wind turbine blades

Introduction of specific elements of product responsibility for rotor blades could be examined. Rotor blade waste is extremely difficult to recycle due to the fiber composites and requires special treatment. A regulation of product responsibility under waste law could contribute to a fair allocation of disposal costs for this comparatively homogeneous waste stream, which must be treated in a similar way, and in the long term ensure an industry, product specific, environmentally friendly and high-quality waste treatment. Introduction of the following specific elements of product responsibility for rotor blades can be examined:

- Information and labelling obligations regarding the material composition of the rotor blades.
- Product and industry-specific technical and organizational approach (industry solution);
- Separate processing with the aim of quality assurance of recycled materials and refuse-derived fuels.
- Commitment to high-quality recycling and ensuring safe disposal.
- Inclusion of the manufacturer's knowledge and processing technologies adapted to the technological change on the product side.
- Allocation of disposal costs and organizational obligations during disposal in line with the polluter- pays principle

3.2.3. Economic analysis for decommissioning and dismantling wind turbines

The economic analysis with respect to wind turbine decommissioning is specified below based on a report from Germany[53].

The report highlights the decommissioning and dismantling cost for an average wind turbine. It also includes a comprehensive assessment of the disposal costs for the various recovered materials from wind turbine.

[53] UBA Study on dismantling old wind power installations (In German)

Table 17. Cost-Revenue breakdown of decommissioning a wind turbine

Wind Turbine decommissioning	Cost (Euros) per wind turbine	Assumption/Descriptions
Preparatory work	7700	Personnel cost + Site preparation cost (2.5 working days/8 hours each/4 workers)
Dismantling wind turbine including the tower	140000 to 270000	Pickup and loading+ Personal+ Approach crane +Main crane+ Additional cost + Insurance + demolition cost for concrete tower (if present) (8 workers/900 tonne crane)
Dismantling the foundation	18133 to 48875	Demolition cost (35 €/m^3) + Loading and transportation (12.5€/m^3) + site restoration/filling (10€/m^3) (315m3 concrete foundation for 2 MW turbine and 850m3 concrete foundation usually used for 4.2 MW wind turbines)
Disposal costs		
Concrete rubble	20150	Disposal cost of 10€/t; 2015 tons of concrete per wind turbine
Glass reinforced plastics	15600	Disposal cost of 400€/t; 39 tons of GRP per turbine
Carbon fibre reinforced plastics	15200	Disposal cost of 800 €/t; 19 tonnes of CFRP per turbine
Steel	-114,660	Revenue of 200 €/t; 90% recovery; 637 ton per wind turbine
Copper	-7920	Revenue of 1600 €/t; 90% recovery; 5.5 tons per wind turbine
Aluminium	-5872	Revenue of 900 €/t; 90% recovery;7.25 ton per wind turbine
Electronic waste	380	Disposal cost of 100 €/t; 3.8-ton electronics per wind turbine
Operating fluids	1495	Disposal cost of 1€/litre; 1.3 ton of oil per wind turbine; 1150 litres for 1 ton

3.2.4. *Wind turbine blade recycling*

Recycling[54] technologies for Wind turbine blade waste along with their Technology Readiness Levels have been described in the Table 18.

Table 18. Wind turbine blade recycling technologies

S.No	Process	Description	TRL Level
1	Cement Co-processing	Glass fibres are recycled as a component in cement mixes which reduces carbon footprint of cement industry by 16%. It is a well-established process but aide pollutant and particulate emissions and is restricted to only glass reinforced composites (blades can also be carbon reinforced composites)	9
2	Mechanical Grinding	Commonly used technology due to effectiveness, low cost and low energy requirements. Although efficient and with high throughput rates the quality of recovered recyclates is compromised and 40% material waste generated during grinding, sieving and processing.	9
3	Pyrolysis	Thermal recycling process which allows recovery of fibre in form of ash and polymer matrix in form of hydrocarbon products. Well established process and the byproducts (syngas and oil) can be used as energy source. However, it recovers fibres with decreased quality due to retained oxidation residue or char.	9
4	High Voltage Pulse fragmentation	Electro-mechanical process that can effectively separate matrices from fibres with use of electricity. Although it comes with low investment, only lab/pilot scale equipment available and only short fibres can be recovered.	6
5	Solvolysis	Solvolysis is a chemical treatment where solvents (water, alcohol and/or acid) are used to break the matrix bonds at a specific temperature and pressure. Solvolysis with supercritical water can be used to retrieve both fibres and resins intact from wind turbine blades. The TRL is low at 5/6 and the process is restricted to carbon fibres only with high investment and running costs	5/6
6	Fluidized Bed	It is well suited to treat mixed material components like turbine blades and can recover energy or potential precursor chemicals in addition to fibre and filler recovery. Process related emissions are a concern and scale up still needs to be developed	5/6

[54] Accelerating Wind Turbine Blade Circularity-WindEurope

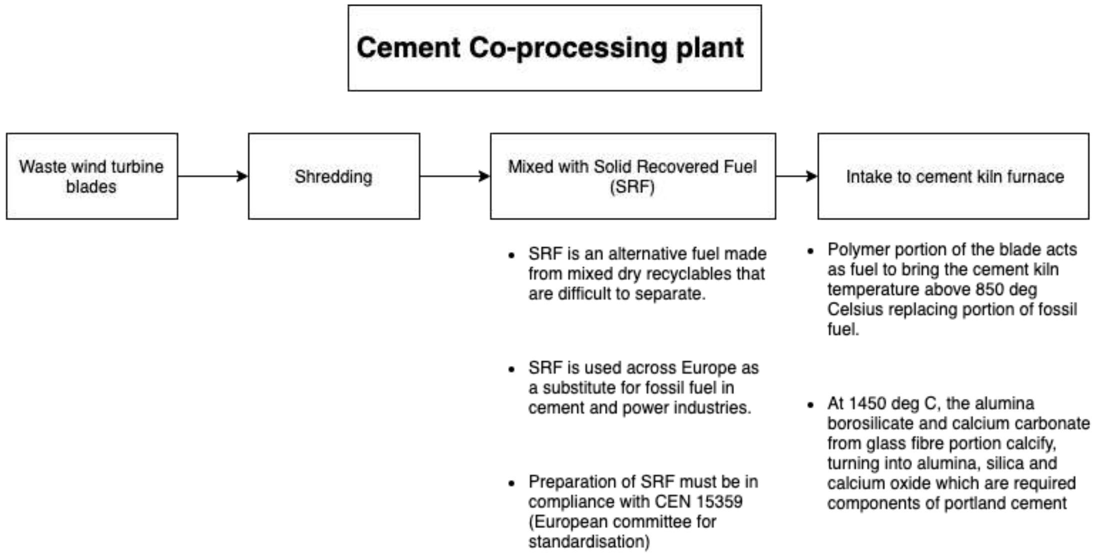
3.2.5. Cement co-processing for wind turbine blade waste[55]

Cement co-processing with waste wind turbine blades is the most commercial option currently available for end of life management. The advantages of cement co-processing lies in the fact that no separate infrastructure cost is needed compared to the other technologies listed in Table 18. A wind turbine blade is made up of glass fibre and polymer matrix. The glass fibre present in wind turbine blade waste is recycled as a component of cement mixes (clinker). The polymer matrix present in wind turbine blade waste is burned as fuel for the process (also called refuse-derived fuel), which reduces the carbon footprint of cement production.It has been reported that cement co-processing reduces carbon footprint of cement industry by 16%.

The other advantages of cement co-processing are that it is highly efficient, fast and scalable. Large quantities of waste can be processed using this technology. It results in slightly increasing energy efficiency of cement manufacturing, thereby helping another major sector with greenhouse gas emissions.It must be noted that no ash is left over after the processing.

The details of the process and current activities are illustrated in the prepared infographic shown in Figure 28.

[55] Nagle, A. J., Delaney, E. L., Bank, L. C., & Leahy, P. G. (2020). A Comparative Life Cycle Assessment between landfilling and Co-Processing of waste from decommissioned Irish wind turbine blades. Journal of Cleaner Production, 277, 123321. https://doi.org/10.1016/j.jclepro.2020.123321



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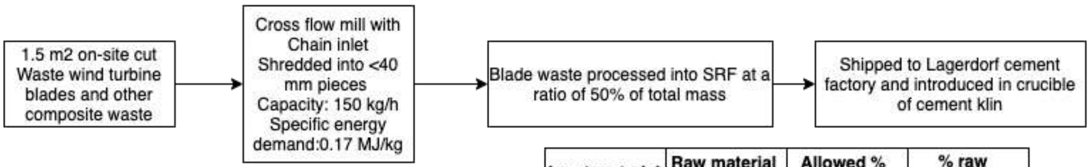

Input material	Raw material equivalent	Allowed % replacement	% raw material
1000 kg blade waste	600 kg coal	10	6
1000 kg blade waste	560 kg E-glass	10	CaO-2%;SiO2-3.1%;Al2O3-
1000 kg blade waste	600 kg coal	50	30
1000 kg blade waste	560 kg E-glass	50	CaO=9.8%; SiO2=15.4%; Al2O3=2.8%

GE VEOLIA

General Electric has entered into agreement with Veolia North America recycle blades removed from its onshore turbines in the United States.Their study suggests that recycling a single 7-ton blade through cement co-processing enables the cement kiln to avoid consuming nearly 5 tons of coal, 2.7 tons of silica, 1.9 tons of limestone and reduces emissions by 27%

DecomBlades

DecomBlades,a project to commercialise recycling of wind blades consists of Ørsted, LM Wind Power – a GE Renewable Energy business, Vestas Wind Systems A/S, Siemens Gamesa Renewable Energy, FLSmidth, MAKEEN Power, HJHansen Recycling, Energy Cluster Denmark (ECD), University of Southern Denmark (SDU) and Technical University of Denmark (DTU).

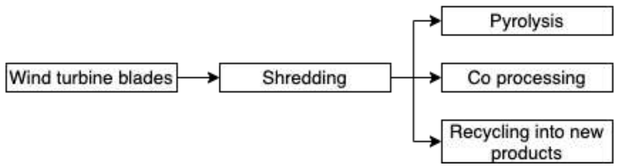

Figure 28. Cement co-processing using wind turbine blade waste

3.3. Summary of Worldwide trends for batteries recycling

Batteries for storage of renewable energy generated from solar and wind are mainly of two main types – either lead acid batteries or lithium based batteries, of varying chemistries.

Treatment and processing technology for batteries: International best practice

Lithium Batteries are becoming commonly with Solar PV systems. Lithium battery recycling involves a combination of mechanical and/or thermal pre-treatment steps, pyro- and/or hydrometallurgical processing.

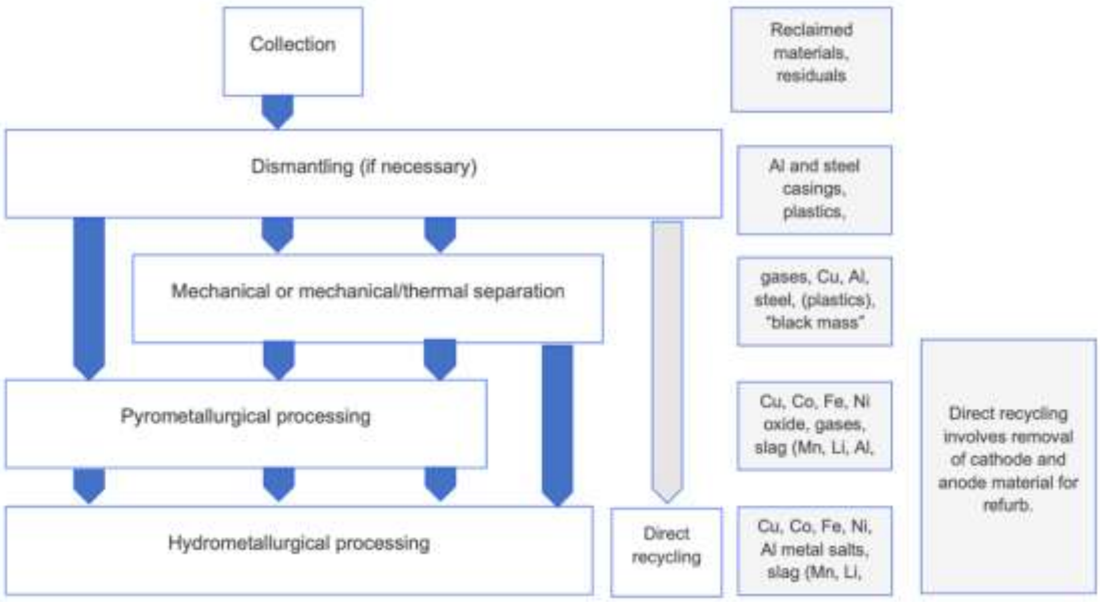

Figure 29: Overview of the different processes for Lithium-Ion Battery recycling

'Initial processing' involves discharge, disassembly and shredding/crushing to produce a mixed metal dust ('black mass') consisting of Li, Co, Ni, other minor metals and graphite representing ~35% of the discarded battery stream. 'High recovery' or full-chain recycling can achieve a total material recovery of ~60%, including Li (lico3), Co (hydroxide), Ni (hydroxide), Fe, Cu and Al (scrap); Material losses include the solvent, plastics and minor metals. Materials can be recovered at suitable purities for cathode manufacturing (or other applications).

Battery reuse, in principle, is likely to have better environmental outcomes than recycling, due to its lower material and energy requirements. In terms of technology, a number of refurbishment methods have passed the demonstration phase. Technology intended to rejuvenate cathodes by bathing them in a soft chemical solution, may be more cost effective than recycling because it does not require the cathode to be rebuilt and keeps materials in form. Another future pathway for refurbishment involves the replacement of whole degraded cells in battery pack systems. In cases where degradation or failures occur as a result of a few cells failing, the direct swapping out for new cells could prolong the life of the battery pack overall. However, for this to work would require that battery packs and systems be designed and constructed to enable cells to be swapped in this way.

Despite the interest and commitment to battery reuse from industry, stakeholders indicate barriers like the need for a robust battery testing system that can quickly determine how many cells have failed, differences in battery sizing – due to specific product requirements

– which creates challenges in terms of creating economies of scale, lack of policy and protocols or certification around the reuse of batteries for energy storage.

Table 19. Economic analysis for lithium battery recycling (Reference from Australia[56])

Technologies for Lithium-Ion Battery Recycling	Description	Operational cost and Margin (Australian Dollars)
Initial processing/ Low Recovery	Recovers steel, Cu and Al and a black mass for downstream processing	$ 1560 per tonne and at a gate fee of about $160 average per unit gate fee is estimated to achieve a gross margin of about $70 per unit or $675 per tonne
High Recovery	Also recovers lithium carbonate, cobalt nickel hydroxide and graphite powder in addition to initial processing	$1730 per tonne and at a gate fee of about $160 per unit gate fee is estimated to achieve a gross margin of about $80 per unit or $740 per tonne

[56] NSW- Equilibrium consulting scoping study

3.4. Analysis of international developments of EOL management of solar and wind power systems

This section provides a summary of the challenges and drivers for end-of-life management of solar and wind power systems internationally.

3.4.1. Drivers for solar PV and wind power waste management

For proper waste management of Solar PV and wind power systems the following are the major drivers.

i) Green Branding of PV and Wind power systems

Both Solar PV and Wind power systems have been classified as green source of energy as compared to the fossil fuel systems. It would therefore be important to maintain the integrity of clean and sustainable source of energy production. Without a suistanable end of life management of these systems, the green branding of solar PV and wind power systems would not be complete. Hence it is an important driver as compared any other equipment for sustainable end of life management

ii) Increase in renewable energy installations:

Solar PV and wind power systems are major sources of renewable energy which can help to reduce the green house gas emissions. Therefore almost all the countries of the world have set targets to install increasing amounts of these systems in the future. This increases the production demand and subsequently the raw material demand of the materials associated with the production. It must be noted that solar PV and wind power systems are mineral intensive. They are constituted by a range of materials in which some are scarce and highly values. This serves as a major driver for recirculation of material from waste PV and wind systems , thereby reduced the burden of raw material demand for the future.

iii) Domestic Industrial development and job creation:

Sustainably managing end of life management of PV and wind power systems through reuse or recycling instead of disposal would provide a opportunity for job creation through the creation of new waste management sectors. It would also allow industrial synergies and new partnerships.

3.4.2. Barriers and enablers for solar PV and wind power waste management

The challenges and enablers vary from country to country, but are synthesized below to give an overview.

Barriers or challenges identified that impede EOL solar and wind power waste management including policy and regulatory barriers as well as technical and financial barriers. Conversely, tackling the barrier provides opportunities and enables the development of recycling of solar and wind power waste.

i) Lack of/ Gaps in data:

Barrier: This includes assessment of quantities and material in stock and estimated waste flows over time.Data gaps regarding existing infrastructure for collection and treatment is also an impediment.

Enabler: Baseline assessment of the installed capacity and average lifespan of products can provide a good estimate of the volume of solar or wind power waste that needs to be handled annually, and accordingly design and plan policies and infrastructure for collection and treatment.

ii) Lack of regulation:

Barrier*:* Most countries do not have any specific regulation for the management of end-of-life solar or wind waste. The countries with specific regulations for EOL management of solar waste (e.g., EU) have been able to create mechanisms and funding structures based on the principle of Extended Producer Responsibility (EPR) to facilitate the collection and appropriate recycling of EOL solar modules due to regulatory pressures. In the absence of regulatory obligations, there is limited interest for solar manufacturers/ developers/ installers/ importers to pay for EOL management.

Enabler*:* Technical guidelines and standards for design and disposal are also tools that can fill partly the gap in regulation. For example, in Japan, the Japan Photovoltaic Energy Association (JPEA) published voluntary guidelines on how to properly dispose of EoL photovoltaic modules and strongly encourages the solar industry to voluntary follow these guidelines.

iii) Unclear definitions or classification:

Barrier*:* The point at which the solar module or wind turbine (or components/ parts thereof) becomes waste is often unclear, especially if there is an economic value still associated with it, creating ambiguity whether it is a waste (generally not having any economic value) or a product (that is bought and has a price). The classification of EOL solar and wind power waste is also not harmonized around the world. While some countries classify as hazardous waste, there are many that have exemption of solar products, either classifying it as special waste or non-hazardous waste for certain activities such as collection and transport.

Enabler: Taking the example of California[57], PV waste can be classified as universal waste. By being classified as universal waste, PV solar panels will be subject to a streamlined set of standards that are intended to ease regulatory burden and promote recycling. For instance, under the universal waste requirements, holders of PV waste may accumulate panels for up to one year, while the general hazardous waste requirements only allow accumulation for 90 days (for large quantity generators). This longer accumulation period will allow handlers to transport the solar panels to destination facilities in bulk rather than on a more frequent basis thereby saving on transportation cost. In addition, the universal waste requirements include fewer labeling and recordkeeping requirements and also allow waste to be transported without a hazardous waste manifest. Facilities will also be able to exclude the weight of solar panels from their generation quantities, likely leading to the ability to qualify for small quantity generator status.

iv) Varying types of panels based on different technologies

Barrier: Varying types of panels based on different technologies require different treatment processes based on their material composition. This creates barriers in treatment and recycling as there are additional costs in sorting and separation of different panel types. Also, as panel technology is rapidly evolving, there may be more types and applications of solar PV panels for example in structural building products (building integrated photovoltaics) that may need alternative dismantling and separation technologies.

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[57] https://www.jdsupra.com/legalnews/california-classifies-solar-panels-as-78219/

Enabler: However, experience with processing multiple product types and technologies from consumer electronic and home appliances has given the recycling industry the ability to adapt processing and treatment technologies to enable intake of changing product types.

v) Limited inflow of products into waste stream in the initial years

Barrier*:* Both solar and wind power installations have long lifespans of over 20 years, and given that the large majority have been installed rather more recently, the waste generated from end-of-life panels and turbines is low. This makes investments in any collection and treatment unviable from a business perspective in the absence of economies of scale below a certain threshold.

Enabler: Interventions to create small scale pilots to test the collection and treatment can be used establish financial and technical baselines while volumes are low, in order to be ready for larger volumes in the near future. Options to export waste to treatment facilities in other countries can fill capacity gaps and overcome lack of domestic infrastructure.

vi) Unavailability of treatment technology

Barrier*:* Recycling and treatment technologies for PV and wind power waste are still at a nascent stage around the world, and many are still in the early stages of technology readiness to move lab and pilot scale to commercial scale.

Enabler*:* Research and development support, combined with industry collaboration in providing material composition and characterization data, particularly regarding toxicity and leaching of hazardous substances can support development of relevant technologies.

4. Regulatory frameworks associated with End-of-Life Management of PV and Wind Turbines in Viet Nam

4.1. Basel Convention

Viet Nam is a Party to the Basel Convention on transboundary movement of hazardous wastes.

The overarching objective of the Basel Convention is to protect human health and the environment against the adverse effects of hazardous wastes. Its scope of application covers a wide range of wastes defined as “hazardous wastes” based on their origin and/or composition and their characteristics, as well as two types of wastes defined as “other wastes” (household waste and incinerator ash; article 1 and annex II).

The provisions of the Convention center around the following principal aims: (i) the reduction of hazardous waste generation and the promotion of environmentally sound management of hazardous wastes, wherever the place of disposal; (ii) the restriction of transboundary movements of hazardous wastes except where it is perceived to be in accordance with the principles of environmentally sound management; and (iii) a regulatory system applying to cases where transboundary movements are permissible.

