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Forecasting WEEE Arising for Electric Vehicle Batteries and Photovoltaic Panels in Ireland

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Rialtas na hÉireann
Government of Ireland

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The EPA is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

The work of the EPA can be divided into three main areas:

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- Large-scale industrial, waste and petrol storage activities;
- Urban waste water discharges;
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1. Office of Environmental Sustainability
2. Office of Environmental Enforcement
3. Office of Evidence and Assessment
4. Office of Radiation Protection and Environmental Monitoring
5. Office of Communications and Corporate Services

The EPA is assisted by advisory committees who meet regularly to discuss issues of concern and provide advice to the Board.

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Authors: Michael Johnson, Narjes Fallah, Sheila Killian and Colin Fitzpatrick

Lead organisation: University of Limerick Department of Electronic and Computer Engineering

Identifying pressures

International energy systems are facing radical changes due to factors such as the electrification of the transportation network and the decarbonisation of the electricity grid. While these developments bring us closer to achieving sustainable and renewable energy systems, they also present a new set of challenges in sustainable management of the associated waste electrical and electronic equipment (WEEE).

One area where these challenges will be particularly evident is in the field of long-life WEEE. Long-life WEEE, or LongWEEE, are electronic appliances and devices that have extremely long use phases or lifetimes compared with the average life cycle of most electrical and electronic equipment. It is imperative that the WEEE management system is prepared to deal with the types and levels of LongWEEE in the future, from both an infrastructural and financial perspective.

The two specific LongWEEE sectors considered in this report are solar photovoltaic (PV) panels and electric vehicle batteries (EVBs). For each sector, projections on the quantities of material expected at end of life and associated financing implications for recycling are assessed and discussed.

Informing policy

The report provides a concise analysis of LongWEEE, specifically the solar PV panel and EVB sectors, projecting the future volumes and considering the financial flows related to these long-life emerging technologies.

A failure to adequately plan for the recycling of these long-life products now may lead to an inadequately financed WEEE recycling system, or one that becomes prohibitively expensive for new market entrants to join.

This research project will support the decision-making process for sustainable WEEE management, providing an evidential basis for the short- and long-term implications of decisions. The report will also help inform the WEEE management system to achieve its mandatory collection and recycling obligations in a financially sound manner.

Developing solutions

This research report identifies challenges and models scenarios for the sustainable management of LongWEEE, specifically the solar PV panel and EVB sectors.

The report projects the quantities of WEEE generated for both sectors, ranging from present day to 2050. One finding from the project is that there is still a lot of uncertainty regarding the quantities of LongWEEE that will be generated in future, so the WEEE management system needs to be prepared to cover a range of eventualities.

The research project also explores the potential costs of recycling for both WEEE sectors based on current practices and costs. Shipping both EVBs and solar PV panels to European destinations for final treatment may involve significant sums of money in the future. This warrants an investigation of domestic pre-treatment options for LongWEEE to reduce these costs and retain value in Ireland.

The project also considers the relative merits of both “pay when placed” and “pay when collected” approaches to financing such LongWEEE products. Due to the high impact of policy on future volumes of these long-life products being placed on the market and the timespans involved, the “pay when placed” model is considered to be the most prudent approach and in line with the current requirements of extended producer responsibility.

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EPA Research Report

Prepared for the Environmental Protection Agency

by

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This report is based on research carried out/data from 1 March 2020 to 30 November 2021. More recent data may have become available since the research was completed.

The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

Globally, energy systems are undergoing two simultaneous and radical transformations: the electrification of the transportation network and the decarbonisation of the electricity grid. While both developments are to be enthusiastically welcomed, it must be acknowledged that they will present a new set of challenges in sustainable waste management. An Extended Producer Responsibility (EPR) system requires producers to pay the full costs of dealing with the waste they produce. It is imperative that those involved in developing and implementing an EPR system ensure that the waste electrical and electronic equipment (WEEE) collection system is adequately financed if mandatory collection and recycling obligations are to be met. The two specific cases considered in this report are solar photovoltaic (PV) panels and electric vehicle batteries (EVBs).

To create forecasts for waste arising from these product categories, the authors created models that projected placed on market data and subsequently applied the appropriate Weibull function to describe waste lifetimes of each category. This resulted in predicted WEEE arising/waste battery data from the present to 2050 for both PV panels and EVBs. The forecast predicts ≈500 EVBs for recycling in 2030, rising to a figure of 32,500 EVBs per annum by 2050. In the case of PV panels, the forecasted scenarios suggest that, by 2050, the approximate volume of PV that becomes WEEE will be between 5,000,000 and 21,000,000 kg per annum (depending on projection scenario).

The results of this modelling contain significant areas of uncertainty, which are discussed in the report. The work presented also explores the costs of recycling for both sectors based on current practices and costs. Shipping both EVBs and solar PV panels to European destinations for final treatment may involve significant sums of money going forward. This warrants an investigation of domestic pre-treatment options for both EVB and solar PV long-life WEEE to reduce these costs and retain value in Ireland.

The report also discusses the merits of both “pay when placed” and “pay when collected” approaches to financing the collection and treatment of such long life products at end of life. While each approach has associated advantages and disadvantages, we lean towards a recommendation of “pay when placed” funding for these long-life WEEE products. Optionally, such a fund could be managed through a mechanism such as an “on-demand performance bond”. Due to the high impact of policy on the future volumes of these products placed on the market and the timespans involved, we consider this the most prudent approach, and in line with the current requirements of EPR.