The Vietnamese regulation on the management of hazardous waste is in compliance with the Basel Convention – Circular No. 36/2015/TT-BTNMT as it includes, for each waste category, along with the Vietnamese Code, the equivalent “A” and “Y” Basel codes as well as the EC code.

The Government of Viet Namalso established a National Technical Regulation on Hazardous Waste Thresholds QCVN 07:2009/BTNMT in which waste is considered to be hazardous if it is named in the list of hazardous wastes issued by the MONRE[58] or it has at least one hazardous nature / one hazardous ingredient exceeding the regulated hazardous waste thresholds.

4.2. Asian agreement on the electrical and electronic equipment regulatory regime

Member countries of the ASEAN shall undertake all necessary measures to ensure that only electrical and electronic equipment (EEE), which comply with Appendix B - ASEAN essential requirements and are registered with the relevant regulatory authority may allowed to be placed in the ASEAN regulated market.

4.3. National regulation on waste and hazardous waste management

Law on Environmental protection 55/2014/QH13 and Law on Environmental protection No. 72/2020/QH14 (To come into force from January 2022 – Replaces Amendment Law No. 35/2018/QH14, Law No. 39/2019/QH14 and Law No. 61/2020/QH14).

The laws promote waste reduction, reuse and recycling; and encourages organizations and individuals to use recycled and environmentally friendly products. These laws emphasize that organizations and individuals have responsibilities for waste reduction, reuse and recycling in order to minimize the amount of waste disposed. Articles 54 and 55 provide for extended responsibility of manufacturers (EPR). Thus, manufacturers and importers are responsible for collecting and recycling the products or packages, which they produce or import. However, the laws do not provide implementation details of the EPR scheme, which is currently under discussion and development in the Draft Decree on Detailing a number of articles of the Law on Environmental Protection 2020[59].

On another hand, both the Law on Environmental protection 55/2014/QH13 and Law on Environmental protection No. 72/2020/QH14 prohibit importation of waste, but they do not prohibit exportation of waste to other countries. Therefore, export of waste from renewable energy systems would be an option for safe treatment or disposal, especially in the initial years when the volume is low; and the technical capacity and economic feasibility are hardly able to recycle and recover the materials in the country.

Draft Decree under the Law on Environmental protection No. 72/2020/QH14 (to come into force from January 2022; and to replace Decision No. 16/2015/QD-TTg of the Prime Minister dated 22/05/2015 on taking back and treatment of discarded products and Circular No. 34/2017/TT-BTNMT dated 4/10/ 2017 on Rules on the Collection and Disposal of Discarded Products).

Pursuant to the Draft Decree, organizations and individuals that manufacture and import products and packages must carry out the responsibility to recycle such products and packages. 3 recycling procedures are proposed: (1) Self-executing recycling; (2) Hire a functional unit to carry out the recycling; (3) Fully authorize a third party to organize the recycling (PRO). In order to facilitate manufacturers and importers to fulfil this responsibility, the Law and its draft Decree add a financial contribution mechanism to the Viet Nam Environmental Protection Fund, to support recycling activities. The financial contribution is determined by product volume or unit. The Viet Nam Importer and

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[58] Circular No. 36/2015/TT-BTNMT on Management of Hazardous Waste

[59] https://monre.gov.vn/VanBan/Pages/ChiTietVanBanDuThao.aspx?pID=257

Production's Office of Expansion of Responsibility (hereinafter referred to as Viet Nam EPR Office) selects and signs a contract with a recycling unit in a form approved by the National EPR Council. The Viet Nam Environmental Protection Fund is responsible for paying the recycling cost under the contract to the recycler. Manufacturers and importers, who fail to perform the recycling responsibility, will be administratively sanctioned.

The law also stipulates the recycling rate, which is calculated according to the actual recycling rate of each product or package; environmental protection requirements, national recycling targets and socio-economic conditions from time to time. The appendix of the draft Decree shows the list of products, packaging, which must be recycled, recycling procedures and implementation roadmaps. However, they only apply for solar PV panels (at least 80% of metal, plastic and glass from a product to be recovered and reused as raw materials for the industrial sector) and the prescribed recycling standards and specifications, but not applies for wind turbines.

Although, pursuant to the draft Decree, wind turbine blade is not subject to EPR regulations, due to all wind power plants are utility-scale projects, which should refer to Decision No. 16/2015/QD-TTg[60] dated May 22, 2015 of the Prime Minister on regulations on recall and treatment of discarded products to strengthen the responsibility of manufacturers and owners in the recall and treatment of discarded products to comply with the provisions of the Law on Environmental Protection. However due to its large volume and compositions as presented in section 3.5.3, we should think about the recycling roadmap in the coming years based on the national recycling targets and socio-economic conditions to save resources and meet the circular economy scheme. EoL wind turbine blades would be transferred to permitted recyclers or disposers even with or without EPR.

However, these articles only focus on waste generated from the facilities and manufactories, which would be collected and transferred to permitted recyclers or disposers. Another problem come from waste generated in households and personal activities, especially for rooftop solar systems. Now, the failure PVs are usually transferred to informal sectors. EPR regulation would be the good mechanism to manage this waste source via manufactures, importers and suppliers under the Article 54 of the new Law. However, the implementation needs to be supported by circulars or detailed instructions of the competent authorities.

Decree No. 38/2015/ND-CP dated 24/4/2015 on the management of wastes and scraps

This Decree provides for waste management including hazardous waste, domestic solid waste, ordinary industrial solid waste, liquid waste products, wastewater, industrial emissions and other specific wastes.

Decree 38/2015/ND-CP also specifies the reduction, reuse, recycling, and recovery of energy from domestic and ordinary industrial solid wastes. The Decree also stipulates the responsibilities of the MONRE, the provincial People's Committees in confirming or adjusting the confirmation to ensure environmental protection requirements for solid waste treatment facilities.

Decision No. 491/QD-TTg on approving the national strategy for integrated management of solid waste to 2025, vision to 2050 on 7/5/2018

The National Strategy for Solid Waste Management has classified specific targets for all waste types and considered waste as a resource. Viet Nam commits to collect, transport and

[60] https://english.luatvietnam.vn/decision-no-16-2015-qd-ttg-dated-may-22-2015-of-the-prime-minister-on-regulations-on-recall-and-treatment-of-discarded-products-94733-Doc1.html

handle 100% of hazardous wastes generated from production, trading, service activities, medical facilities, craft villages and electrical - electronic equipment, and 85% of household waste in urban areas by 2025. Large-scale treatment facilities using modern technologies are prioritized.

Electronic device manufacturers must establish and publish discarded product collection points/systems in accordance with the law. Consumers are responsible for transferring discarded products to the collection points / systems or organizations / individuals, that are eligible for collection and transportation according to regulations. Hazardous waste is encouraged to collect and process inter-regions and inter-provinces. The State encourages the construction of specialized treatment and recycling facilities for specific types of hazardous waste.

Decree No. 40/2019/ND-CP on amendments to Decrees on Guidelines for the Law on Environmental protection dated 13/5/2019

Ordinary industrial solid wastes must be separated and classified separately from hazardous wastes. If not being classified, they must be managed according to the hazardous waste regulations. Ordinary industrial solid wastes are classified into 03 groups: (1) ordinary industrial solid wastes that are reused and recycled as raw materials for the production process; (2) solid waste used in the production of construction materials and levelling; (3) ordinary industrial solid waste must be treated by incineration and burial methods.

Ordinary industrial solid waste owners must classify ordinary industrial solid wastes and have storage equipment and areas meeting technical requirements. The ordinary industrial solid waste owners can transfer ordinary industrial solid waste to objects according to the provisions of law. During the transfer process, the owners must make a handover record of ordinary solid industrial waste. Organizations and individuals that reuse, pre-process, recycle, treat, co-treat, and recover energy from ordinary industrial solid waste by themselves, must meet technical requirements and management processes. They must prepare annual ordinary industrial solid waste management reports. If they are also hazardous waste owners, the reports will be integrated into the periodic hazardous waste management reports. The owners make ad-hoc reports on ordinary industrial solid waste generation at the request of competent state management agencies.

Circular No. 18/2020/TT-BCT on Provision on project development and sample power purchase agreement on solar power projects dated 17/07/2020

In 2020, the Ministry of Industry and Trade (MOIT) issued a Circular No. 18/2020/TT-BCT on Provision on project development and sample power purchase agreement on solar power projects[61] stating that project investors are responsible for the collection, handling, and disposal of all materials, equipment, and wastes generated from solar power projects throughout all the life stages of the power projects, as per the provisions of the Law on Environmental Protection – Article 130. It is expected that the Electricity and Renewable Energy Authority (EREA) under the MOIT will oversee the management of solar power waste and ensure that the waste is disposed of or recycled in compliance with environmental regulations.

[61] https://www.moit.gov.vn/documents/40224/0/TT+18+2020-07-17_Thong+tu+quy+dinh+ve+dien+mat+troi+%28BW%29.pdf/3789fb1f-73be-4a17-819e-5ccbd90ecb54

4.4. Classification of waste from EOL photovoltaic modules and wind power plants.

In Viet Nam, hazardous waste is classified in accordance with the Circular No. 36/2015/TT-BTNMT "Management of Hazardous Waste", and its Appendix 1 which contains the list of waste classified as hazardous.

The Circular stipulates that all production facilities and manufactures that generate hazardous waste, must collect, store, report and sign contracts with functional units to collect and treat hazardous waste.

These facilities must register as hazardous waste source owners and submit their dossiers to the provincial Department of Natural Resources and Environment (DONRE), where the hazardous waste generating facility is located. Hazardous waste treatment organizations and individuals must have an appropriate hazardous waste disposal license or hazardous waste management practice license.

Circular No. 36/2015/TT-BTNMT also specifies the list of hazardous wastes, technical requirements and management procedures for hazardous waste source owners; regulates the shape, size, color and content of warning signs, and prevent use in hazardous waste management.

EoL solar photovoltaic modules (EOL-PV) can be considered as pertaining to category 19 02 (Waste from Electrical and Electronic Equipment). By exclusion, EOL-PV cannot however be classified under any of the sub categories 19 02 01 to 19 02 04 for the following reasons:

- 19 02 01 and 19 02 02 are related to transformers and capacitors containing PCBs (19 02 01), or discarded equipment containing or contaminated by PCB (19 02 02); PCB are typically contained in equipment (transformers, capacitors, ballasts) manufactured before the year 1980. This is not applicable to solar PV modules in Viet Nam, all of which are less than 10 years old.
- 19 02 03 concerns equipment containing chlorofluorocarbons, HCFC, HFC. This is also not applicable to EOL-PV as none of the component of a PV contain these chemicals at any stage.
- 19 02 04 is for discarded equipment containing free asbestos. Again, this material is not used in any of the component of a PV.

Therefore, EOL-PV can be classified as hazardous waste only if they pertain to one of the following categories.

- 19 02 05 (discarded equipment containing hazardous components) or
- 19 02 06 (hazardous components removed from discarded equipment), or
- 15 01 09 (Discarded electronic components or other electrical equipment having electronic components containing hazardous substances except for circuit boards not containing dangerous substances exceeding hazardous waste thresholds)

This approach is similar to the European Union, where the EOL-PV are classified either as discarded equipment (16 02 14 and 20 01 36) or discarded equipment containing hazardous component (16 02 13* and 20 01 35*).

It may be noticed that, although several components of the EOL-PV cannot be considered as hazardous, there may be some components containing hazardous substances for which it is necessary to perform a careful classification. This may vary from brand to brand, for instance some PV glasses may contain antimony at different concentration and only the manufacturer could know whether the concentration of antimony in the glass would lead to the classification of glass as hazardous waste.

Therefore, the detailed classification as hazardous or non-hazardous waste of EOL-PV should indeed be undertaken by the manufacturers, who should provide a documentation certifying such classification based on the Vietnamese regulation.

For wind power plants, (EOL-WP) the situation is indeed very similar, except that due to the size of these plants only the classification related to components should be considered. Therefore, the question is whether these wastes have to be considered as 19 02 06** (hazardous components removed from discarded equipment or not.

Based on this approach, to verify whether specific components of an EOL-PV or EOL-WP may be classified as hazardous under the Vietnamese, it is necessary to check whether any of the hazardous characteristics listed in the regulation apply to EOL-PV and EOL WP to provide a detailed guidance on the waste classification of the EOL-PV and EOL-WP. Indeed no new regulation is needed: however due to the complexity of the matter, such classification guidance could have an enormous and beneficial impact on the management of EOL-PV and WP.

4.5. Focus on specific waste stream from PV panels: the issue of Antimony-treated glass

Glass represents around 70% of the weight of a PV panel. The majority of glass used in the PV panel manufacturing is enriched with antimony. Antimony is used in solar panel glass to improve stability of the solar performance of the glass upon exposure to ultraviolet radiation and/or sunlight. The combination of low iron content, antimony and/or patterning results in glass substrate with high visible transmission and excellent light refracting characteristics[62]. It is therefore of outmost importance to ensure that waste glasses are properly categorized and classified to ensure their recycling as raw material in the float glass industry.

In compliance with QCVN 07:2009/BTNMT on "National technical regulation on hazardous waste thresholds"[63], a waste is classified as hazardous if *"There is at least one inorganic or organic hazardous component that at the same time exceeds the value of the absolute content (H_{tc}) and leaching concentration (C_{tc})"*. For antimony, the H_{tc} threshold value is established in Table 20 of the regulation as 20 ppm, whilst the leaching concentration threshold is 1 mg/l.

More specifically, in PV glass modules antimony is used in form of antimony oxide, with a concentration ranging from 0.1 % (1000 ppm) to 1 % (10,000 ppm) exceeding the regulatory H_t value for antimony (20 ppm). Additionally, to be classified as hazardous, the eluate concentration should also exceed the regulatory threshold (C_{tc}) of 1 mg/l. A document from the Ministry of Renewable Energy in India suggests a concentration of antimony in the glass in the order of 0.3 %, a value of antimony in the eluate in the order of 0.21 mg/l[64].

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[62] Solar cell using low iron high transmission glass with antimony and corresponding method. https://patents.google.com/patent/US8802216B2/en

[63] http://vbpl.vn/botainguyen/Pages/vbpq-toanvan.aspx?ItemID=125608

[64] Concept Note/ Blue Print on Management of Antimony Containing Glass from End-of-Life of the Solar PV Panels

Based on the information above, it seems therefore that antimony glass from EOL photovoltaic panels should be not considered as hazardous waste, although the confirmation would require a specific analytical certificate issued in compliance with Vietnamese rules.

Although the threshold limit values are different, the classification of hazardous waste based on the concentration of hazardous chemicals is regulated in a similar way by the Vietnamese[65] or European regulation (Table 20).

Table 20. Classification of hazardous waste based on the content of hazardous chemicals following the EU and VN regulation

EU regulation (Waste Directive 2008/98)	VN regulation (Circular on the management of hazardous wastes No. 36/2015/TT-BTNMT)
"Any waste marked with an asterisk (*) in the list of wastes shall be considered as hazardous waste pursuant to Directive 2008/98/EC, unless Article 20 of that Directive applies. For those wastes for which hazardous and non-hazardous waste codes could be assigned, the following shall apply: — An entry in the harmonised list of wastes marked as hazardous, having a specific or general reference to 'hazardous substances', is only appropriate to a waste when that waste contains relevant hazardous substances that cause the waste to display one or more of the hazardous properties HP 1 to HP 8 and/or HP 10 to HP 15 as listed in Annex III to Directive 2008/98/EC." A hazardous property can be assessed by using the concentration of substances in the waste as specified in Annex III to Directive 2008/98/EC or, unless otherwise specified in Regulation (EC) No 1272/2008, by performing a test in accordance with Regulation (EC) No 440/2008 or other internationally recognised test methods and guidelines.	1.8.1. Possible hazardous waste (*): hazardous thresholds of wastes must be applied according to environmental standards on hazardous thresholds of wastes to determine whether a waste is hazardous. If hazardous thresholds of wastes are not applied, it will be identified as a hazardous waste. If some characteristics and hazardous contents are not regulated by any technical regulations, international standards shall in accordance with instructions of environment authorities. 1.8.2. Hazardous waste (**): a waste is identified as a hazardous waste without applying hazardous thresholds of wastes.

[65] QCVN 07:2009/BTNMT on the National Technical Regulation on Hazardous Waste Thresholds

Table 21. Classification of End-of-Life photovoltaic panels based on the EU and Vietnamese regulations

EU regulation (Waste Directive 2008/98)	VN regulation (Circular on the management of hazardous wastes No. 36/2015/TT-BTNMT)
16 02 wastes from electrical and electronic equipment	19 02 wastes from electrical and electronic equipment
16 02 13* discarded equipment containing hazardous components (1) other than those mentioned in 16 02 09 to 16 02 12 16 02 14 discarded equipment other than those mentioned in 16 02 09 to 16 02 13	19 02 05* discarded equipment containing hazardous components
16 02 15* hazardous components removed from discarded equipment	19 02 06* hazardous components removed from discarded equipment
16 02 16 components removed from discarded equipment other than those mentioned in 16 02 15	15 01 09* Discarded electronic components or other electrical equipment having electronic components containing hazardous substances except for circuit boards not containing dangerous substances exceeding hazardous waste thresholds

Based on both the CLP and GHS classification of hazardous substances, antimony oxide is classified as a potential carcinogenic compound (Carc. category 2, suspected of causing cancer).

Under the European Regulation (Directive 2008/98), antimony containing glasses can be considered as non-hazardous only if the concentration of antimony oxide in the glass is less than 1%.

However, even if the concentration of antimony is lower than 1%, the concerns about the environmental and toxicological properties of antimony has led some manufacturers of photovoltaic panels to use antimony-free glass for their products[66][67].

A similar situation may occurr for the recycling of silicon, as the PV crystalline silicon wafers are usually doped with a range of elements that may include arsenic, lead, antimony, and many others[68]. For this reason,is likely that silicon wafers need to be classified as hazardous waste in Viet Nam, even if an accurate categorization may be done only on the basis of laboratory analysis.

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[66] Fsolar website: https://www.fsolar.de/en/application-areas/photovoltaics

[67] Borosil website: https://www.borosil.com/what-we-do/solar-glass/product-information

[68] Lu et al, (2019). Thermodynamic criteria of the end-of-life silicon wafers refining for closing

the recycling loop of photovoltaic panels. SCIENCE AND TECHNOLOGY OF ADVANCED MATERIALS. 2019, VOL. 20, NO. 1, 813–825. https://doi.org/10.1080/14686996.2019.1641429

Silicon wafer recycling needs specialised metallurgic treatment for the removal of dopants and the manufacturing of high purity silicon ingots suitable for the market, therefore the situation is different from the case of glass which may be recycled by common glass manufacturing plants, provided the glass is categorized as non-hazardous waste.

5. Existing waste management infrastructure in Viet Nam for EOL Solar and Wind power installations

5.1. Storage and collection

Storage. Based on our investigation, in utility-scale solar power plants, all faulty solar PVs are stored as hazardous waste in the plants' temporary storage areas. The temporary storages are designed in compliance with the Circular 36/2015/TT-BTNMT. All plants have dossiers of waste owners, which are registered with and submitted to provincial DONRE periodically. The faulty solar PVs are isolated with other hazardous wastes such as waste oil and oil-contaminated waste to prevent chemical interaction among different materials. The plants keep this waste category and wait for specific instructions from the authorities. However, as hazardous waste, faulty PVs can be kept in the temporary storage within 12 months. Beyond the time limit, because there is no feasible transportation and treatment plan or a suitable hazardous waste treatment facility has not been found, an annual report on the storage of hazardous wastes at the generating facility must be submitted to provincial DONREs.

Up to now, there hasn't any solid waste generated in wind power plants in Viet Nam as the country just started the implementation of this technology and most of the equipment is still under the warranty of manufacturers and providers, normally 5 – 25 years. If wind blades, nacelles and towers have faults or problems, they will be removed from the turbine and kept within the wind power plants. The manufacturers, suppliers and installers have responsibility to fix and change the faulty part based on their terms of contract.

Collection. Similar to WEEE management in Viet Nam from large institutional consumers, most of the solar EoL waste generated from utility-scale plants is collected by licensed hazardous waste treatment facilities pursuant to the contracts with the solar power plant owners. These facilities are responsible to pack and label faulty panels to prevent toxic material leakage.

Particularly, equipment of wind turbines and its auxiliaries have big sizes thus it is difficult to be collected directly. In addition, Viet Nam does not have any experience for this waste type. Simply, wind blades and towers can be cut into small parts which can be transported by vehicles or waterways to solid waste collection centers. In fact, at present, no wind turbine EOL are investigated due to new operations and under warranty period.

Viet Nam does not have a formal program to categorize and collect electric and electronic waste from households. Currently, the collection of electric and electronic waste is mainly performed by individuals working in scrap metalwork, equipment repairing centers and urban environmental companies (URENCO). After collection, electric and electronic waste is dismantled at big centers such as Trang Minh (Hai Phong) Bui Dau, Phan Boi (Hung Yen), Te Lo (Vinh Phuc) or private agents.

Figure 30. Electronic waste sorting in Viet Nam[69]

5.2. Transportation

Solid waste in Viet Nam can be transported by various ways, e.g. formal methods (vehicles and ships with licensed equipment and facilities) or informal methods (scrap collectors by bikes or trolleys). “Informal” or not properly arranged transportation of hazardous waste can obviously cause dispersion of hazardous waste in the environment or even damage for the environment. Hazardous waste can only be transported by licensed waste management companies.

At present, faulty panels were transported to hazardous waste treatment facilities by road. The facilities make a schedule (approx. 6 months) to collect and transport fault panels from several solar power plants in the same region simultaneously. The simultaneous transportation will reduce the number of transportation times and save treatment cost. While turbine blades or towers are transported by super-weighted vehicles then by large – size ships.

- Vehicles and ships must meet technical requirements and management processes to prevent toxic material leakage into ambient environment.
- Vehicles transporting hazardous wastes must have a Global Positioning System (GPS) connected to an online information network to locate and record hazardous waste transport itineraries.
- A vehicle or equipment may only be registered for one license for hazardous waste disposal, except for sea, rail or air transport.

[69] https://kinhtemoitruong.vn/bao-dong-tinh-trang-o-nhiem-rac-thai-dien-tu-tai-viet-nam-11854.html

Figure 31. Viet Xanh manufacturing - trading - services company limited collect and transport hazardous waste for CPC Dak Lac (Source: EVNCPC DakLak)[70]

Figure 32. The on-road transportation of a 57 – m turbine blade for Trung Nam - Ninh Thuan Wind power plant[71]

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[70] https://cpc.vn/vi-vn/Tin-tuc-su-kien/Tin-tuc-chi-tiet/articleId/103471

[71] https://dantri.com.vn/doanh-nghiep/hanh-trinh-vuot-nui-cua-nhung-canh-quat-gio-lon-nhat-viet-nam-2018092409443118.htm

Figure 33. The waterway transportation of a 57 – m turbine blade for Trung Nam Ninh Thuan Wind power plant [72]

5.3. Disposal options for waste generated from EOL renewable energy plants

5.3.1. *Existing infrastructure for recycling and treatment in Viet Nam*

In Viet Nam there are currently 115 hazardous waste treatment licensed companies with an overall capacity of 1.5 mill. tons/year. As of March 30, 2020, 114 of these companies were operational (51 in the North, 07 in the Central and 56 in the South regions). They are registered and licensed by the Ministry of Natural Resources and Environment (MONRE). The list of existing hazardous waste treatments factories are shown in Annex 0.

According to a survey by the MONRE, hazardous waste is treated by incineration, landfill (pre-treated by physical, chemical and biological methods, solidification) and recycling technologies.

From households or individuals, recycling is largely manual, by informal collectors and recyclers. Recyclable wastes such as metals, plastic and paper are sold to scrap collectors and then sent to craft villages or recycling facilities. Waste recycling technology in craft villages is mostly old and outdated, conducted in substandard infrastructures with small production scale, leading to serious environmental pollution.

5.3.2. *Metal recycling: ferrous and non-ferrous*

The Vietnamese aluminium market has been estimated to register a compound annual growth rate (CAGR) of over 7%, over the forecast period 2019 – 2024. According to the

[72] https://dantri.com.vn/doanh-nghiep/hanh-trinh-vuot-nui-cua-nhung-canh-quat-gio-lon-nhat-viet-nam-2018092409443118.htm

Viet Nam National Coal and Mineral Industry Holding Corporation Limited (VINACOMIN) and the World Bureau of Metal Statistics, alumina production in Viet Nam amounted to approximately 1.4 million metric tons in 2020, from 181 aluminium manufacturing factories in 2020[73].

According to the draft amendment of the steel industry development plan, the steel billet production will rise up to 57.3 mill tons in 2025 and 66.3 mill tons in 2035 from 32.3 mill tons in 2020. Steel production from scrap is considered an environmentally friendly solution because it utilizes renewable raw materials to produce new products with less energy consumption and greenhouse gas emissions (only 20%) in comparison with production from raw materials. The domestic supply of scrap iron and steel supplies 40% of the demand, with 60% raw materials imported to meet production requirements. In 2020, Viet Nam imported more than 6.3 million tons of scrap iron and steel with an average price of about 6 million VND/ton. Japan, with 3.3 million tons/year, accounts for over 52.3% of the total amount of imported iron and steel scrap.

5.3.3. *E-waste recycling*

According to statistics of the Vietnam Environment Administration, Ministry of Natural Resources and Environment, the total amount of e-waste in Viet Nam in 2018 was 116,000 tons, mainly generated from households (electronic appliances), offices (computers, copiers, fax machines, etc.), faulty electronic product sets and illegally imported waste devices. It is estimated that the amount of e-waste in Viet Nam increases by 100,000 tons per year.

However, Viet Nam does not have a formal program for sorting and collecting e-waste. Public awareness about e-waste recycling is also not high. Consumers sell discarded electronics to informal e-waste collectors in the scrap trade. Some e-waste is collected by urban environmental companies. Most e-waste found its way to craft villages where it dismantled before being exported to China. Investment in modern recycling facilities has been hampered by the limited and unstable flow and access to e-waste.

5.3.4. *Battery recycling*

Recycling of certain battery chemistries such as Lead Acid Batteries (LAB) is mature in comparison to more recent battery chemistries such as Lithium based batteries. Different materials may be reclaimed at the different steps with a recovery rate of 25-60% depending on the chosen technology[74].

Lead acid batteries

Batteries and accumulators discarded from vehicles, equipment and household appliances are covered classified as **hazardous waste pursuant to Circular No. 34/2017/TT-BTNMT**. However, there is only limited capacity and investment and therefore a large informal battery recycling sector due to various reasons, such as:

(1) Cost of discarded battery recovery and treatment is more than the production cost of a new battery;

(2) Manufacturers cannot compete with informal collectors, who can collect discarded batteries and accumulators from households and garages;

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[73] https://world-bureau.co.uk/

[74] Zhao, Y., Pohl, O., Bhatt, A. I., Collis, G. E., Mahon, P. J., Rüther, T., & Hollenkamp, A. F. (2021). A Review on Battery Market Trends, Second-Life Reuse, and Recycling. Sustainable Chemistry, 2(1), 167-205.

(3) Sanctions for violations on waste batteries are not strong enough to force manufacturers and importers to have responsibility for their products;

Dong Mai lead recycling craft village in Hung Yen province is a typical example of battery recycling in Viet Nam. Over 500 workers participate in discarded battery collection and recycling.

These facilities often simply separate lead-containing components from the rest of the battery during battery handling and recovery:

- Pour acid/alkali solution into pre-arranged plastic containers and rinse the jar with water.
- Separate components into plastic and lead. The plastic part is put into the tank for about 30 minutes to remove the remaining acid, then transferred to the water tank to be rewashed. Clean plastic is taken out to dry, stored and sold for recycling.
- The lead-containing parts are washed, then sold for lead recycling.

Some large-scale battery manufacturers in Viet Nam also set up their waste battery recovery points. The Southern Battery Joint Stock Company (Pinaco) is the largest battery manufacturer in Viet Nam nationwide and has 5 points for collecting discarded batteries and accumulators located in Ho Chi Minh City, Dong Nai, Da Nang and Hanoi. GS Battery Viet Nam Co., Ltd also announced 8 waste battery recovery points, located in the southern provinces (5 points in Ho Chi Minh City, 2 points in Binh Duong and 1 point in Tay Ninh province).

Lithium batteries

At present, Viet Nam does not have experiences on lithium batteries recycling.

5.3.5. *Glass recycling*

“Horizontal” recycling of flat glasses from PV into new flat glasses for the same application would possibly represent the most desired option, as there would be no loss of value in the recycling. Recycling of flat glass (from EOL PV) to container glass is also an acceptable option. However, the value of the glass is usually too low to cover the collection of glass cullet. Therefore, the recycling of glass needs to be subsidized. In the Netherland, the recycling of flat glass is supported with a levy of 0.4 euro for each m^2 of flat glass collected.

On the technical side, one of the main challenges to ensure the flat-to-flat glass recycling is on the side of proper shredding/ crushing of the waste glass. A “flat to flat” project[75] has been established in the EU with the purpose to demonstrate innovative crushing method to ensure that flat glass is recycled into flat glass.

In Viet Nam, at the end of 2020, the installed capacity for glass manufacturing was in the order of 5120 tons/ day (355 mill. m^2/year), including 3370 tons/day of floating glass[76]. The estimated cumulative generation of glass cullet from EOL photovoltaic plants (as from this report) would range from 8,000 to 105,000 tons in 2030, which is around 5,61% of the current installed capacity for glass manufacturing. Theoretically, the floating glass industry could have enough capacity to accommodate the recycling of glass from EOL PV in the medium term (2030) and long term (2050).

[75] https://www.agc-flattoflat.eu/dissemination/photo-gallery/

[76] https://moc.gov.vn/vn/tin-tuc/1176/67145/dau-tu-phat-trien-vat-lieu-xay-dung.aspx

5.3.6. *Co-processing of fiber reinforced polymers in cement kilns.*

Based on the estimates provided in section 2.4.3 of this report, the cumulative amount of EOL blade will reach between 1.079 – 3.745 Kilo tons in 2030, rising to 7.484 – 67.912 Kilo tons in 2040 and between 88.254 – 346.079 Kilo tons in 2050.

Co-processing of reinforced (carbon or glass) polymers in cement kiln is a procedure which is both recommended by the manufacturers of polymers and by the cement industries. Based on a report from the European Composites Industry Association[77], processing of composite materials for the production of clinker can ensure a CO_2 saving from 5% to 16% depending on the amount of waste polymers processed. In the co-processing process, 100% of the composite waste is "recovered" in the form of energy and raw materials, resulting in approximately 67% material recovery. The mineral part of the composite, i.e., silica, calcium carbonate, alumina, etc., is integrated into the clinker; and approx. 33% is energy recovery[78].

A recent inquiry carried out in Viet Nam with cement kilns capable to process plastic waste revealed that the cost charged for pre-processing and co-incinerating plastic waste is currently in the order of 2,41 million VND per ton of plastic waste (around 105 USD/ton). The cost does not include investments needed to purchase equipment for the pre-processing of plastic waste (shredders). This figure reveals that the market is not mature yet, as plastic waste is perceived by cement kiln factories as a waste rather than a resource (fuel), in spite of the fact that the calorific value of plastic waste is higher than the one of coal.

In spite of the above, the cement industry has the capacity to absorb quite a large amount of waste material, provided that the quantity and the quality of the waste are consistent with time. The FPT security report[79] the yearly production of cement in Viet Nam in 2020, is estimated in the order of 101 million tons. This industry could therefore represent a valuable option for the recycling of the waste carbon-fiber wing blades generated by the EOL WP plants. Investment would be needed on the side of pre-processing of these waste (dismantling, cutting, grinding) as well as the collection and transportation infrastructure.

In Viet Nam, some cement factories are applying their own hazardous waste treatment systems within their facilities. The economic efficiency may be very high due to the saving of raw materials and fuels (the flammable hazardous wastes contribute to the heat supply and some hazardous waste categories have the composition suitable for cement production). In addition, co-processing in the cement kiln takes advantage of the existing cement production systems, which saves investment costs in infrastructure. In addition, the hazardous wastes are well treated in cement kilns are. No secondary ash and slag are generated as a component of the finished cement products.

The number of cement kilns operating co-incineration of hazardous waste in Viet Nam is not known. Some plants – like the former Holcim plant, now Insee – have quite a long experience in the treatment of hazardous waste. The Holcim plant performed, under the joint FAO UNDP/GEF project "Building Capacity to Eliminate POPs Pesticides Stockpiles", the destruction of around 1000 tons of hazardous waste contaminated by POPs pesticides. Other

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[77] European Composites Industry Association, Composites Recycling Made Easy, https://eucia.eu/about-composites/sustainability

[78] Krauklis, A.E.; Karl, C.W.;Gagani, A.I.; Jørgensen, J.K.Composite Material RecyclingTechnology—State-of-the-Art and Sustainable Development for the2020s. J. Compos. Sci.2021,5, 28.https://doi.org/10.3390/jcs5010028Rec

[79] Cement Industry Update Report, April 2020 http://www.fpts.com.vn/FileStore2/File/2020/05/14/Eng_Cement_Industry_Update042020_4d1632a8.pdf

plants, including the But Son Cement kiln in North Viet Nam, have agreement with URENCO for the treatment of waste with high calorific content (including plastic) used for the replacement of coal. In general cement kilns are safer in term of emission to the atmosphere, due to the very high temperature at which they operate and the fact that all the ash residues are incorporated in the product (the clinker). However, this technology is still not very well developed in Viet Nam and few incineration firms have the technical knowledge related to the safe handling and storage of waste.

5.3.7. *Recycling of rare earths and metals*

Recycling of rare earth elements has historically been low (less than 1%). However, reuse and recycling of NdFeB rare earth permanent magnets for wind turbines are more straightforward as they are relatively large, accessible, and demountable. In regard to recycling, several options exist. The magnets are processed into powder/alloy by using downsizing in hydrogen atmosphere, through dissolution of the NdFeB rare earth permanent magnet followed by a purification process, or by melting the magnet into a master alloy.

By means of hydrogen embrittlement, the magnets are crushed and turned into new magnets processed. Hitachi from Japan has developed a pyrometallurgical process to recover Raw Earth Elements (REE) from hard drives. After dismantling the hard drives and exposing the magnets, the REE are recovered at a temperature around 1000°C. This process takes place without the use of acids. Hitachi already has a micro-scale plant with a throughput of 40 kg magnets per day.

5.3.8. *Incineration*

Incineration, using two-stage static incinerators and rotary incinerators, is a popular technology in hazardous waste treatment facilities due to the wide range of hazardous waste that can be treated. In general, all waste which are not easily recyclable and which have a good calorific value – like polymers, plastic, wood - should be considered for incineration or co-processing in cement kiln. Metallic and glass components, or waste with high content of metal and glass are not suitable for incineration due to the high amount of solid residue they generate. Two-stage static furnace technology has the advantage of commercial, availability, reasonable investment cost, ease to operate in accordance with the Vietnamese situation. For this reason, most of the hazardous waste incinerators in Viet Nam have relatively small design/permit capacity. A number of incinerators are equipped with activated carbon systems to treat exhaust gas and with heat recovery to generate electricity. Rotary kiln technology is now gradually being applied in Viet Nam: 2 licensed hazardous waste treatment facilities are equipped with rotary kiln incinerators. Unfortunately, some small local incinerators are not equipped with suitable air pollution control systems, and this results in significant emissions in the atmosphere. The problem also affects several large-capacity incinerators, where there are still problems such as poor sorting and loading of waste, inefficient energy recovery from waste treatment, ineffective pollution control etc. Recent sampling and analysis carried at the stack of waste incinerators and industrial plants in the Binh Duong province under the UNDP/GEF project "Viet Nam POPS and Sound Harmful Chemicals Management Project"[80], revealed that 8 out of 9 incineration plants have Dioxin/Furan flue gas concentrations exceeding from 1.2 to more than 40 times the national

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[80] Mecie Viet Nam (April 2019). Package: "Support to integrate institutional framework and regulations on management and reporting of persistent organic substances (POPs) and toxic chemicals in Binh Duong province". Project: Management of persistent organic pollutants (POP) and toxic chemicals in Viet Nam (ID: 91381)

regulatory limit of 0.6 ngTeq/m^3 set by QCVN 61:2016/BTNMT. Considering that the regulatory limit is already 6 times higher than the recommended Stockholm Convention BAT value, these data are obviously alarming.

5.3.9. *Landfilling*

The situation of landfills in Viet Nam is rather critical and needs a substantial improvement both on the side of management of waste, control and regulation. Due to backlogs in the implementation of hazardous waste classification, it is unclear how much industrial waste or hazardous waste currently goes to landfills. There are 660 landfills with capacity of 7,385,000 tons/year. Out of these 660 disposal sites, only 30% are classified as sanitary landfills with a daily cover over the waste. As landfilling is the cheapest treatment option, industrial waste which is not classified as hazardous could find the way to municipal landfills. Nationally, about 22% of the collected waste currently goes to various treatment facilities, instead of landfilling. The remaining is thrown away indiscriminately[81].

6. Management of EOL renewable energy plants – recommendations for Viet Nam

The renewable energy production in Viet Nam started at a significant level only in 2018. As the lifetime of a renewable energy equipment varies from 20 to 30 years, the generation of waste will initially be only associated to the failure of the equipment. This represent an opportunity which should not be missed for setting up a proper system for the waste manage of EOL renewable energy plants. Towards this, recommendations are based on the challenges and given current technological possibilities identified in the study. The recommendations have been arranged according to the following topics:

- Waste management and categorization;
- Waste recycling technology by waste typology;
- Financial aspects and EPR;

6.1. Waste management and categorization

6.1.1. *Waste segregation and Development of guidelines for PV and WP dismantling and waste categorisation.*

Although a very small fraction of solar PV panels and wind turbines contain hazardous substances, in case these substances exceed the threshold limit for hazardous waste and cannot be segregated, the entire material will have to be categorized as hazardous. This is the case for instance of silicon wafers doped with heavy metals or antimony containing glass. As hazardous chemicals may be contained in several components of both PV and WP plants, a detailed categorisation of products, components and fractions from EOL- PV and WP needs to be undertaken to establish where hazards substances are present or may be formed during treatment. Such a categorisation should be developed by manufacturers, who should provide a documentation regarding the composition of their products. The waste categorisation should be in line with existing regulation such as Circular 36/2015/TT-BTNMT. Improper categorisation – either by classifying waste as non-hazardous despite the presence of hazardous substance, or vice versa – can lead to in the first case to environmental

[81] https://documents1.worldbank.org/curated/en/504821559676898971/pdf/Solid-and-industrial-hazardous-waste-management-assessment-options-and-actions-areas.pdf

pollution or, in the second case, to loss of valuable resources and unviable economic burden for transport and disposal.

A guidance document for the categorisation of waste from renewable energy plants and their components should be developed in collaboration with the manufacturers or importers of these plants. This would represent an enormous advantage and would avoid that waste from EOL PV and WP components are improperly categorized. For PV panels, dismantling guidelines could be provided by manufacturers to importers and waste managers to ensure that EOL PV are properly dismantled. In addition, information on the classification of waste generated by EOL PV and WP should be provided by the importers or manufacturers of such equipment.

Notably, the proper categorization of waste may be needed even if the manufacturers opt for taking back the equipment at their end of life, or in case of failure. More specifically, there will be the need to establish whether component of EOL PV and WP plants have to be considered waste (and in this case their transport will have to comply with the national and international rules on waste management) or equipment under maintenance (and in this case their transport have to comply only with rules on the transportation of goods). This could have a significant impact on the modality to be adopted for the transboundary movement of these materials.

6.1.2. Establishing a register of licensed waste treatment facilities, by waste category and process.

One of the difficulties in solid waste management is the collection, management, updating, and exchange of data on the current state of solid waste generation and treatment. Currently, only some localities are building their solid waste management database systems, e.g. Ho Chi Minh City, Da Nang city, Thai Nguyen city, however there is no linkage with the management agencies at all levels, and the existing databases do not follow a common standard, with clear difficulties related to the exchange of data.

To improve the efficiency of collection and treatment of different categories of waste, it is therefore recommended to develop a national register, available online, of all the licensed waste treatment (i.e. disposal or recycling facilities), by location, category of waste and process. Only in this way the waste generator would have the possibility to identify in advance the operators compliant with the current technical rules related to the management of specific type of waste, including waste generated by EOL PV and WP plants.

6.1.3. Strengthen the formal collection and treatment of EOL PV and WP waste.

Collection and aggregation are currently seen as the main bottleneck for the sound environmental management of EOL from solar power rooftop systems, which is now operated mainly by informal sectors.

Indeed, for some low-value, easily recyclable materials like glass and plastic, rather than technological constraints, the most challenging aspect could be the establishment of collection and dismantling infrastructures. Again, this apply more to PV rather than WP, as the last, due to their size and complexity, would more likely be managed within dedicated service chains established by the manufacturers.

However, the proper dismantling, based on up to date knowledge of the equipment to be dismantled, is the only way to ensure that the recyclable material is efficiently and safely extracted from the EOL equipment. This will likely require ensuring the financial viability of the collection system and of dismantling centers.

As already discussed in the section of glass recycling, a “collection fee” could make feasible the recycling of materials that otherwise would just be dumped in landfills because of their low recycling value. The collection fee should be ensured through the establishment of a proper EPR mechanism, where the importer, the manufacturers or the owners of the equipment will pay in advance the cost for the collection and disposal of the waste generated by renewable energy plants reaching their end of life.

Currently, in Viet Nam, the collection and recycling of electric electronic waste, including lead acid batteries, is still dominated by the informal sector. Based on a report from MONRE (2020), *“The biggest existing problem that Viet Nam does not have an e-waste recycling industry due to the lack of stable and large enough inputs of e-waste. Viet Nam does not yet have a management system that can control a large amount of e-waste and recover valuable materials, etc. Most of the e-waste is manually recycled in approximately 90 craft villages scattered around the country, which use manual techniques to sort, pre-process, melt and cast the metals from e-waste[82] ”.* Currently, the formal recyclers of E-waste are not competitive as they have to comply with strict environmental rules which are instead disregarded by the informal recyclers. However, the shifting from the current informal management of E-waste toward a more sustainable management could have a significant social impact, given that *around 13 per cent of rural households rely on informal recycling activities to make a living throughout the year. These craft villages support around 10 million workers and have become a significant source of income for agricultural households* (MONRE 2020, cited above).

From the above it can be seen that the issue is not limited to EOL PV, although this will be one of the dominant electronic waste streams in the future. PV need to be dismantled in a standardised and efficient way, so that all the recovered materials can be properly sent to specialised facilities which can recycle the waste with the maximum efficiency. This will require centralised facilities capable to process a large amount of modules at a small cost, and with a tight environmental control of the operation. These centers will generate significant amount of recyclables which can be processed by already existing technologies, whilst for other materials (like silicon wafers) proper technologies will have to be established.

It is therefore recommended to timely establish strict rules and a favourable financial environment to ensure that the recycling of EOL PV and WP are managed only within a formally established waste management circuit. As the issue of informal recycling is not affecting only waste from RE plant, but in general the management of all the E-waste, this could be an opportunity to progressively strengthen and regulate the whole E-waste sector. That could entail i) Establishing a list of waste (including obviously waste from RE and their components) which can only be processed in licensed facilities; ii) support to the informal operators to aggregate and shift toward licensed and environmentally safe management of waste; iii) ensuring an effective enforcement of the above rules through tight supervision. Again, that would need the establishment of a proper financial mechanism based on mandatory agreement among the purchaser and the importer/manufacturers, or, preferably, by an EPR system.

6.2. Waste recycling technology by waste typology

[82] MONRE (2020). Country Report On E-Waste Of Viet Nam. Available at http://bioie.oie.go.th/oieqrcode/uploadFile/oie621360278_1459684422.pdf

6.2.1. Waste for which recycling facilities are already available in Viet Nam

The technology for aluminium, copper, steel, plastic and glass recycling is already available in Viet Nam, and if properly organized can already ensure the treatment of a significant amount of waste from EOL PV and WP plants. There is already an existing industrial infrastructure of secondary smelters and recyclers of steel, copper, aluminium, and certain plastics. Collaborating with glass manufacturers is recommended to identify technical capacity and technical viability and adaptations which may be needed to ensure that the special glass from used PV can be recycled to generate glass for new PV. The sorted and segregated fractions of such waste need to be channelized to these facilities for downstream recovery of materials. The flow through these channels should be strengthened through technical specifications for recycling and recovery.

6.2.2. Waste for which the development pre-treatment process may be needed

Concerning WP waste, particularly blades, these can be first treated in existing plastic shredding and recycling facilities before they can be co-processed in cement kilns. The composite wing blades of the WP plants have usually a composition which is well known by the manufacturers, and which is also rather uniform. The technology for the recycling of plastic in cement kiln is still not widely developed in Viet Nam, and the technology for pre-treatment of fibre-reinforced polymers (FRP) is completely missing. Investment is therefore needed on the side of pre-treatment (size reduction, shredding) and feeding to cement kilns. The co-processing of FRPs is only possible through the establishment of quality standards and procedures that need to be agreed between the manufacturers of the WP blades and the cement industry. The process is potentially profitable although it is demonstrated that for plastic waste, the income generated through the fuel and material saving is just enough to cover the pre-treatment costs[83]. Therefore, even in this case there may be the need to establish a subsidizing mechanism which could be potentially shared by manufacturers of WP plants and the cement industry. However, considering that the co-processing of plastic waste has a smaller emission of GHG compared to the use of fossil fuels and raw material from mining, carbon credit should be also assessed as a potential financial source.

The possibility of co-processing of composite wind blades in a cement plant need therefore be first established through a pilot. On a side note, if the pilot is successful the process could be extended to a wide number of FRP waste, including for instance car parts, end-of-life boat hull, etc. If found technically suitable by cement plants, the necessary safeguards and technical requirements should be specified.

Concerning EOL PV, one stream which could need the development of a specific pre-treatment capacity concern glass. The high stability and high transparency glass used in PV has higher value compared to the normal glass, and downcycling this glass into low value glass (i.e. glass containers) may represent a loss of value. Currently there is not enough waste glass from EOL PV to justify the cost of dedicated production lines to manufacture new PV glass from waste PV glass (horizontal recycling). However in the future, when large amount of PV could reach their end of life, the direct recycling of PV glass (including antimony added glass) into new PV glass could be a viable option, which, similarly to co-processing of FRP, could also generate some GHG saving. Therefore, establishing technical exchange and collaboration with glass manufacturers is recommended to identify, in the mid-term, technical capacity and technical viability and adaptations for the horizontal recycling

[83] Lafarge-Holcim and GIZ, 2019. Guidelines on Pre- and Co-processing of Waste in Cement Production, Use of waste as alternative fuel and raw material.

of PV glass. In the short term, EOL PV glass could be recycled into common floating glass or container glass, after proper pre-treatment and shredding.

6.2.3. Waste for which dedicated technologies are missing in Viet Nam and need to be established

Some rare earth and critical raw materials present in solar PV and WP products and components are not only an environmental priority, but will increasingly represent a strategic aspect related to the availability of limited raw materials for manufacturing. In the report is clearly described how, for instance, critical raw materials needed for PV and WP technologies have now a geo-strategic importance. The capacity in the medium-long term, to establish country-based technologies for the extraction of these materials from waste (not only PV or WP, but also E-waste) is therefore also strategic.

The recommendation here is to invest on the development of such technologies, and at the same time ensure the long-term storage of these waste stream from PV and WP waste which may have a high content of high value or geo-strategic elements. At the same time, recycling targets for PV panels should be established by component and material value, and not only on the basis of the ratio of the overall weight of the recycled material compared to the weight of the panel, as that could results in low or zero recovery of high value/hazardous materials like silicon, silver, lead, copper, cadmium, tellurium which are more difficult and expensive to recover, and constitute less than 10% of the panel by weight.

It was learned from international overview of end of life management of PV and WP systems that although the inclusion of PV panels in WEEE directive in EU has been effective in establishing proper end of life management of panels, it still lacks in encouraging the recycling or recovery of high value materials. WEEE directive mandates 85% recovery and 80% weight reuse/recycling targets for PV panels. This provides a loophole for recyclers to recover just the easily recyclable materials like glass and aluminium from the PV panels which make up more than 80% of a panel by weight. This results in the missed recovery of high value materials like silicon, silver, lead, copper, cadmium, tellurium which constitute less than 10% of the panel by weight. Therefore, individual material quotas are necessary instead of the bulk recovery targets, to ensure sustainable end of life management.

In Viet Nam, according to the draft Decree guiding the implementation of the revised Law on Environment, currently at least 80% of metal, plastic and glass can be recovered in the manufacturing of products to meet the requirements of scrap used as raw materials for production in industries. Although this quota is modest, it represents Viet Nam's considerable efforts in recycling useful products. Therefore, it is necessary to implement ongoing research and discussion in the technical and policy sphere regarding setting individual material quotas that should be integrated into overall recycling and recovery targets so as ensure sustainable end of life management.

6.2.4. Non-recyclable waste: incineration and landfilling

Incineration or landfilling should be considered as the last disposal option for waste which are categorised as non-recyclable. Whenever possible, incineration should include recovery of energy from the calorific content of waste, and landfilling should be based on engineered sanitary landfills limited to marginal waste streams which cannot be recycled or incinerated. In general, both incineration and landfilling should be discouraged because of their environmental impact and their non-compliance with the criteria of circular economy.

Landfilling

Viet Nam's costs of landfilling is very low. For municipal waste, based on the figures sourced by MONRE and reported in the recent WB report[84], the landfilling cost is only 4USD/ton, which obviously "*represent an underspend when compared to landfill costs required in properly engineered and controlled landfills without impacts to the surrounding environment"*. Although this cost is for municipal landfill, it's a clear indicator of the landfilling cost in the country. Furthermore, based on the same report, only 30% of landfill sites can be classified as a sanitary landfill with daily coverage of waste.

To reduce waste to landfill, higher disposal costs can be applied, including disposal tax. The higher income should be used for establishing safe and engineered landfills, compliant with international standards. However, in general, landfilling of recyclable waste should be discouraged. For example, in Australia, the landfill levy rate varies from $71 to 199.2 per tons; from 1 April 2020, landfill tax rates in the UK are £94.15 per tonne for active waste and £3.00 per tonne for inactive waste. In Austria, the current rate for mass waste or hazardous landfills is EUR 29.80 per tonne.

The EU landfill directive (1999) bans the landfilling of certain hazardous wastes and of recyclable waste. A review of European waste management policy has shown that landfill bans effectively divert waste from landfill and drive towards energy recovery. In the situation of Viet Nam, **the combination of the increased landfill fee and ban (alongside several other waste management policies and regulations) will therefore help to ensure that residual waste treatment will be shifted significantly away from landfilling towards proper treatment methods.**

Coupling landfill restrictions with a product stewardship scheme may also be an effective intervention to promote collection and recycling activities of PV and Wind turbine systems. A clear, consistent, and informative education and awareness that is accessible to diverse communities should form a major part of any extended producer responsibility (EPR) approach. However, incentives and recycler investments are required to develop domestic capability and capacity to avoid stockpiling issues.

Incineration

In Viet Nam there are several norms regulating the emission standard for incineration. The Decree 38/2015/ ND-CP of the Government establishes the modalities for the control of industrial emissions. Sources generating a large emission volume need to register and perform automatic monitoring. The Decree however does not establish provisions on automatic emission monitoring for solid waste incinerators.

According to the National Technical Regulation on Industrial Waste Incinerator (QCVN 61-MT:2016/BTNMT), periodic environmental monitoring must be carried out each 3 months. Automatic and continuous environmental monitoring is required for particulate, NOx, SOx, CO. Flue gas sampling and analysis for dioxin/furan must only be carried out in case of burning waste containing organic halogen components exceeding the hazardous waste

[84] Solid and industrial hazardous waste management assessment, options and action area to implement the national strategy. World Bank, 2018, available at

https://documents1.worldbank.org/curated/en/352371563196189492/pdf/Solid-and-industrial-hazardous-waste-management-assessment-options-and-actions-areas.pdf threshold as prescribed in QCVN 07:2009/BTNMT or in some cases other special requirements according to the specific requirements of the licensing authority.

However, as there are no requirements related to the monitoring location and time for each type of production or the official recording for the solid waste processed, is hard to identify cases of waste containing halogenated substances which would trigger the monitoring of dioxin and furan.

Indeed, a recent survey carried out by UNDP under the GEF project on POPs management[85] revealed that the emission of U-POPs of incinerator of industrial waste exceed frequently the national standards. Furthermore, the national standard for U-POPs emission from industrial incinerator is not compliant with the BAT established under the Stockholm Convention, of which Viet Nam is a party.

For the above reason it is recommended, from one side to improve the technical regulations on incineration to make the compliance with environmental standards more stringent, and from the other side to limit incineration of waste from WP and PV only for specific waste stream which cannot be easily recycled and at the same time are not strategic, taking also in consideration that waste with high calorific value should be preferably assessed for co-processing in cement kiln.

In this framework, it should mention that the "Ecolabel" project[86], of which the concept has been approved by the the GEF, will provide technical and financial assistance to improve the regulation on U-POPs emission of industrial facilities and to demonstrate Air Pollution Treatment System allowing the compliance of industrial facilities with the U-POPs related provisions established by the Stockholm Convention.

6.2.5. Waste to be exported

Transboundary movements of waste may be needed, especially in the initial period before the development of local technical and financial capacity in Viet Nam for the recycling or disposal of EOL WP and PV waste. Until then, especially until volumes are low, there may be a need to export collected fractions for further treatment and processing. Towards this, it is important to ensure that Basel Convention provisions are followed and are aligned with national legislation and guidelines prescribed for treatment and handling of solar PV and WP waste. Export of waste is already possible under the current regulations. It is suggested that the officials and competent authority responsible for Basel notifications is provided with the training and capacity building to be able to appropriately authorize the consent notifications.

[85] Vietnam POPS and Sound Harmful Chemicals Management Project, GEF 5067,

[86] Reduce the impact and release of mercury and POPs in Viet Nam through lifecycle approach and Ecolabel, GEF10519

6.3. Financial aspects and EPR

6.3.1. Establish a financial mechanism that ensures sustainability, in compliance with the polluter pay principle.

It is estimated that the total investment cost for solid waste management will reach approximately US$ 13 billion by 2030. This estimate excludes operational costs which are estimated to increase annually by US$ 2.2[87]. This cost need evidently to be internalised, in other word it cannot be passed on the shoulders of the community or the government, but need instead to be covered by the waste generator, in compliance with the polluter pays principle. Only in this way the waste generators will find an incentive in the reduction or recycling of waste.

Concerning EOL from renewable energy plants, the experience of other countries in collecting and treatment of PV panels in the past years, as well as more extensive experience from waste streams such as electronics and electrical equipment (WEEE) indicates that the intrinsic material value of waste could, for the majority of waste streams, exceed the total costs of collection, aggregation, transport and treatment. For the EOL PV and WP waste, it is suggested to carry out with urgency a detailed cost analysis to set an operational and financial plan for the collection, transport, and recycling of such waste, with clear identification of the financial sources in compliance with the polluter pays principle.

6.3.2. EPR regulation in Viet Nam.

Currently, according to the draft Decree guiding the implementation of the Law on Environmental Protection (2020), an EPR-based legislation has been introduced to include the financial responsibility for manufacturers/ importers/ producers to ensure the take-back and recycling costs of collection, aggregation, transport and treatment are covered, through recycling fees.

Manufacturers and importers may choose one of the following forms of recycling according to the provisions of the Law on Environmental Protection: a) Carry out the recycling by themselves; b) Hire a recycling unit to carry out the recycling; c) Fully authorize a third party to organize the recycling (hereinafter referred to as PRO).

Manufacturers and importers can also choose the form of financial contribution to the Viet Nam Environmental Protection Fund. The deposit is made according to the quantity and volume of manufactured and imported products sold to the market. The deposit shall be paid and refunded at the Viet Nam Environmental Protection Fund or the provincial environmental protection fund or a financial or credit institution as prescribed by law. Where the deposit is left over, the credit institution is responsible for returning the remaining deposit to the organization or individual that has made the deposit for environmental protection. Currently, there are very limited information on the effectiveness of this mechanism. However, there is indeed the risk that the centralization of the huge financial turnover needed for waste treatment in only one ministry agency could easily represent a bottleneck of the whole system. It is recommended therefore to assess the administrative workload that the current centralized system would entail, with the purpose to progressively move toward a further decentralization of the EPR financing.

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[87] https://documents1.worldbank.org/curated/en/352371563196189492/pdf/Solid-and-industrial-hazardous-waste-management-assessment-options-and-actions-areas.pdf

As explained, an EPR-based legislation for waste management in Viet Nam is being discussed. However, EoL from WP plant are not covered under this in the absence of implementing legislation. Although WP plant are mostly industrial plants and may be regulated with schemes different from the EPR (like for instance during permitting procedures), this is not the case of rooftop plants which are mostly owned by private individuals. Bringing EPR based legislation would create the obligation for manufacturers/ producers or importers of PV panels and WP plants to ensure that they have systems and processes in place to take-back and send the end-of-life products for recycling. The EPR-based regulation could be introduced under existing legislation preferably as a Circular.

The product scope of the EPR legislation should cover all types of solar PV and WP products, including both consumer-facing products such as solar rooftop home systems as well as large B2B utility scale installations.

The EPR legislation should be deliberated with stakeholders including relevant government ministries, solar and wind product manufacturers/ importers, installers, developers, recyclers and other relevant organizations. The legislations stipulated details on solar PV EoL, however it is also necessary to provide clarity on the definition of wind power waste, scope of products covered under the legislation, targets for collection and recycling (ideally) as well as other aspects such as reporting and authorization requirements for treatment providers.

EPR legislation can be developed through a stakeholder process to define the objectives, scopes and operational mechanisms, including the financing mechanism. The EPR-structure can be implemented through several models, such as:

1. **A state-run model**, similar to China, where the Ministry collects the EPR fees (more like an eco-tax) and manages the system. There are hybrid models, such as in Taiwan, that has a state run EPR system, but totally ring-fenced and autonomously operated.
2. **A producer driven model through a Producer Responsibility Organisation (PRO)** that is typically a not-for-profit organization. PV cycle in Europe is a PRO set up by the industry for compliance under the WEEE regulations. The PRO model is also being replicated in countries such as Kenya and South Africa etc for e-waste, often including solar panels, although not for wind power systems.
3. **A market driven model** such as in UK and Germany where a mix of compliance service providers compete for businesses for collection and recycling of e-waste. To ensure fulfilment of target obligations, trading of treated volumes is possible, although it has been seen to create unfair incentives.
4. **Recycler driven model** – this is common place where there is no regulation or funding for waste collection and treatment. Entrepreneurial business operators, in the formal and informal sectors, recycle waste that can provide them with valuable fractions. This leads to cherry picking of only those parts that are valuable, leaving the rest to be disposed of in the environment.

The stakeholder process will need to explore the options for operationalization of the EPR system in detail, and identify the most relevant and suitable structure for Viet Nam as there is no one-size-fits all. As the stakeholder process can take several years, it is suggested to embark on it at the earliest so as to have a system ready for Viet Nam when volumes increase.

6.3.3. EPR for rooftop PV modules

Currently PV plants owned by households, like small rooftop plant, are not regulated as industrial or hazardous waste. Moreover, in the absence of any EPR scheme, once they break down, they are simply not managed. Only if the purchaser has established a private maintenance contract with the provider, faulty or EOL equipment can be take back by the provider. Otherwise, these equipment are just stored in the houses or taken by informal recyclers. As explained in this report, EPR is the key mechanism to ensure that PV equipment is properly managed at their end of life, basically by making mandatory the agreement between purchaser and provider on the certified recycling of EOL equipment. Based on the example from some EU countries, the recommendation is that the buyers of PV equipment sign a contract with authorised waste management operators for the disposal or take back of their equipment, with the proper allocation of funds, already when purchasing the equipment. This will have the advantages to i) internalize the environmental cost of the disposal of EOL PV; ii) ensure that such material is properly disposed or recycled by certified operators; iii) secure the budget for the disposal of the EOL PV equipment. From the financial standpoint, one of the peculiarities of the EPR in the case of PV equipment is the delay from the time of signature of the disposal/ recycling contract envisaged by the EPR (to be signed when the equipment is purchased) and the effective disposal of the EOL or failed equipment: that delay could last up to more than 20 years. This could require a sound financial management of the funds set aside for EPR to avoid their loss of value compared to the disposal/recycling market cost.

Annexes

Annex 1: Material Breakdown – photovoltaic panel

The Global Solar PV market has been dominated by crystalline silicon modules (Multi-Si+Mono-Si), which accounted for 95% of the market share for the past five years. Thin film-based modules led by CdTe constitute the rest of the market.

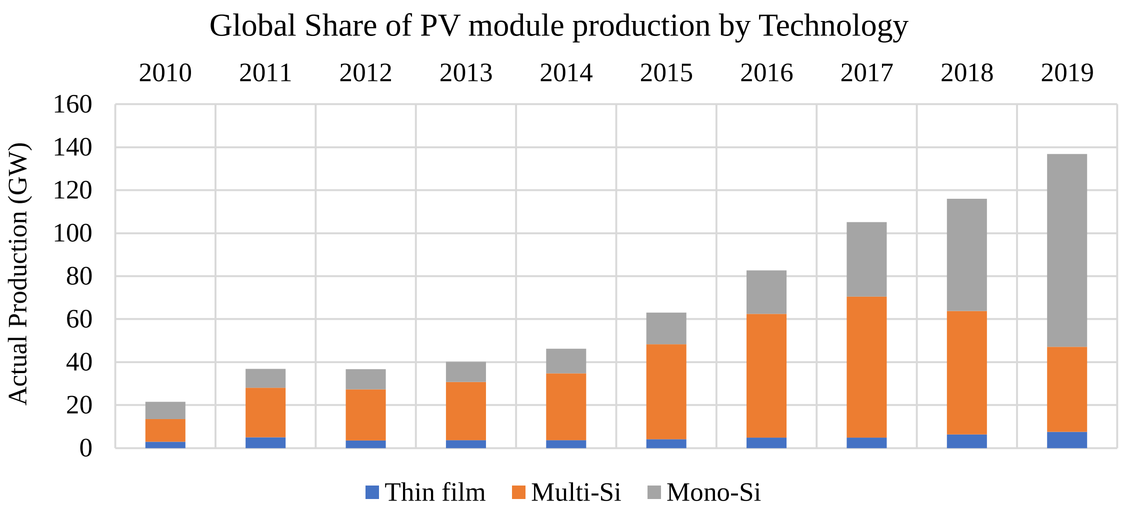


Figure 34. Global Market share of PV production - By technology[88]

Currently, the most common c-Si PV panel rated at 300 W with Back Surface field (BSF) solar cells is made of various components as shown in Figure 35.

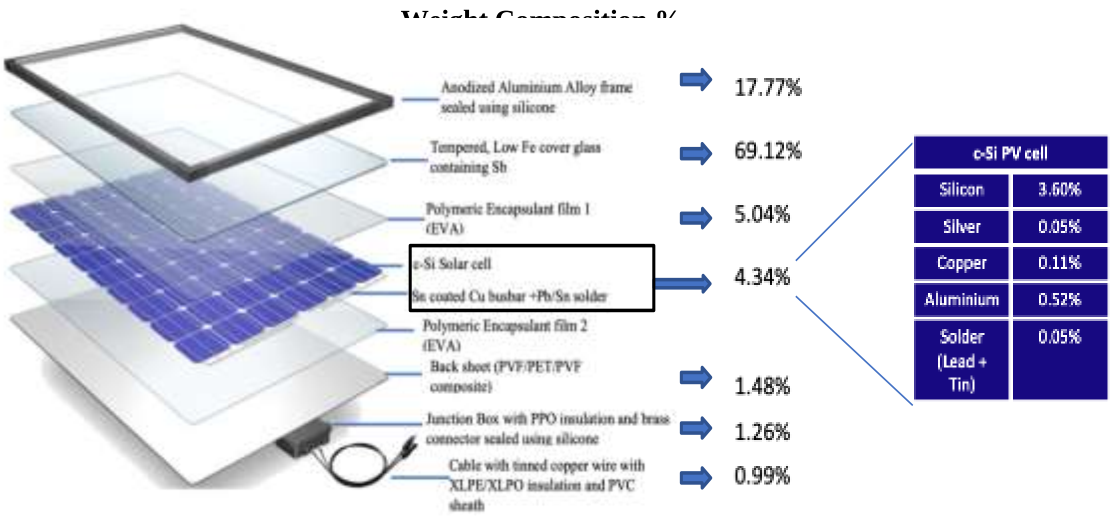


Figure 35. Material breakdown of crystalline silicon PV panel (Total weight: 22.2 kg)[89]

[88] Fraunhofer-Photovoltaics Report 2020

[89] EU-JRC Study

A mainstream CdTe Thin film solar module rated at 420 W consists of the components as shown in Figure 36.

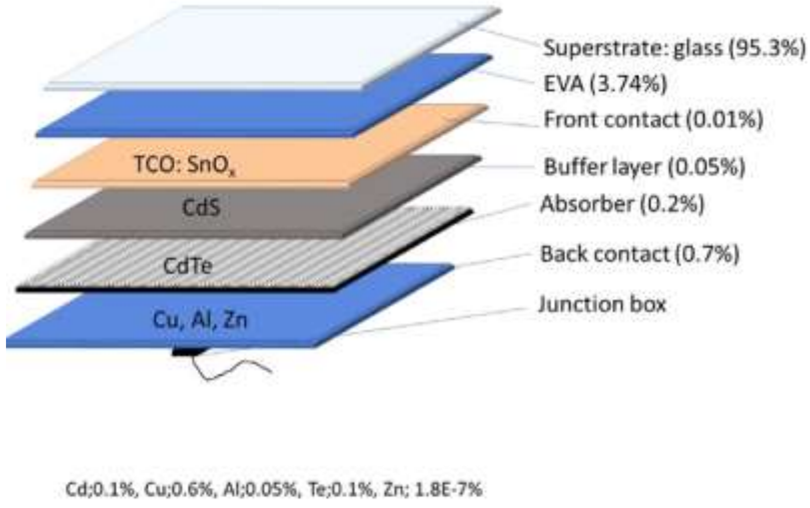


Figure 36. CdTe PV module material breakdown (total weight: 34.5 kg)[90]

In all the major PV panels discussed above, glass is the major component by weight. The composition of glass in each of the PV technology across time period is charted in Figure 37.

[90] Environmental impacts of c-Si and CdTe Modules – Research study (Maani et al.)

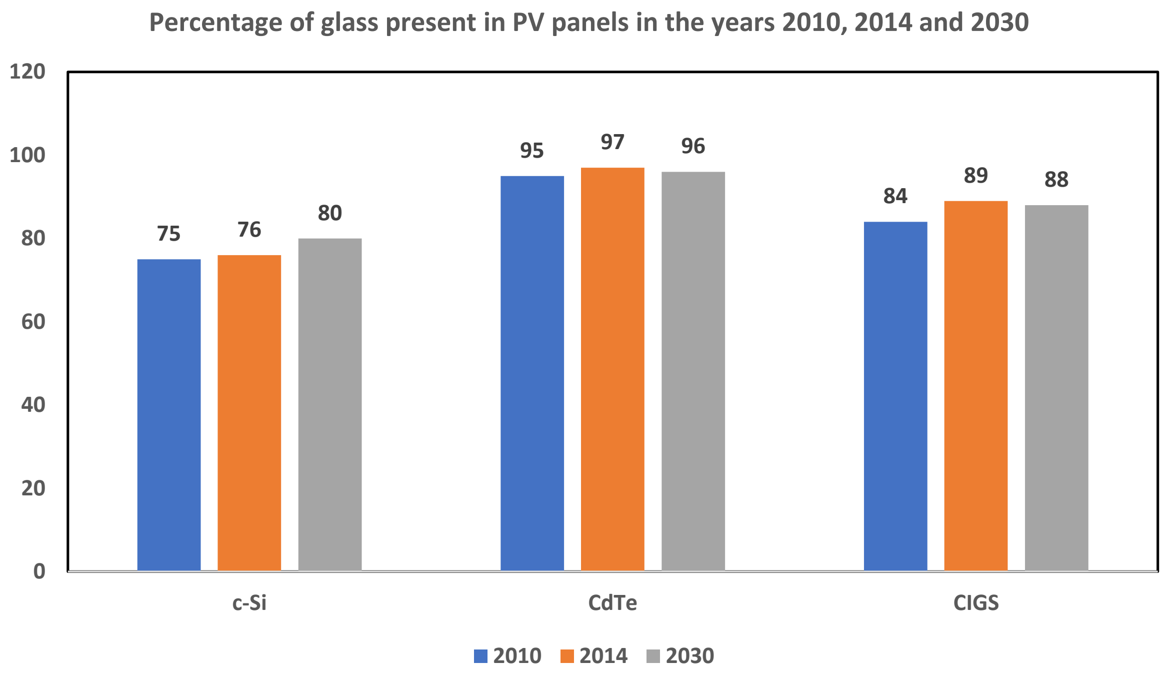


Figure 37. Glass composition of PV panels (by weight)[91]

Although the major composition of PV panels is constituted by non-hazardous materials, there are critical, high value and hazardous materials present. The hazardous material content in PV modules is shown in **Table 22** below**.**

Table 22. Toxic metal content in PV modules

Type of PV module	Content of Polluting/Hazardous substance
c-Si PV module	
Lead (Pb)	0.7 to 1 g/kg of module in Solder
Beryllium (Be)	0.15 to 2 % in CuBe alloy to improve mechanical properties of Copper
Antimony (Sb)	100-300 ppm in front glass of module
CdTe PV module	
CdTe	0.7 to 1.4 g/kg of module
Lead (Pb)	0.1 to 1 g/kg of module
Beryllium (Be)	0.15 to 2% in CuBe alloy to improve mechanical properties of Copper
Antimony (Sb)	100-300 ppm in front glass of module
CIGS PV module	
CdS	0.03 g/kg of module
Selenium (Se)	0.02 g/kg of module
Antimony (Sb)	100-300 ppm in front glass of module

[91] ENEA-Socio Economic Study (In Italian)

The material breakdown for 1 MW PV system is detailed in **Table 23** below. Apart from the composition of PV panels, the materials present in mounting structure, tracking systems and foundations are considered below.

Table 23. Material breakdown for 1 MW PV system (Multi-Si, CdTe, CIGS)

Material	Weight in Tones
Steel	67.9
Concrete	60.7
Glass	46.4
Aluminum	12.5
Plastics	4.8
Copper	7
Crystalline Silicon PV module	
Silicon	4
Silver	0.02
CdTe PV module	
Cadmium	0.035
Tellurium	0.035
CIGS PV module	
Copper	0.02
Indium	0.01
Gallium	0.003
Selenium	0.022

There is an imminent supply constraint for production of PV systems, projected by experts, given the volume of installations planned in future across the world. The critical raw materials in Solar PV production are highlighted in Figure 38.

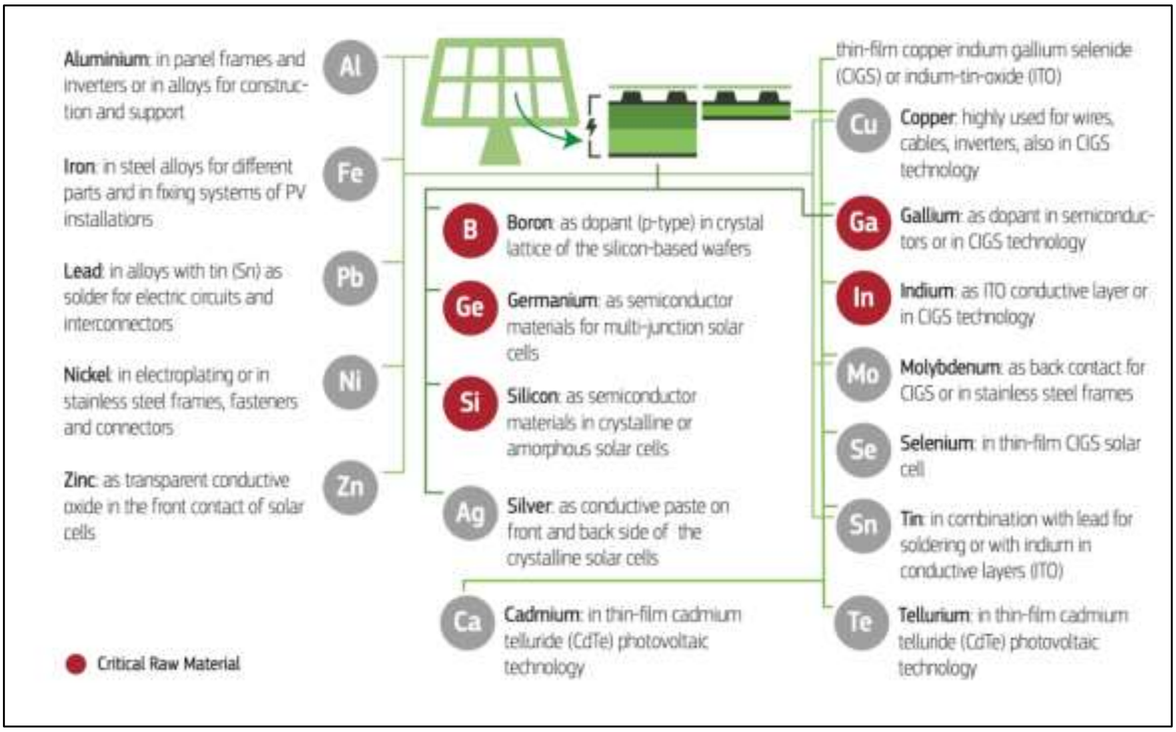


Figure 38. Chart depicting the Raw materials embedded in PV panels with their criticality highlighted

The need for sustainable EoL management of PV panels is illustrated Figure 39. The variation in raw material availability and material security among the various nations in the world clearly emphasizes the need for urban mining of materials contained in PV panel waste.

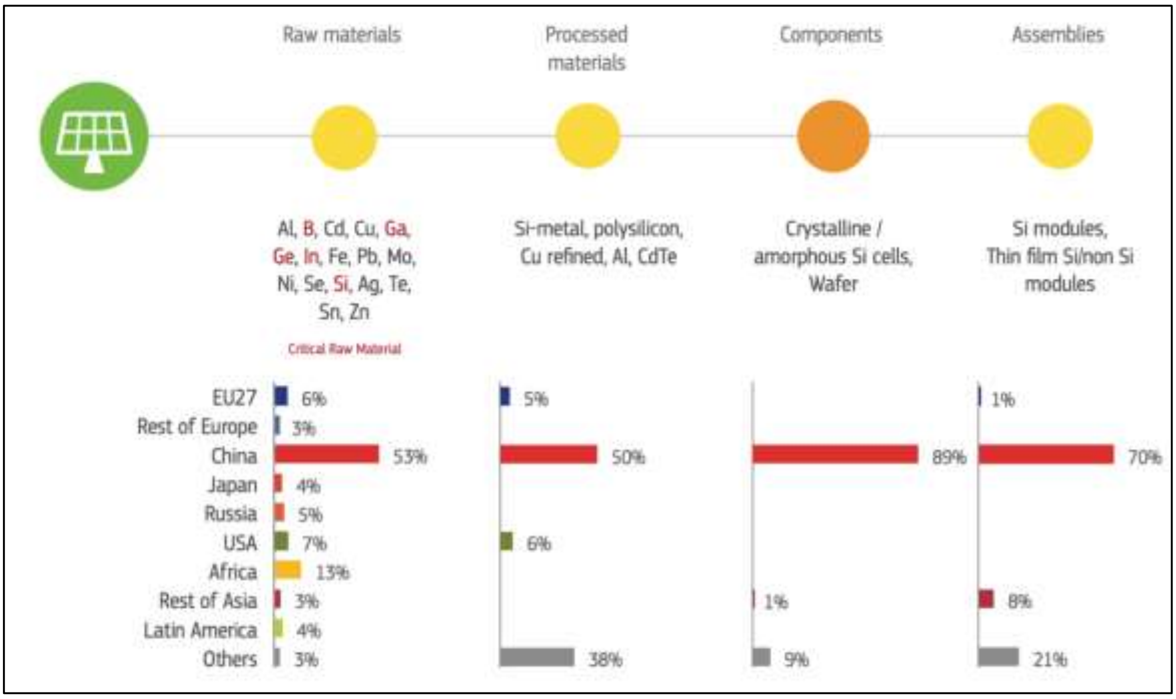


Figure 39. Supply chain control of various nations highlighted across the stages of PV panel production

Urban mining or sustainable material recovery from PV panel waste can relieve the supply constraints in the future. It must also be noted that secondary raw material production is less energy intensive than primary production for most of the materials associated with PV panels. The European data can be considered as upper limit across the world, given the absence of circular approach in most of other countries.

Table 24. Contribution of recovered materials on the demand for raw materials in Europe: (EOL – RIR)[92] and Economic value of the materials recovered € / tons

Material Type	Material	% of Recovery	End-of-Life (Recycling Input Rate) %	Economic Value (€ / kg)
High Value	Silver	94	55	490
Toxic	Cadmium	95	0	2.6
	Lead	93	75	1.9
	Selenium	80	1	39.84
Critical	Gallium	99	0	318.5
	Indium	75	0	282.1
	Silicon(sand and metal)	95	0	0.8
Other	Aluminium	99	12	1.6
	Copper	96	17	5.3
	Tin	99	32	15
	Zinc	90	31	2.4
	Tellurium	95	1	72
	Glass cullet	98		1.6
	Polymer	80		

[92] ENEA-Socio Economic Study (In Italian)

Annex 2: List of companies licensed for hazardous waste treatment in Viet Nam

Currently, Viet Nam there are 115 hazardous waste treatment facilities licensed by MONRE. As of March 30, 2020, 114 facilities were in operation (51 in the North, 07 in the Central and 56 in the South). the number of companies inspected in 2019 are 35 and 2020 are 03.

No.	Name	Region
1	Nguyet Minh 2 Trading - Service – Environment Co. Ltd	Southern
2	Tan Thuan Phong Co. Ltd	Northern
3	Green Environment Production and Trade Service Co. Ltd	Northern
4	Nhu Kiet Manufacture and Trade Co. Ltd	Southern
5	Green Environment JSC	Southern
6	BINH PHUOC Green Environment Technology Company	Southern
7	Dai Lam Son Co. Ltd	Southern
8	Green Industrial Environment Co. Ltd	Northern
9	Siam City Cement (Viet Nam) Co. Ltd	Southern
10	SAO VIET Environment JSC	Southern
11	Van Loi Co. Ltd	Northern
12	Ho Chi Minh City Urban Environment Co. Ltd (Ho Chi Minh URENCO)	Southern
13	Hoa Binh Industrial Waste Recycling and Treatment JSC	Northern
14	Phu HA Enviroment Co. Ltd	Northern
15	Tien Thi Production and Trading Co. Ltd	Southern
16	Ha Loc Co. Ltd	Southern
17	Thanh Lap environment treatment and trading Co. Ltd	Southern
18	Urban Environment Co. Ltd 11 – URENCO 11	Northern
19	Viet Tien Environment Co. Ltd	Northern
20	An Sinh environmental technology JSC	Northern
21	Lilama Electic Mechanic and Environmental Corporation	Central
22	Ngoc Thien Co. Ltd	Northern
23	Viet Khai Environmental Treatment Services Trading Co. Ltd	Southern
24	Binh Duong Water Environment JSC	Southern
25	Ngoc Tan Kien Co. Ltd	Southern
26	DUNG NGOC Co. Ltd	Southern
27	PETROLEUM ENVIRONMENTAL AND TECHNICAL SERVICE CO. LTD	Southern
28	VietXanh Environmental Manufacturing – Trading – Service Co. Ltd	Southern
29	Thanh Cong Corporation JSC	Northern
30	Thye Minh (Viet Nam) Industrial Co. Ltd	Southern
31	Thuan Thanh Environment JSC	Northern
32	Thien Phuoc Co. Ltd	Southern

No.	Name	Region
33	Sen Vang Environment Co. Ltd	Southern
34	Thanh Tung 2 Co. Ltd	Southern
35	Viet Thao Environment JSC	Northern
36	Dai Thang Development Trading & Manufacturing Co. Ltd	Northern
37	Tai Tien Co. Ltd	Southern
38	Hoa Anh JSC	Northern
39	Quoc Viet Environmental Science and Technology Co. Ltd	Southern
40	Dong Anh Electrical Equipment Corporation – JSC	Northern
41	Veritas Environment Co. Ltd	Southern
42	Hue Phuong VN. GE	Southern
43	Urban Environment Co. Ltd 10 – URENCO 10	Northern
44	Minh Phuc Green Environment JSC	Northern
45	CAO GIA QUY Environment Co. Ltd	Southern
46	Tuoi Sang Environmental Co. Ltd	Southern
47	Song Tinh Co. Ltd	Northern
48	Viet Bac Non Ferous Metals JSC	Northern
49	Hai Dang Trading JSC	Northern
50	Viet Nam Mineral Import – Export, Adaptation and Exploitation Co. Ltd	Northern
51	Viet Nam Handles Clean Environment Co. Ltd	Southern
52	Thien Thanh Environment JSC	Southern
53	Thanh Sinh Co. Ltd	Southern
54	AM NGA PHUOC Co. Ltd	Southern
55	Vu Hoang Environment and Chemical Technology Co. Ltd	Southern
56	Hung Phat Urban Environment Co. Ltd	Northern
57	Sao Sang Bac Ninh Environmental Treatment Co. Ltd	Northern
58	Tung Nguyen HS hazardous waste treatment Co. Ltd	Southern
59	Nghi Son Envi Co. Ltd	Northern
60	Toan Thang Service Trading Co. Ltd	Northern
61	Thao Duong Green environment JSC	Southern
62	Green Environment Trading and Production Co. Ltd	Southern
63	Viet Uc Environment JSC	Southern
64	Daewon Chemical Vina Co. Ltd	Southern
65	An Giang City Urban Environment Co. Ltd	Southern
66	Thai Tuan Environment Co. Ltd	Southern
67	ThangLong Metal Co. Ltd	Southern
68	Duong Dung Production Trading Co. Ltd	Southern

No.	Name	Region
69	Green Earth JSC	Southern
70	Saehan Green Vina Co. Ltd	Northern
71	Anh Dang Environmental Service Co. Ltd	Northern
72	VIET NAM ENDI. JSC	Northern
73	An Sinh Trading and Construction Co. Ltd	Central
74	Khanh Du Trading Co. Ltd	Northern
75	Viet Xuan Moi Environment JSC	Northern
76	Vu Hoang Environment and Chemical Technology Co. Ltd	Northern
77	Environment Resources Investment and Technical JSC	Northern
78	Quang Nam URENCO	Central
79	Khanh Hoa Urban Environemnt JSC	Central
80	Phuc Thien Long Trading Co. Ltd	Southern
81	Anh Tuong Co. Ltd	Northern
82	Chat Thai Ha Tinh Industry Processing Co. Ltd	Northern
83	Hai Phong URENCO	Northern
84	Sonadezi Services JSC	Southern
85	Hau Sang Trading and Environment Co. Ltd	Central
86	My Nga Environment Service and Trading Co. Ltd	Southern
87	Nghe an Environmental Treatment JSC	Northern
88	Urban Environment Co. Ltd 13 – URENCO 13	Northern
89	VINACOMIN Environment Co. Ltd	Northern
90	Phu Hung Trading and Warehouse Service JSC	Northern
91	DRET., JSC	Northern
92	Matsuda Sangyo (Viet Nam) Co. Ltd	Northern
93	Sonadezi Environment JSC	Southern
94	Tra Vinh Environment Co. Ltd	Southern
95	Binh Phuoc Environment JSC	Southern
96	JTEK Export and Import, Produce and Trading JSC	Northern
97	Cu Lao Xanh Co. Ltd	Southern
98	Quy Tien Environment Co. Ltd	Southern
99	Anh Giau General Service and Trading JSC	Southern
100	Vuong Anh JSC	Northern
101	Hoa Binh High Tech Environment JSC	Northern
102	Tuan Dat Co. Ltd	Southern
103	Binh Nguyen Trade Investment and Development Co. Ltd	Northern
104	Nghi Son Cement Corporation	Northern
105	Nguyet Minh 2 – Vinh Phuc TSE Co. Ltd	Northern

No.	Name	Region
106	HUE Urban Environment And Public Works JSC	Central
107	Hanoi Environment Co. Ltd	Northern
108	Dong Mai Co. Ltd	Northern
109	Mien Dong Environment JSC	Southern
110	Tien Phat Environment Production Co. Ltd	Southern
111	Da Loc Trade – Construction JSC	Southern
112	Quoc Dai Thanh Environment JSC	Southern
113	Song Cong Environment Co. Ltd	Northern
114	Ngan Anh Co. Ltd	Northern
115	Quang Ngai Health Care company	Central

Annex 3: Existing utility-scale solar power plants in Viet Nam as of 2020

No.	Plant	Installed capacity (MWp)	Number of PV panels	PV panel capacity (W)	Type	Efficiency (%)	Efficiency degradation rate (%)	Construction date	COD	Area (ha)
	An Giang	**310**								
1	Sao Mai Solar PV1	210	600000	330				Feb-19	02/12/2020	120.0
2	Van Giao 1	50							20/6/2019	60.0
3	Van Giao 2	50							20/6/2019	60.0
	Ba Ria – Vung Tau	**292**								
4	Da Bac	61	184850	330				Dec-18	2019	62.0
5	Da Bac 2	61	184000	340	Poly-Si			Dec-18	2019	48.0
6	Da Bac 3	50						Dec-18	2019	60.9
7	Da Bac 4	50						Dec-18	2019	48.0
8	Gia Hoet 1 lake solar power plant	35	75000	470					12/12/2020	40.0
9	Tam Bo lake solar power plant	35	75000	470					12/12/2020	41.4
	Ben Tre	**30**								
10	Ben Tre	30								
	Binh Dinh	**534.5**								
11	Tay Son 1	49								
12	Tay Son 2	30								
13	Phu My	216	750036	290				29/5/2020	31/12/2020	386.4
14	My Hiep	50	113624	440	Mono Half-cell	19.91			11/12/2020	58.3
15	Cat Hiep	49.5						29/10/2018	06/06/2019	60.0
16	Eco Seido Tuy Phong	40	143000	330				28/03/2018	12/06/2019	130.0
17	Fujiwara Binh Dinh	50	151440	330	Poly-Si			Apr-18	Feb-19	60.0
18	Dam Tra O	50							20/12/2020	60.0

No.	Plant	Installed capacity (MWp)	Number of PV panels	PV panel capacity (W)	Type	Efficiency (%)	Efficiency degradation rate (%)	Construction date	COD	Area (ha)
	Binh Phuoc	**850**								
19	Thac Mo	50	125000	400	Mono C-Si	19			11/12/2020	57.0
20	Loc Ninh 1,2,3,4,5	800	2290000	350	Mono C-Si				31/12/2020	
	Binh Thuan	**1617.95**								
21	Ham Phu 1	49		260						
22	Ham Phu 2	49	148470	330	Mono Half-cell	19.91				54.2
23	Binh Tan 1	49								
24	Binh Tan 2	49								
25	Song Binh 4	49								
26	Song Binh 5	49								
27	Solar system in Vinh Tan Power Complex - phase 1	6.2						Dec-18	23/01/2019	
28	Solar system in Vinh Tan Power Complex - phase 2	42.65	121900	350	Poly-Si			Dec-18	22/06/2019	49.2
29	Da Mi	47.5	143490	330	Poly-Si			2017	13/05/2019	60.0
30	Mui Ne	40	110000	365	Mono Perc			12/10/2018	04/06/2019	38.0
31	Hong Phong 1A	150	591360	330	Poly				Jun-19	207.0
32	Hong Phong 1B	325	394240	330	Poly				Jun-19	140.0
33	Hong Phong 4	48	123200	400	Mono C-Si	19.4		Oct-18	30/5/2019	57.6
34	Hong Phong 5.2	48	123000	390	Mono C-Si					58.0
35	Song Luy 1	46.7	127960	365	Mono Perc	21.3		23/09/2018	May-19	45.5
36	Vinh Hao	33			Mono & Poly				30/6/2019	38.0
37	Vinh Hao 4	50								
38	Vinh Hao 6	50						25/10/2018	18/06/2019	60.0
39	Phong Phu	42	127260	330				Aug-18	27/04/2019	60.0

No.	Plant	Installed capacity (MWp)	Number of PV panels	PV panel capacity (W)	Type	Efficiency (%)	Efficiency degradation rate (%)	Construction date	COD	Area (ha)
40	Son My	50	120000	420	Mono C-Si				Mar-19	60.0
41	Phan Lam 1	37	95000	390	Mono C-Si			11/01/2019	25/6/2019	46.6
42	Phan Lam 2	49	126000	390	Mono C-Si			Oct-18		58.8
43	Hong Liem	50	132000	380					Dec-20	
44	Ham Kiem	49								110.0
45	Binh An	50								58.9
46	Thuan Minh 2	50								60.0
47	Tuy Phong	30						19/09/2018	Jun-19	58.7
48	VSP Binh Thuan II	29.9								40.9
	Ca Mau	**50**								
49	Ca Mau	50							Jun-2019	63.0
	Dak Lak	**1030**								
50	Srepok 1	50	151200	330	Mono C-Si		0.75	19/10/2018	31/01/2019	60.0
51	Quang Minh	50	151200	330	Mono C-Si		0.75	19/10/2018	31/01/2019	60.0
52	Long Thanh - Phase 1	10							May-19	60.0
53	Xuan Thien - Ea Sup	830	2000000	415					16/11/2020	875.3
54	Ia Lop 1	50								65.0
55	BMT Krong Pak	30	86000	350				Oct-18	25/04/2019	34.5
56	Jang Pông Dak Lak - phase 1	10							09/05/2019	60.0
	Dak Nong	**94.4**								
57	Cu Jut	50	187890	330				Jun-17	20/04/2019	60.0
58	Truc Son	44.4	188000					Feb-18	14/06/2019	50.8
	Gia Lai	**122**								
59	TTC Krong Pa	69	209100	330				Mar-18	04/11/2018	

No.	Plant	Installed capacity (MWp)	Number of PV panels	PV panel capacity (W)	Type	Efficiency (%)	Efficiency degradation rate (%)	Construction date	COD	Area (ha)
60	Chu Ngoc	53						Jan-19	28/05/2019	18.0
	Ha Tinh	**50**								
61	Cam Hoa	50	153000	330	Poly-Si			15/01/2019	01/07/2019	50.0
	Khanh Hoa	**300**								
62	AMI Khanh Hoa	50	146780	340				24/08/2018	30/05/2019	67.2
63	Van Ninh	100	225996	440					26/12/2020	120
64	Cam Lam VN + KN Cam Lam	100	253165	395	Q Cell				25/06/2019	135.0
65	Song Giang	50	135600	365	Mono C-Si	18.81		Nov-18	08/05/2019	60.0
	Long An	**536.6**								
66	Sao Mai Solar PV2	50	150000	330						
67	Duc Hue 2	49								
68	BCG Dang Duong/BCG-CME Long An 1	40.6	123000	330	Poly-Si	18.1		16/09/2018	23/06/2019	50.2
69	EuroPlast Long An	50	128000	390	Mono C-Si			21/09/2018		
70	Solar Park 3	50							Jul-20	56.0
71	Sola Park 4	50							Aug-20	58.0
72	Duc Hue 1	49	147000	330	Poly-Si		0.7		20/4/2019	51.0
73	Duc Hue 2	49	190000	260	Poly-Si		0.7		20/4/2019	58.0
74	Solar Park 01 + 02	100							Jun-19	118.0
75	TTC Duc Hue 1	49	147000	330	Poly-Si		0.7	31/08/2018	May-19	51.0
	Ninh Thuan	**2508.3**								
76	BIM 1, 2, 3 Complex	330	1000000	300				Jan-18	27/04/2019	220.0
77	Nhi Ha	50	151440	330					Jun-19	60.0
78	BP Solar 1	46	124380	370	Mono C-Si			Jun-18	20/01/2019	62.0

No.	Plant	Installed capacity (MWp)	Number of PV panels	PV panel capacity (W)	Type	Efficiency (%)	Efficiency degradation rate (%)	Construction date	COD	Area (ha)
79	Nhi Ha – Thuan Nam 13	50	151400	330				May-18	Jun-19	60.0
80	Nhi Ha - Bitexco	50	150000	330					Jan-21	60.0
81	CMX Renewable Energy Viet Nam	168						09/06/2018	18/06/2019	186.0
82	Thuan Nam 19	49	185000	265				01/04/2018	24/6/2019	73.5
83	Ninh Phuoc 6.1, 6.2	58.3						12/06/2018	Jun-19	83.3
84	Phuoc Huu – Nha Trang Bay	65	175680	370	Mono Perc	19.1		30/06/2018	20/06/2019	70.0
85	Phuoc Huu – PC 1	30	91650	330		19.1		Jul-18	Jun-19	33.0
86	SP – Infra Ninh Thuan	50	122000	410	Mono Perc	19.9		Apr-18	Oct-18	58.7
87	Bau Ngu Lake	50	163200	310				31/03/2018	Jun-19	75.0
88	Gelex Ninh Thuan	50	153600	330	Mono C-Si		0.5	04/06/2018	02/07/2019	60.0
89	My Son	62	148000	420				27/06/2019	2020	80.0
90	My Son 2	50	120000	420				27/06/2019	2020	60.0
91	Ha Do - Ninh Phuoc	50	121952	410	Mono Perc	19.9			24/10/2020	58.7
92	Sinenergy Ninh Thuan 1	50	151520	330	Poly-Si		0.8	10/12/2018	2019	60.9
93	Thuan Nam	52								
94	Thuan Nam 12	50								
95	Thuan Nam 13	73	150000	487					Mar-19	80.0
96	Thuan Nam 19	49	185000	330					20/06/2019	73.5
97	Thuan Nam 19 A	50						08/04/2019	31/10/2019	59.5
98	Trung Nam Ninh Thuan	204	700000	300	Mono C-Si		1.1	07/07/2018	2019	60.9
99	Xuan Thien – Thuan Bac	256								259.0
100	Thien Tan 1.2	100	264000	380		20			31/12/2020	
101	Thien Tan 1.3	50	132000	380		20			31/12/2020	
102	Phuoc Thai	50			Poly-Si				31/7/2020	65.0

No.	Plant	Installed capacity (MWp)	Number of PV panels	PV panel capacity (W)	Type	Efficiency (%)	Efficiency degradation rate (%)	Construction date	COD	Area (ha)
103	Phuoc Ninh	45	113925	395						14.0
104	Adani Phuoc Minh Solar farm 1	50							19-Dec	59.8
105	Van Ninh	100								
106	Nui Mot lake 1	71	112308	445					Dec-20	
107	Nhi Ha Bitexco - Phase I	50	151440	330				01/10/2018	10/09/2019	60.0
	Phu Yen	**456**								
108	Thanh Long	50			Poly-Si					50.0
109	Xuan Tho 1, 2	99.216	752640					17/11/2018	Jun-19	120.0
110	Europlast Phu Yen	50	119292	420	Poly-Si			Nov-18	30/6/2019	56.2
111	Hoa Hoi	257	752640	330				17/11/2018	10/06/2019	252.0
	Quang Binh	**49.5**								
112	Dohwa - Le Thuy	49.5	150000	330					31/12/2020	58.8
	Quang Ngai	**68.8**								
113	Mo Duc (Duc Minh solar power plant)	19.2	53000	365	Mono PERC	18.81		Aug-15	26/04/2019	24.0
114	Binh Nguyen	49.6	150327	330	Mono & Poly			20/09/2018	04/06/2019	56.0
	Quang Tri	**149.5**								
115	LIG Quang Tri	49.5	135600	365	Mono C-Si			Oct-18	22/05/2019	58.6
116	Gio Thanh 1	50	150000	330				26/6/19	Dec-19	65.0
117	Gio Thanh 2	50	150000	330				26/6/19	Dec-19	60.0
	Tay Ninh	**828.8**								
118	TTC An Hoa	118.8	360000	330				25/05/2018	06/01/2019	120.0
119	Dau Tieng 1, 2, 3	500	1800000	420		17		23/06/2018	2019	700.0
120	Tan Chau 1	50	152000	330						60.0

No.	Plant	Installed capacity (MWp)	Number of PV panels	PV panel capacity (W)	Type	Efficiency (%)	Efficiency degradation rate (%)	Construction date	COD	Area (ha)
121	Bach Khoa A Chau 1	30	91000	330			0.7		Aug-19	60.0
122	Tri Viet 1	30	91000	330			0.7		Aug-19	60.0
123	HCG	50						Nov-18	Aug-19	117.0
124	HTG	50						Nov-18		
	Thanh Hoa	**30**								
125	Yen Dinh	30	117000	250				Oct-17	Feb-19	12.6
	Thua Thien - Hue	**148**								
126	TTC Phong Dien	48	145560	330				01/01/2018	25/09/2018	45.0
127	TTC Phong Dien 2	50		260					May-19	38.5
128	Phong Dien 2	50							2019	58.0
	Tra Vinh	**165**								
129	Trung Nam Tra Vinh	165	440000	375				19/01/2019	Jun-19	171.0
	Vinh Long	**49.3**								
130	VNECO Vinh Long	49.3	137000	360						49.7
	Total	**10,271**	**28,000,000**							

Annex 4: Existing Wind power plants in Viet Nam

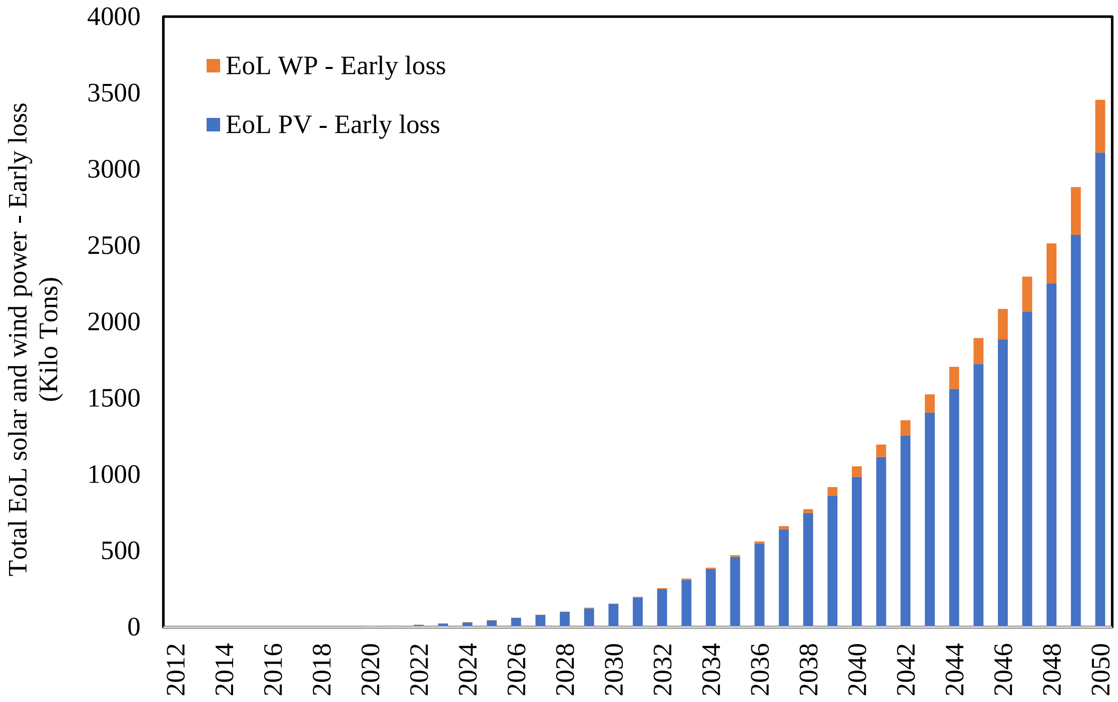
No.	Plant	Installed capacity (MW)	Productivity (mill. kWh)	Number of turbines	Turbine capacity (MW)	Turbine height (m)	Blade length (m)	COD
1	Binh Thanh	30	85	20	1.5	80	37	Apr-12
2	Phu Quy	6	25.4	3	2	60	37	Aug-12
3	Bac Lieu 1	99	320	62	1.6	80	42	Oct-12
4	Con Dao	4		2	2			2015
5	Phu Lac	24	59	12	2	95	50	Sep-16
6	Huong Linh 1,2	60	244.7	30	2	95	54	May-17
7	Mui Dinh	37.6	105	16	2.35	65		Nov-18
8	Dam Nai	40	110	16	2.5	120	52	Nov-18
9	Trung Nam Ninh Thuan - phase 1	39.95	426	17	2.35	84.6	50	Apr-19
10	Trung Nam Ninh Thuan - phase 2	64		16	4	116	50	Dec-19
11	Trung Nam Ninh Thuan - phase 3	48		12	4	135	60	Jul-05
12	Wind farm Tay Nguyen	50		15	3.5	65	65	Feb-20
13	Win Energy Chinh Thang	50						Apr-20
14	Cong ly Soc Trang	30	84	15	2	82.5	42	Apr-20
15	Binh Dai	30	84					Oct-20
16	Dong Hai 1 – phase 1	50		13	4			10/10/2020
	Total	**662.5**		**249**				

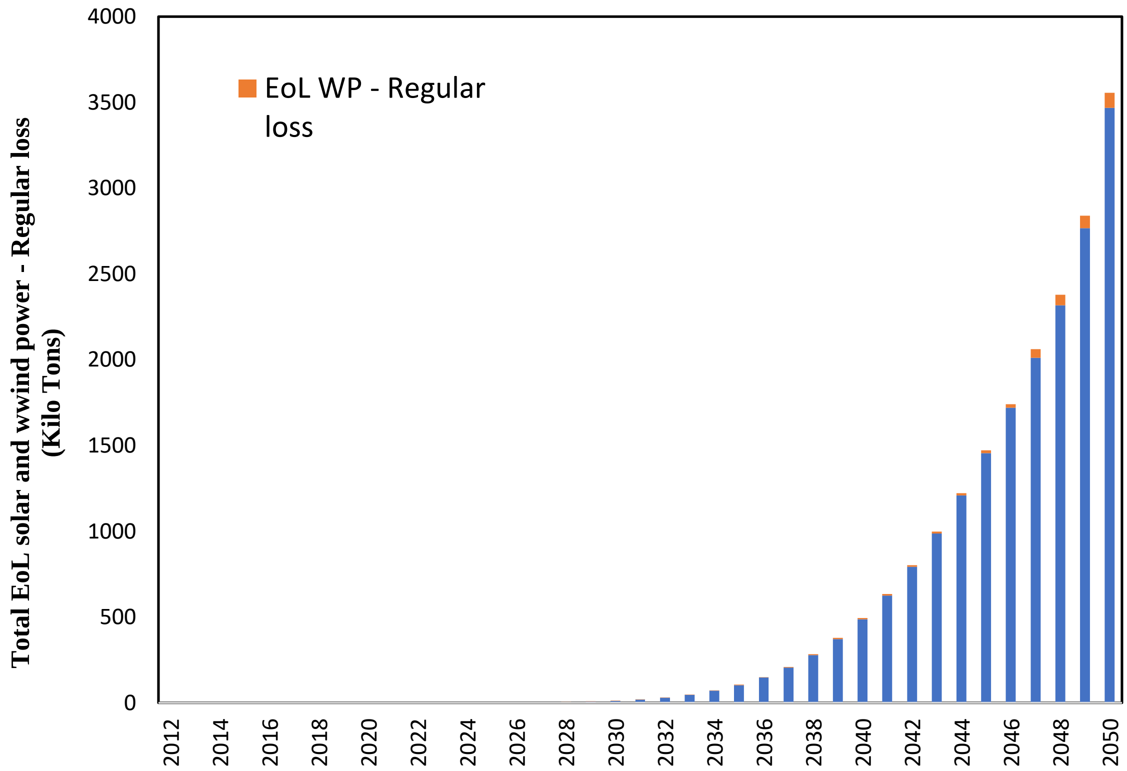
Annex 5: Total EoL solar and wind power in Viet Nam

Annex 13.4. Total EoL waste from solar and wind power in Viet Nam from 2012 – 2050

Year	EoL PV (Kilo Tons)		EoL WP (Kilo Tons)		Total EoL (Kilo Tons)	
	early	regular	early	regular	early	regular
2012			0	0	**0.0**	**0.0**
2013			0	0	**0.0**	**0.0**
2014			0	0	**0.0**	**0.0**
2015			0	0	**0.0**	**0.0**
2016			0	0	**0.0**	**0.0**
2017			0	0	**0.0**	**0.0**
2018	0.0	0.0	0.0	0.0	**0.0**	**0.0**
2019	0.4	0.0	0.0	0.0	**0.4**	**0.0**

Year	EoL PV (Kilo Tons)		EoL WP (Kilo Tons)		Total EoL (Kilo Tons)	
	early	regular	early	regular	early	regular
2020	3.8	0.0	0.0	0.0	**3.8**	**0.0**
2021	7.7	0.0	0.0	0.0	**7.8**	**0.0**
2022	13.5	0.0	0.1	0.0	**13.6**	**0.1**
2023	21.4	0.1	0.1	0.0	**21.5**	**0.1**
2024	31.5	0.3	0.1	0.0	**31.6**	**0.3**
2025	44.0	0.6	0.2	0.1	**44.2**	**0.7**
2026	59.5	1.3	0.4	0.1	**59.9**	**1.4**
2027	77.9	2.4	1.6	0.5	**79.5**	**2.9**
2028	99.3	4.2	2.1	0.7	**101.4**	**4.9**
2029	123.8	6.9	2.6	0.9	**126.5**	**7.8**
2030	151.4	11.0	3.7	1.1	**155.2**	**12.1**
2031	194.8	18.4	4.5	1.3	**199.3**	**19.8**
2032	248.1	29.9	6.0	1.6	**254.1**	**31.6**
2033	310.2	46.8	7.1	2.0	**317.3**	**48.7**
2034	381.1	70.6	8.7	2.3	**389.8**	**72.9**
2035	460.6	103.4	10.8	2.8	**471.4**	**106.1**
2036	547.7	146.9	13.5	3.2	**561.1**	**150.2**
2037	641.3	204.5	20.2	4.5	**661.4**	**209.0**
2038	747.4	278.8	25.8	5.5	**773.2**	**284.3**
2039	862.3	372.3	55.6	6.2	**917.9**	**378.5**
2040	985.3	487.5	67.9	7.5	**1053.2**	**495.0**
2041	1114.4	625.9	82.7	8.3	**1197.1**	**634.2**
2042	1255.6	792.7	100.2	9.7	**1355.8**	**802.4**
2043	1405.2	987.6	120.6	11.4	**1525.8**	**999.1**
2044	1561.1	1209.1	143.9	13.6	**1705.0**	**1222.7**
2045	1723.5	1456.0	169.9	16.5	**1893.4**	**1472.5**
2046	1885.9	1719.4	198.3	21.0	**2084.2**	**1740.4**
2047	2065.2	2010.9	232.1	50.4	**2297.4**	**2061.2**
2048	2252.5	2317.4	262.5	60.7	**2515.0**	**2378.1**
2049	2570.5	2767.1	313.5	73.3	**2884.0**	**2840.4**
2050	3109.8	3468.2	346.1	88.3	**3455.9**	**3556.4**


EoL WP - Early loss
EoL PV - Early loss
Total EoL solar and wind power - Early loss (Kilo Tons)
4000
3500
3000
2500
2000
1500
1000
500
0
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
2036
2038
2040
2042
2044
2046
2048
2050


EoL WP - Regular loss
Total EoL solar and wwind power - Regular loss (Kilo Tons)
4000
3500
3000
2500
2000
1500
1000
500
0
2012
2014
2016
2018
2020
2022
2024
2026
2028
2030
2032
2034
2036
2038
2040
2042
2044
2046
2048
2050

Annex 6: International Case Studies: photovoltaic power plants

Annex 6.1: Germany

i) *Current and projected installed capacity.*

Solar PV Capacity (Cumulative)	49.9 GW[93] at end of 2019
Target PV Capacity	98 GW by 2030

The German PV market started growing in the 1990s. In that decade the first support schemes were introduced, clearly targeted at residential use. Germany was the world's largest PV market[94] for two consecutive decades only to be overtaken by China in 2015. There are over 1.7 million PV systems in Germany as of 2019.

ii) *Current and projected generation of waste from EOL PV*

According to IRENA[95], Germany's end-of-life PV panel waste volumes in 2030, for two scenarios - regular-loss and early-loss scenarios - would be between 0.4 million t - 1 million t, increasing to 4.3 - 4.4 million t respectively in 2050.

According to UBA[96], PV waste potential in 2020 in Germany would have been in the range of 8879 tonnes to 51578 tonnes.

According to ElektroG[97], around 7865 tonnes of PV modules were collected for treatment in 2018 in Germany whereas 3595 tonnes were collected in 2017 and 9167 tonnes in 2016.

iii) *Summary of the country policy on EOL management*

The EU Directive on Waste Electrical and Electronic Equipment from 2002 and the Recast WEEE Directive (WEEE Directive, 2012/19/EU) are transposed to national legislation in Germany by the Electrical and Electronic Equipment Act (ElektroG[98]). The new law came into force on October 24, 2015. Photovoltaic modules fall under the scope of category 4 "Consumer electronics and photovoltaic modules", whereby manufacturers of photovoltaic modules have an obligation for take-back and recycling of PV modules, and need to register under ElektroG since February 1, 2016.

Registration must be completed by the manufacturers before photovoltaic modules are offered or sold in Germany. Inverters have been in the scope of the ElektroG since 2005. Storage systems are to be registered as industrial batteries according to the BattG[99]. Prior to

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[93] Fraunhofer-Photovoltaics Report 2020

[94] BMWi (Article in German)

[95] IRENA-EoL management of Solar PV

[96] https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2020-07-15_texte_135-2020_eag-daten2018.pdf

[97]https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2020-07-15_texte_135-2020_eag-daten2018.pdf

[98] ElektroG

[99] BattG

the implementation of the revised ElektroG in Germany, there were a number of non-regulatory initiatives which organised the collection and recycling of end-of-life PV panels. They were mainly based on voluntary producer initiatives (e.g. PV CYCLE).

iv) *Recycling technologies and list of technology providers*

- **PV Cycle** has 68 collection centers in Germany. Solar modules from manufacturers who are members of PV Cycle are recycled free of charge. In the case of smaller quantities of solar modules, these are taken by the owner to one of the collection points. With quantities of more than 40 solar modules, PV Cycle picks up the modules on site.
- **Reiling Unternehmensgruppe** is a recycling company providing environment-friendly collection of decommissioned PV modules and the recirculation of valuable materials contained therein. The detailed recycling process can be visualized in this video.
- Suez setup a Silicon PV Recycling facility in the town of Knittlingen in south-western Germany in 2018. The facility uses a new recycling process, which combines mechanical, thermal and electrochemical treatment, with capacity to recycle 50,000 used end-of-life photovoltaic modules per year. The company believes the waste volume to increase to 50,000 tonnes per year in 2026 and 200,000 tonnes per year in 2040 in Germany.
- First Solar operates a commercial recycling facility for CdTe modules in Germany. Their CdTe PV module recycling technology is a combination of a mechanical and a chemical treatment.
- Secondsol is another second-hand marketplace existing for PV modules and inverters. They report that repair/refurbishment costs for PV modules range from approximately 20€ up to 90€ per module[100], considerably depending on the handled volume, the quantity or severity and type of failure/defect, as well as on the required characterization/testing, prior to and after repair.
- Suncrafter is a startup that has developed off grid energy stations made up of upcycled PV system components. They believe their business model will be viable in areas where access is prioritized over efficiency.
- pvXchange offer quality inspection services, repair and secondhand marketplace for used solar PV panels. At their service location in Bremen and in on-site installations, pvXchange carry out quality and performance tests on solar modules and components.
- RINOVASOL provides refurbishment and recycling of PV panels using patented technology and have processed close to half a million used PV panels.

v) *Challenges / opportunities*

Germany could also face a particular problem that might aggravate PV system decommissioning. According to the framework of the Renewable Energy Act (EEG), renewables operators can sell their electricity for a fixed price guaranteed for 20 years. This time period is nearing its end for PV systems installed in the early 2000s. Those systems will no longer receive any subsidized, fixed feed-in tariffs for the electricity that they feed into

[100] Tsanakas et al.

the public grid. For some, the achievable proceeds do not even offset the costs of running expenses or repairs. Under these circumstances, owners could decide to dismantle their system - and dispose of it. An analysis commissioned by BSW and conducted by EUPD Research projects that 446,000 installations with a combined capacity of 3.37 GW are vulnerable to early decommissioning by 2030[101].

Annex 6.2: Italy

i) *Current and projected installed capacity*

Solar PV Capacity (Cumulative)	20.9 GW[102] at end of 2019
Target PV Capacity	52 GW by 2030

Among the characteristics of the Italian photovoltaic (PV) is the great prevalence of small plants, which have a power lower than or equal to 20 kW These represent 90% of the total plants, but 21% of the total power. From 2013, after the three-year period 2008-2011, growth continued especially in the segment of small installations in the domestic sector which, at the end of 2018, had over 670 thousand systems.

ii) *Current and projected generation of waste from EOL PV*

Italy is in second place, after Germany, for the quantity of panels sent for recycling in the period between 2010 and 2015, of approximately 2000 tonnes. According to IRENA[103], Italy's end-of-life PV panel waste volumes in both regular-loss and early-loss scenario would be between 140,000 tonnes and 0.5 million tonnes in 2030 and and 2.1-2.2 million tonnes in 2050 respectively.

iii) *Summary of the country policy on EOL management*

All photovoltaic systems entered into operation from 1 July 2012 must have a certificate, issued by the manufacturer or importer of the modules, certifying the adherence of the same to a European System or Consortium (PRO) that guarantees recycling modules at the end of their useful life. This certificate must also be sent by the person in charge of the plant to Gestore dei Servizi Energetici/Guarantor of Electric Services (GSE[104]) in order to benefit from the incentive rates.

There are no disposal charges to be paid by the Operator / Owner of the system as these are already included in the cost of the modules (paid upon purchase), but the labor cost of dismantling will remain to be paid.

The Legislative Decree 49 of 2014[105] also establishes that photovoltaic panel producers can meet their obligations both individually and collectively through a non-profit Consortium

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[101] EUPD-BMW research

[102] IRENA Statistics-2020

[103] IRENA-EoL management of Solar PV

[104] https://www.gse.it/servizi-per-te/fotovoltaico/conto-energia/gestione-moduli

[105] Photovoltaic waste assessment in Italy

recognized by the Ministry of the Environment. Individual or collective consortium, however, must demonstrate that they are in possession of ISO 9011: 2008 and 14000, OHASAS 18001 or other equivalent system certifications[106].

The following were the different policies that mentioned EoL management of Solar PV panels in Italy:

- IV Conto Energia, May 2011: Mandates producers to join a consortium for EoL management of PV panels
- V Conto Energia, July 2012: The same regulations for EoL management continued in fifth energy bill with financial guarantee to be provided by withholding the feed in tariff incentives.
- Legislative Decree 14 March 2014, n. 49: Implements WEEE Directive 2012/19 / EU
- Legislative Decree 118/2020: Amends the Legislative decree 49/2014 to mandate producer responsibility for PV panels irrespective of installation time and to condition allocation of finance for collection and processing.
- Gestore dei Servizi Energetici/Guarantor of Electric Services (GSE[107]) develops and manages the guidelines for proper EoL management of PV panels along with the certification and returning of upheld feed in tariff incentives to producer on successful disposal of PV waste.

iv) *Recycling technologies and list of technology providers*

Producer Responsibility Organizations in Italy: PV CYCLE[108], COBAT[109],Ecoem, Ecolight, Ecoped, Eco-PV, E-cycle s.c.a.r.l., ERP Italy, My Energy, RAEcycle, Remedia.

There are various recyclers operating in Italy for managing the PV waste. Among them, the most notable PV Recycling process (FRELP) is detailed below with provision of comprehensive data on technical and economic parameters.

FRELP project was carried out by SASIL S.p.A through funding from the European LIFE+ program. The project concentrated on developing technology for full recovery of mono and polycrystalline silicon PV panels. The project ran between 2013 and 2016. FRELP stands for Full Recovery EoL Photovoltaic panel. The phases of the project were as follows:

- Robotic mechanical detachment of aluminium profiles, glass connectors and PV sandwich
- Thermal combustion of the Eva to recover metallic silicon and other metals
- Acid leaching to separate silicon from other metals by filtration
- Electrolysis to recover copper and silver and acid water neutralization treatment.

v) *Challenges / opportunities*

[106] https://www.rinnovabili.it/energia/fotovoltaico/riciclo-fotovoltaico-cosa-succede-pannelli-fine-vita-666/

[107] https://www.gse.it/servizi-per-te/fotovoltaico/conto-energia/gestione-moduli

[108] https://registeritaly.pvcycle.org/

[109] www.sole.cobat.it

- Although constantly growing, ***the collection quotas are lower than the annual collection targets*** introduced with the WEEE Directive 2012/19. The Directive established that starting from 1 January 2016 the collection target corresponded to 45% (deriving the ratio between the total weight of WEEE collected and the weight of EEE placed on the market in three previous years). Since 2019 this target has risen to 65%, far from the collection rate of less than 43% in 2018.
- ***The percentage of "preparation for reuse" is rather low***, which in 2015 corresponded to 1%. It must be said that the European Directive has neither given clear indications nor provided propulsive thrust to reuse activities since it gave an aggregate target for WEEE "prepared for reuse and recycling ".
- There were reported cases[110] in Italy of ***PV panel waste of around 60 tons*** (valued 4 million euros) which were sent to PV Recycling plant in Sicily were instead rebadged with false labels and ***smuggled to Syria and Africa***. The reason was attributed to producers or plant owners not choosing reliable PV recyclers but opt for the cheapest option. Also, it can be pointed to the lack of regulations or standards for second-hand PV panels.

Annex 6.3: Australia

i) *Current and projected installed capacity*

Solar PV Capacity (Cumulative)	**18.5 GW[111] as of Sep 2020**
Target PV Capacity	**44 GW by 2030**

Australia's rooftop solar installations are the highest in the world on a per capita basis, with approximately 50 million or 18.5 Giga Watts (GW) installed so far (as of 30 September 2020). Forecasts suggest there will be more than 1 million panels requiring replacement annually by 2031[112].

ii) *Current and projected generation of waste from EOL PV*

According to IRENA, Australia's end-of-life PV panel waste volumes in 2030 in the regular-loss and early-loss scenarios would be between 30,000 tonnes and 145,000 tonnes and in 2050 counting 0.9 and 0.95 million tonnes respectively. Reclaim PV Recycling claims that approximately 300,000 PV modules will need to be disposed of annually up to 2030, rapidly increasing to 5 million modules per annum by 2035 as legacy modules reach the end of their life span. Additionally, an estimated 8–10% of the 11- plus million modules installed in Australia since 2009 are failing due to 'manufacturing faults and untested, environmentally deficient components'.

[110]https://www.pv-magazine.com/2020/02/05/italian-pv-panels-sent-for-recycling-were-instead-smuggled-to-syria-and-africa/

[111] IRENA Statistics-2020

[112] IRENA Statistics-2020

Another estimate by Macquarie University forecasts 800,000 tonnes of PV modules to reach end-of-life in 2047, with the intrinsic economic value of materials of this solar waste estimated at US$1.25 billion[113].

iii) *Summary of the country policy on EOL management*

There are currently (in May 2021) **no regulations** for management of waste PV panels at the federal level.

The Product Stewardship Act 2011 is designed to reduce the amount of hazardous waste going to landfill as well as increase recycling and recovery of valuable materials. Under the Act, the Minister for the Environment publishes a list of additional product classes to be considered every year. For 2016–17 the product list included a class covering PV cells, inverter equipment and system accessories, such as batteries, for domestic, commercial and industrial applications.

At a state level, in 2012 South Australia was the first government to ban e-waste from landfill, alongside investing in recycling infrastructure. However, their definitions of e-waste are designed to support the National Television and Computer Recycling Scheme (NTCRS), so PV components are exempted from the ban to date; this may change if the Commonwealth legislation is updated.

In 2014 the Victorian Government committed to a ban on e-waste going to landfill, with regulatory measures that came into force in June 2019.

In 2018 Sustainability Victoria[114] commissioned an assessment to identify options for a nationally coordinated approach to product stewardship of photovoltaic systems and to implement a national system of shared responsibility for end-of-life PV products.

iv) *Recycling technologies and list of technology providers*

Reclaim PV Recycling[115] is an Australian owned and operated solar panel recycling company utilizing a robust recycling process through Pyrolysis - a well-known thermal deconstruction technique - to delaminate PV panels into their component parts by passing them through a high-temperature furnace. Upon completion of the thermal extraction process, the recovered components are sorted and placed into collection bins for delivery to materials companies, ensuring all recoverable materials are available for re-use. Reclaim PV is simultaneously securing environmental licenses to conduct full scale recycling operations at an initial rate of 70,000 panels per annum and is putting the call out for end-of-life solar panels from anywhere in Australia. Reclaim PV already has circa 70,000 panels partly processed at its Lonsdale site and its leased warehouse in Brisbane.

v) *Challenges / opportunities for the country.*

Australia is among a number of developed countries that export the majority of its WEEE to developing countries. This is illegal under the Basel Convention, since these countries have

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[113] Northern Territory- EoLPV Study

[114] https://www.sustainability.vic.gov.au/About-us/Research/Solar-energy-system-lifecycles

[115] https://www.pv-magazine.com/2021/02/08/australias-first-large-scale-pv-recycling-operation-amps-up-waste-collection/

limited measures to protect workers using informal recycling techniques. More specifically, the Basel Ban Amendment makes it illegal to send hazardous wastes to developing countries.

Annex 6.4: USA

i) *Current and projected installed capacity*

Solar PV Capacity (Cumulative)	**60.5 GW[116] at end of 2019**
Target PV Capacity	**393 GW by 2030**

In the last ten years, the U.S. has experienced an accelerated growth of PV deployment with an average annual growth rate of 65%.

ii) *Current and projected generation of waste from EOL PV*

According to IRENA[117], end-of-life PV panel waste volumes in 2030 according to the regular-loss and early-loss scenario would be between 170,000 tonnes and 1 million tonnes and in 2050 according to regular loss and early loss scenario would be between 7.5-10 million tonnes respectively.

iii) *Summary of the country policy on EOL management*

Federal level: There are no specific regulations for take back of solar photovoltaic panels at the federal level in United States of America. The disposal of waste PV panels are currently governed by Resource Conservation and Recovery Act (RCRA).

State of Washington: The Washington state department passed a bill HB 2645 on March 2020 which concerns the takeback and stewardship of Solar PV panels. It mandates PV module manufacturers to submit stewardship plan by July 1st, 2022, failing which they would be subjected to a penalty of $10,000 for each sale.

California had classified PV panels as hazardous waste under SB 489 regulation in 2015. The Department of Toxic Substances Control (DTSC) proposed changes in hazardous waste program to classify PV waste as universal waste which was approved by EPA in 2020.

The **North Carolina** Department of Environmental Quality in 2019 (NCDEQ) passed House Bill 329 (SL 2019-132) in 2019, which requires the NC Environmental Management Commission (EMC) to establish a regulatory program to “govern the management of end-of-life photovoltaic modules and energy storage system batteries and wind energy systems.” As of July 2019, the funding mechanism was not established yet.

The **New York** State Senate passed Senate Bill S2837B,” Solar panel Collection Act” on July 2018 which is currently awaiting approval of the assembly.

The bill enacts the "solar panel collection act" which would require solar panel manufacturers to collect used panels and requires educational outreach relating thereto along with establishment of collection goals and reporting.

The SB 942 would require manufacturers selling solar modules in the state to implement a collection and recycling program at no cost to the system owner, and creates a landfill ban.

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[116] IRENA Statistics-2020

[117] IRENA-EoL management of Solar PV

New Jersey SB 601: In 2019, This Bill established the New Jersey Solar Panel Recycling Commission to develop recommendations and report recycling and end-of-life management options for the state.

iv) *Recycling technologies and list of technology providers*

- First Solar is a leading manufacturer of CdTe Thin film solar panels. The company has established a closed loop network for collection and recycling of used thin film modules with 90% material recovery. They have operational facilities in US, Malaysia and Germany.
- Solar Energy Industries Association is running a National PV Recycling Program which focuses on partnering with companies that have prior expertise in recycling glass, silicon, aluminium, scrap metal, and electronics. The aim of the program is to make SEIA partners capable to recycle solar panels and inverters.
- Cleanlites Recycling: recycled around 900 metric tons of solar PV panels as of 2018
- ECS Refining: Solar PV processing/recycling since around 2008
- Tekovery: processed a little more than 15,000 panels (which is about 272 metric tons).
- Recycle PV: Offers a comprehensive nationwide PV recycling program with Solar CowboyZ, PV CYCLE and RINOVASOL. A fee-structure is charged to recycle solar panels that have broken glass or major structural damage.

v) *Challenges / opportunities for the country*

One challenge is also that there is a mesh of laws – some states has laws, others don't. No standard or specification that is common/ harmonized across the country.

PV solar panels have been previously subject to the full requirements of California's hazardous waste regulations. DTSC has recognized that these stringent requirements led to challenges related to the disposal of PV solar panels.

DTSC noted that the current regulations require holders of PV waste to determine whether toxic substances are present and in what quantities. These requirements lead to more stringent management obligations for solar facilities and increase associated management costs.

The California Department of Toxic Substances Control (DTSC) amended revisions to its hazardous waste regulations that will allow PV modules to be managed as "universal waste" from January 1, 2021.

By being classified as universal waste, PV solar panels will now be subject to a streamlined set of standards that are intended to ease regulatory burden and promote recycling. For instance, under the universal waste requirements, holders of PV waste may accumulate panels for up to **one year,** while the general hazardous waste requirements only allow accumulation for **90 days** (for large quantity generators). This longer accumulation period will allow handlers to transport the solar panels to destination facilities in bulk rather than on a more frequent basis thereby saving on transportation cost.

Annex 6.5: Korea

i) *Current and projected installed capacity*

Solar PV Capacity (Cumulative)	**10.5 GW[118] at end of 2019**
Target PV Capacity	**58.5GW by 2030**

ii) *Current and projected generation of waste from EOL PV*

In August 2019, the Korea Photovoltaic Industry Association (KOPIA), the energy ministry and the environment ministry signed an innovative memorandum of understanding to make it mandatory for PV panel producers to recycle their products under extended producer responsibility (EPR) regulations which is expected to come into force[119].

According to IRENA120, Korea's end-of-life PV panel waste volumes in 2030 according to the regular-loss and early-loss scenario would be between 300,000 tonnes and 820,000 tonnes and by 2050 according to the regular loss and early loss scenario would be 1.5 and 2.3 million tonnes respectively

iii) *Summary of the country policy on EOL management*

There are no specific guidelines or regulations governing the end-of-life management of waste PV modules in Korea. The Government of Korea is planning to enforce Extended Producer Responsibility Scheme for PV modules in 2023[121].

iv) *Recycling technologies and list of technology providers*

Korea Evaluation Institute of Industrial Technology (KEIT) established a high value PV recycling technique funded by the Ministry of Trade, Industry & Energy (MOTIE), Republic of Korea. As a result of this technique 95% by weight[122] or more material recovery from PV panels is deemed possible.

v) *Challenges / opportunities for the country*

Korea's Ministry of Trade, Industry and Energy is building a facility with capacity to process 3600 tons/year for recycling photovoltaic panels which will be operational by the end of 2021[123].

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[118] IRENA Statistics-2020

[119] https://www.koreatimes.co.kr/www/nation/2020/08/371_294244.html

[120] IRENA-EoLEoL management of Solar PV

[121] https://www.pv-magazine.com/2020/10/08/south-korea-to-introduce-new-rules-for-pv-recycling/

[122] https://www.koreatimes.co.kr/www/nation/2020/08/371_294244.html

[123] https://recyclinginternational.com/business/korea-ramps-up-recycling-to-meet-demand-for-pv-panels/31270/

Annex 6.6: Japan

i) ***Current and projected installed capacity***

Solar PV Capacity (Cumulative)	**61.8 GW[124] at end of 2019**
Target PV Capacity	**150 by 2030**

ii) ***Current and projected generation of waste from EOL PV***

According to IRENA[125], Japan's end-of-life PV panel waste volumes in 2030 and by 2050 according to the regular-loss and early-loss scenario would be between 200,000 t and 1 million t and 6.5-7.6 million tonnes respectively.

iii) ***Summary of the country policy on EOL management***

Japan is still in the process of developing and setting up guidelines for safe and efficient of PV recycling.

The Japan Photovoltaic Energy Association (JPEA) has published voluntary guidelines on methods to properly dispose end-of-life solar PV modules on December 2017[126]. Manufacturers, importers and distributors of photovoltaic modules have been invited to provide information on the chemical substances contained in the products and to inform the waste disposal companies.

iv) ***Recycling technologies and list of technology providers***

NPC Group has processed 25,340 used PV panels as of October 31st, 2020 at Matsuyama Factory in Ehime, Japan. An automatic PV panel disassembly line has been installed in the facility that utilises a heated blade for separation of panels instead of crushing thus enabling higher separation efficiency.

Annex 7: International Case Studies: Wind power plants

Annex 7.1: USA

i) ***Current and projected installed capacity***

Current Cumulative installed capacity	105 GW at the end of 2019
Projected Capacity	300GW at end of 2030

ii) ***Current and projected generation of waste from EOL WP***

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[124] IRENA Statistics-2020

[125] IRENA-EoLmanagement of Solar PV

[126] https://www.pv-magazine.com/2018/08/29/japanese-government-hails-new-quality-guidelines-for-pv-projects/

Wind projects established in 1980s totalling 43 MW of installed capacity were fully decommissioned in 2017[127].

The Electric Power Research Institute[128] estimates there will be 2.1 - 4 million tons of cumulative blades between 2020 and 2050 in the US. The projected amount of blade waste could vary from about 200,000 tons per year (based on a 15- year lifetime) up to about 370,000 tons per year (based on a 25-year lifetime) by 2050.

iii) *Summary of the country policy on EOL management*

There are no federal level policies to manage EoL waste from wind turbines in the US.

The North Carolina Department of Environmental Quality in 2019 (NCDEQ) passed House Bill 329 (SL 2019-132) in 2019, which requires the NC Environmental Management Commission (EMC) to establish a regulatory program to "govern the management of end-of-life photovoltaic modules and energy storage system batteries and wind energy systems."

iv) *Recycling technologies and list of technology providers*

- ACMA has developed a technician certification wind turbine blade repair module[129] to support the wind industry. Standard blade refurbishment procedures may include visual and/or ultrasonic inspection and natural frequency measurements; then blades can be repaired, repainted, weighed and balanced as needed[130].
- Re-Wind project compares sustainable end–of–life (EOL) repurposing and recycling strategies for composite material wind turbine blades using Data Driven Structural Modelling in a Geographic Information Science (GIS) platform coupled with environmental, economic and social Life– Cycle Sustainability Assessments (LCSA).
- The renewable energy division of the GE Electric announced it had begun contracting recycling company Veolia North America to take blades from U.S. wind farms it is in the process of repowering, shred them up, and use them as a feedstock in cement kilns. Using shredded blade waste to produce cement, a technique known as co-processing, was first deployed commercially in Europe about a decade ago. This application could help solve the enormous climate impact of cement-making, which involves heating limestone to more than 2,700 degrees F in a furnace.GE estimates that by burning blades instead, the carbon emissions of cement production can be cut by 27 percent.
- Carbon Rivers is a Certified Small Business founded by engineers and scientists, headquartered in Knoxville, TN. They have developed a glass to glass reclamation technology that processes glass fibres from wind turbine blades into composite intermediates that can be used to produce final composite products again.

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[127] American Wind Energy Association

[128] Wind Turbine Blade Recycling- Preliminary Assessment - EPRI

[129] Wind Turbine Blade Recycling- Preliminary Assessment - EPRI

[130] https://backend.orbit.dtu.dk/ws/files/128071350/Wind_Turbine_Blades.pdf

- Global Fibreglass Solutions[131], an US based start-up has developed a solution to recycle wind turbine blades into pellets and fibreboards that can be used in flooring and walls. The facility has the capacity to process 6000 to 7000 blades per year.
- Wind turbine blades are currently landfilled under 30 feet from the ground in Lake Mills, Iowa; Casper, Wyoming and Sioux Falls, South Dakota. Casper in Wyoming[132] charged $675’485 for landfilling 1000 wind turbine blades. The city council has approved a landfilling fee of $59/ton for wind turbine equipment. Cost of disposal is currently between $400 and $800 per ton for the blades.

v) *Challenges / opportunities*

There is a challenge with the lack of policy[133] in the U.S. regarding end-of-use considerations for turbine blades, further contributing to the status quo of storage or disposal as solid waste in landfills. Currently it is less expensive to dispose of wind turbine blades in landfill in the US compared to long distance transport and efficient recycling. This lack of regulatory pressure ensures blockage in developing other EoL options for waste wind turbine blades.

US states could consider policy mechanisms to drive market development of alternative solutions, such as increased producer responsibilities. States could support construction of regional recycling infrastructure—particularly in states with larger portions of wind power such as Texas or Iowa—to address the end-of-use stage for wind turbine blades[134].

Annex 7.2: Germany

i) *Current and projected installed capacity*

Current Cumulative installed capacity	**60.8 GW at the end of 2019**
Projected Capacity	**96 W at end of 2030**[135]

ii) *Current and projected generation of waste from EOL WP*

Considering an average lifetime of 20 years for the turbines, a study by UBA[136] estimates from 2021, generation of waste concrete up to 5.5 million tonnes per year and steel nearly one million tonnes per year, in addition to copper and aluminum. The study highlights that the existing recycling infrastructure in Germany is equipped to process these amounts but points to the uncertainty with regard to the recycling of the rotor blades, for which the forecast indicates significant amounts starting in 2024 of up to roughly 70,000 tonnes per year.

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[131] https://markets.businessinsider.com/news/stocks/global-fiberglass-solutions-becomes-the-first-us-based-company-to-commercially-recycle-wind-turbine-blades-into-viable-products-1027906087

[132] Casper Landfill in Wyoming

[133] https://blog.ucsusa.org/james-gignac/wind-turbine-blades-recycling

[134] Recycling wind turbine blades in US- Article

[135] Wind Power Europe-Forecast 2030

[136] UBA Study on dismantling old wind power installations (In German)

The study by UBA also considered the forecast of disposal/decommissioning cost for Wind turbines in Germany which stays around 100 million euros up to 2031 and then rapidly increases to up to 450 million euros in 2038. This can be explained due to the increasing amounts of modern wind turbines with higher hub height retiring between 2030 and 2040.

iii) *Summary of the country policy on EOL management*

Dismantling:

Decommissioning of wind turbines is regulated by the Renewable Energy Sources Act, 2017. Some provisions are also made in the Building Code.

The dismantling of wind turbines in Germany is subject to construction law regime and, to a large extent, to immission (concentration of pollutants and substances in the environmental media in a specific place and at a specific time) control law.

Legislation Framework For Resource Management:

Metals: Germany follows the EU Waste Framework Directive (2008/98/EC) for the treatment of metals (Umwelt Bundesamt, 2014). This is transposed in the Commercial Waste Ordinance, 2002.

Composites: A ban on directly landfilling waste with a total organic content (TOC) higher than 3% came into force in 2009. Considering blades contain an organic part due to the resin that glues together the glass fibres, they cannot be landfilled.

Rare earths: Under the EU Waste Framework Directive (2008/98/ EC), rare earth elements are listed as non-hazardous. To date, there is no specific European or national legislation related to rare earths.

Oils: Waste oil management is regulated by the Waste Oil Ordinance of 01.05.2002 and Article 19 of the Federal Water Act.

Site Restoration: Paragraph 35 (5) of the Building Code has the following provisions: "The operator has to issue a declaration of commitment to dismantle the installation and remove all soil sealing when permanently abandoning the site". The Federal States Committee for Soil Protection has commissioned.

iv) *Recycling technologies and list of technology providers*

German Environmental Agency (UBA) has conducted an in depth assessment[137] of waste amounts, financial aspects and state of art dismantling techniques for EoL wind turbines.

Currently the only industrial scale recycling of blade material is performed by Zagons Logistik in Melbeck, Germany. They use the mechanical recycling approach and produce a material tha-t works well as a filler in cement production. This material is then sent off to Holcim AG/Geocycle cement plant in Lägerdorf for further processing into a fully functional product. In 2012 the company reprocessed about 400- 500 tonnes of material per month, i.e. 5 000-6 000 tonnes per year[138] The Melbeck plant has a total current capacity of 30,000 tons/ year. Cost is around 150 EUR/ton (gate fee).

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[137] UBA Study on dismantling old wind power installations (In German)

[138] https://www.windpowermonthly.com/article/1124486/complexities-recycling-begin-bite

Neocomp is a Bremen based waste management company that shreds and converts wind turbine blades made of Glass fibre reinforced plastics into high quality alternative fuel or recycled fibres that can generate electricity for energy intensive cement plants.

v) *Challenges / opportunities*

The Federal German Construction Code obliges the operators to provide financial securities in order to restore the original condition of the built-up area. However, no general guidelines do exist so far regarding the dismantling process. Furthermore, no specific targets under waste law for the waste generated during the dismantling of wind turbines or disposal routes for the individual materials have been defined.

Annex 7.3: Denmark

i) *Current and projected installed capacity*

Current Cumulative installed capacity	**6.1 GW at the end of 2019**
Projected Capacity	**9.3 GW at the end of 2030**[139]

ii) *Current and projected generation of waste from EOL WP*

Onshore installed capacity in Denmark is very saturated and an increase on the installed capacity is forecasted after 2045. On the other hand, the offshore capacity experiences a high increase until 2030, which corresponds to 210 MW/year. However, after 2030 the offshore capacity follows closely the onshore forecast. Due to this rise of the offshore capacity it is observed that in the years 2040 to 2045 the blade waste material derived from offshore wind turbines will exceed the material from onshore and will reach almost 4500 t. The onshore waste blade material available over the years appears to have significant fluctuations, following the changing growth rate of this industry with the time lag of the wind farm operational lifetime.

iii) *Summary of the country policy on EOL management*

Dismantling:

The municipality sets the conditions for decommissioning in the building and operating permit is initially issued. Decommissioning must start 1 year after the wind farm has stopped operating at the latest.

Legislation Framework For Resource Management:

Concrete: Article 2(2) of the Environmental Protection Act, 2016 states that municipalities must adopt regulations on sorting of building and construction waste, allocation of construction and demolition waste and notification of quantities thereof.

Oils: Denmark follows the EU Waste Framework Directive (2008/98/EC) for the treatment of waste oil via provisions in the Statutory Orders on Waste. Waste oils are primarily treated by regeneration and/or incineration with energy recovery.

[139] Wind Power Europe-Forecast 2030

Site Restoration: A common requirement is to remove all equipment, including the foundation, as deep as 1m below the surface and rehabilitate the area.

iv) *Recycling technologies and list of technology providers*

Miljøskærm is a Danish startup that recycles wind turbine blades (fibre glass) and develops material that can be used as noise barrier. The startup utilises an innovative separation technique that grinds the wind turbine blades to small pieces of 1-2 cm and then encloses them in recycled plastic case to form noise barrier. They expect to process 50-100 tons of material (3-6 blades) this year. They have sold the material as a noise barrier for a price of 100 euros per m^2. The company estimates that 12,000 tons of glass fibre material is discarded annually in Denmark, most of which originates from wind turbines.

Refiber is another company based in Denmark who have developed patented technology to convert glass fibre waste from wind turbine blades into insulation materials.

Annex 7.4: Netherlands

i) *Current and projected installed capacity*

Current Cumulative installed capacity	**4.5 GW at the end of 2019**
Projected Wind power capacity	**19.5GW at the end of 2030**[140]

ii) *Summary of the country policy on EOL management*

Dismantling: The dismantling of wind turbines falls under the Building Decree 2012[141].

Legislation Framework For Resource Management:

Concrete: Under the Dutch legislation, lap 3, concrete from renovation or demolition of buildings, roads and other infrastructure must be recycled or reused.

Metals: According to Sectorplannen lap 3, sector plan 12, all metals (ferrous and nonferrous) should be brought to a recycling plant.

Composites: Under the 3rd edition of the National Waste Management Plan, landfilling of composite waste is banned 'in principle'. However, wind park operators can benefit from an "exemption" if alternative solutions are considered too costly i.e., where the cost of treatment is higher than the benchmark value of €200/tons.

Oils: The 'Sector plan 56 Afgewerkte olie' states that oil from wind turbines should be primarily treated by regeneration and/or incineration with energy recovery.

Site Restoration: There is no specific legislation regulating the removal of wind turbine foundations in the Netherlands. Instead, any foundation removal requirements are set in the agreements between the landowner and the operator.

iii) *Recycling technologies and list of technology providers*

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140 Wind Power Europe-Forecast 2030

141 https://wetten.overheid.nl/zoeken

Extreme Eco solutions is a startup based in Netherlands who in partnership with SUEZ have built a demonstration path consisting of lightweight tiles made from wind turbine blades.

Demacq Recycling utilises high quality cold water cutting technology onsite to cut wind turbine blades for easy transportation. The company converts composite waste into a recyclate that can be used for building bridges.

In Rotterdam five used wind turbines blades have been made into slide tower, tunnels, ramps, and slides in a 1,200 sqm children's playground named Wikado. Decommissioned blades have been reused in playground, bus stations and outdoor seat in city of Terneuzen[142].

iv) *Challenges / opportunities*

Netherlands forbids landfilling of composite waste (wind turbine blades included) under 3rd edition of national waste management plan. There is an exception if alternative treatment of waste cost more than 200 euros/ton. Wind turbine blades are landfilled in the country despite the ban using the above exception. The waste management department of the Ministry of infrastructure claims there are no real applications in processing and or recycling the wind turbine blades in Netherlands as the reason for deviation[143]. This is confirmed by Wind Europe Survey which indicates the cost of mechanically recycling wind turbine blades in the Netherlands ranges between 500-1,000 euros/ton including onsite pre-cut, transport and processing. Mechanical recycling itself costs between 150-300 euros/ton.

[142] What happens to all old wind turbines ? - BBC

[143] Alternatives on afterlife use of amortized wind turbine blades in the Netherlands

Annex 7.5: United Kingdom

i) *Current and projected installed capacity*

Current Cumulative installed capacity	**24 GW at the end of 2019**
Projected Wind power capacity	**37.5GW at the end of 2030**[144]

ii) *Current and projected generation of waste from EOL WP*

United Kingdom will be leading, accounting for around 37– 40% of European offshore blade waste material until 2050.The overall capacity in 2050 is forecasted to be a little lower than 55,000 MW, which is almost half of the capacity estimated for Germany. However, in United Kingdom the majority of the capacity will be offshore after 2022. As a result, the total waste material from offshore is expected to be higher than from onshore from 2030 onwards, and in 2050 the total blade waste material is anticipated to be approximately 45,000 t, 65% of which due to offshore. It must be noted that the offshore capacity is increasing with a rate of 1333 MW/year until 2035, which is very high and corresponds to half of the offshore capacity rate installed in Europe in total. After 2035 the offshore capacity appears to experience a saturation with almost no new installations. However, this saturation is not identified on the blade waste material due to the time lag between installation to decommissioning. On the other hand, the onshore capacity is relatively saturated with an average rate of increase around 250 MW/year. The total onshore blade waste material increases until 2030 and then fluctuates until 2050.

iii) *Summary of the country policy on EOL management*

Dismantling:

Decommissioning requirements are set in the planning conditions for each project that has received permission. Most projects will have agreed a ‘decommissioning bond’ with the local planning authority at the point of planning consent to cover the costs of decommissioning, usually in the form of a planning condition.

Legislation Framework For Resource Management:

Concrete: There is no special legislation in place on the disposal of onshore wind turbine foundations in the UK.

Metals: The UK follows the EU Waste Framework Directive (2008/98/ EC) for the treatment of metals. From 1 January 2015, UK waste regulations require businesses to separate recyclable material from other waste (e.g. the Waste (England and Wales) Regulations 2011 as amended in 2015).

Oils: In Scotland, Wales and Northern Ireland waste oil management is regulated by the Pollution Prevention Guide under the section ‘Safe storage and disposal of used oils (PPG8)’. In England waste oil management is regulated by the ‘Control of pollution (oil storage) (England) regulations 2001’. This legislation is similar to that of Scotland, Wales and Northern Ireland.

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[144] Wind Power Europe-Forecast 2030

Site Restoration: Decommissioning requirements are set in the planning conditions for each project that has received permission. The consenting authority can include requirements for restoration of land to an acceptable condition as part of the planning approval process.

Annex 8: The view of the key stakeholders

The following ministries were consulted for this research:

- Electricity and Renewable Energy Authority (EREA) under Ministry of Industry and Trade (MOIT);
- Viet Nam Environment Administration (VEA) under Ministry of Natural Resources and Environment (MONRE);
- The Department of Science and Technology for Economic Technical Branches under Ministry of Science and Technology (MOST).

The views of the EREA: The development of renewable energy is an inevitable trend in Viet Nam. Rooftop solar power is a clean, renewable power source that is dispersed, in small scales, consumed locally, contributes to reduce the loss of transmission, distribution, making use of the existing grid infrastructure of the industry. Electricity, which is generated mainly during the daytime, during peak hours of the power system helps to reduce the load peak. This is also a type of renewable energy that takes advantage of the roof area in residential areas, businesses that already have adequate grid infrastructure, convenient to connect... so economic sectors such as households and enterprises should be encouraged to invest in self-used electricity supply and the residual resale to Viet Nam Electricity (EVN).

The FiT schemes have many advantages for the strong development of both wind and solar energies, but they demonstrate several inadequacies and limitations. The ministry is preparing a new decision on electricity prices in which utility-scale and floating solar power systems will apply competitive bidding schemes, whilst rooftop solar system will have a new FiT. The new FiT will range from US cent 5.2 to 5.8 per kWh depending on capacities. This FiT is 30 % lower than the previous ones that is in line with the current situation characterised by:

- The mature technology;
- The declining trend of prices of the equipment for rooftop solar power system;
- The high efficiency of panels resulting in an even lower investment cost per Wh produced.

The FiT 3 for solar power will be revised yearly to be suitable with real situation.

Up to present, there is not any regulations on management of waste generated from solar and wind power systems. It is better to separate normal compositions and hazardous waste. The normal composition, which is accounted for more than 80 % of the panel volume and 85 % of wind blade, can be recycled. The remaining, mostly consisting of EVA and heavy metals in PV panels, is considered hazardous waste and hazardous substances in turbine blades. Soon after the project COD, the plant owners often sign contracts with a functional unit to handle as hazardous wastes, but they do not know the treatment processes. The consideration of hazardous waste may cause difficulties in the solar power development in the future. Following this work, EREA recommends expanding the research on the material composition modification under extreme conditions of both solar and wind power, water leakage from solar panels in case of faulty or broken PVs and their environmental impacts.

The views of VEA/MONRE. The consultation focused on the environmental impact assessment and post EIA process. Approximately 80 % of EIA reports of renewable energy projects were approved by the provincial departments of natural resources and environment. However, MONRE has periodic investigations on environmental protection of renewable energy projects. In addition, MONRE has set up 3 hotlines for environmental issues, so that environmental problems can be identified and notified to MONRE, in order to then find suitable solutions.

Based on the Law on Environmental Protection 2014, residential communities have the rights to monitor projects and their environmental impact. In the Law on Environmental Protection 2020, residential communities are considered to be a main subject in environmental protection. They play an essential role in information disclosure, public consultation as well as supervision and criticism of environmental protection activities. The overall target of the new law is to protect residential health and ensure that people can live in a healthy environment. In order to facilitate the residential community in environmental protection, the Law has added regulations on the establishment of an online system for receiving, processing, responding to feedback, recommend and consult organizations, individuals and communities on environmental protection, thereby helping the community to participate in monitoring environmental protection activities through information technology, interacting with smart applications on mobile phones.

Department of Science and Technology for Economic Technical Branches under Ministry of Science and Technology (MOST). The Government has assigned the Ministry of Science and Technology to conduct research on handling solutions for EoL waste from solar power plants. In the first phase, the ministry is focusing on solutions for solar cells and inverters. In the second phase, a technical standard on the quality of solar panels is planned. Furthermore, in the near future, the ministry will promote a pilot study on the collection, handling, and treatment of solar PV wastes.

Several stakeholder consultations have been conducted with provincial DOITs and DONREs. DOITs are only in charge of electricity generation and grid connection as well as technical safety in power plants. DONREs are responsible for managing and monitoring environmental issues. In the absence of any specific federal legislation, EoL waste from solar power is registered as hazardous waste and managed by hazardous waste dossiers as stipulated in Circular No. 36/2015/TT-BTNMT.