1 Introduction

Globally, energy systems are undergoing two simultaneous and radical transformations: the electrification of the transportation network and the decarbonisation of the electricity grid. While both developments are to be enthusiastically welcomed, it must be acknowledged that they will present a new set of challenges in sustainable waste management.

One area where these challenges will be especially evident is in the field of long-life waste electrical and electronic equipment (WEEE). Long-life WEEE are electronic appliances and devices that have extremely long use-phases or lifetimes compared with the average life cycle of most electrical and electronic equipment (EEE). The two specific cases considered in this report are solar photovoltaic (PV) panels and electric vehicle batteries (EVBs). PV solar modules are designed to generate clean and renewable energy over a long lifetime, typically 20–25 years. As the first significant PV installations are only just being realised in Ireland,[1] high-volume recycling is still projected to be many years away. However, the International Renewable Energy Agency has predicted that the share of global e-waste accounted for by PV panels will grow from 0.1% in 2014 to over 10% by 2050.[2] With regard to electric vehicles (EVs), 8646 new electric cars were registered in 2021, an increase from 4013 registrations in 2020 and 3444 in 2019. National policy specifies that 100% of all new vehicles sold will be zero emissions by 2030, and the batteries of such vehicles are the second form of long-life WEEE to be considered.

These long-life products pose two challenges for waste management systems. In the first instance, the introduction of new long-life products can have major impacts on how WEEE collection targets are calculated. The current method employed for setting the collection target is that 65%, by weight, of the average volume of EEE placed on the market (POM) in the previous 3 years should be collected. In the short term, this will lead to a dramatic increase in the current collection target; however, these products will not be available for recycling for many years into the future.

European Union (EU) Member States that fail to plan for this or to incorporate appropriate modelling into the target-setting process may miss their targets, not only risking reputational damage, but also, potentially, being subject to infringement procedures and ultimately fines from the EU. The WEEE Directive also permits that the WEEE arising method be used to set the collection targets, and, for solar PV and other long-life WEEE, this would actually be more appropriate, but that a "placed on market" target-setting approach is applied to more standard WEEE streams.

A revised WEEE Directive that allows different target-setting approaches for different WEEE streams would be preferable. In such a scenario, targets could be set using the "WEEE arising" method for solar PV and long-life WEEE, but a "placed on market" approach would continue to be used for more standard WEEE streams. Furthermore, Member States should be allowed to choose the method to be used for product category.

Second, it is imperative that stakeholders involved in developing and implementing an Extended Producer Responsibility (EPR) system ensure that the WEEE collection system is adequately financed if it is to meet its mandatory collection and recycling obligations. There are a number of approaches available to producers currently placing products on the market, but their adequacy to fund recycling that will need to be paid for more than a decade into the future is currently coming under scrutiny. It is essential to understand the potential financial implications associated with these options to prevent unsustainably high recycling costs when very large quantities of items such as PV panels or EVBs come on stream for recycling. The choices and implications of charging current producers as they place products on the

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[1] https://www.pv-magazine.com/2022/05/23/ireland-allocates-1-53-gw-of-pv-in-second-renewables-auction/ (accessed 11 January 2024).

[2] https://www.irena.org/publications/2016/Jun/End-of-life-management-Solar-Photovoltaic-Panels (accessed 11 January 2024).

market or deferring the charges until the products present for recycling need to be fully considered, and impacts such as projecting the future costs and volumes of collection and recycling, how cash reserves should be managed and the impacts on future new market entrants must be traded off. Failure to plan appropriately for this may lead to an inadequately financed recycling system or one that is prohibitively expensive for new market entrants to join.

To address these challenges, the "LongWEEE" (Long-life Waste Electrical and Electronic Equipment) project was conceived. The aim of this project is to provide an analysis of long-life WEEE and waste EVBs by projecting the future volumes and considering the financial implications related to long-life emerging technologies such as solar PV panels and EVBs. Such forecasts and projections will enable decisions that contribute to the long-term sustainable management of WEEE in Ireland, supporting evidence-based policy decisions in target setting and financing.

1.1 Report Layout

The LongWEEE report provides a study of future waste flows and a financial model for long-lifetime products such as PV panels and EVBs. Specifically, the report is structured as follows:

- **Introduction.** Chapter 1 introduces the concept of long-life WEEE products and discusses some of the pressures and challenges that will need to be addressed in the responsible environmental management of such – challenges to be addressed by the research carried out as part of this project.
- **Literature review.** The literature review (Chapter 2) for this project considers the specific long-life WEEE products identified in the literature, looking at EVB and solar PV panel research and publications. The directives or legislation that govern the recycling and safety/environmental considerations of each type of product are examined. As the project is concerned with projecting future volumes of these long-life WEEE products, the literature review also considers volume projection research and academic literature for both EVBs and solar PV panels at this point.
- **EVB modelling.** Chapter 3 of the report presents the process adopted and predictions/results generated for modelling the number of EVBs that will reach end of life (EOL) between now and 2050 in Ireland across a range of different conditions and scenarios.
- **PV modelling.** Chapter 4 looks at forecasting solar PV WEEE for the timeframe 2020–2050. The methodology adopted and approach used are described, and the model results are presented.
- **Financial costing.** Chapter 5 considers the financial considerations and costings associated with the recycling of EVB and solar PV WEEE in the future. Two distinct financing options are discussed, and estimates of the financial costs of recycling the projected quantities of both WEEE streams are provided.
- **Stakeholder inputs.** Chapter 6 presents different perspectives from stakeholders on the issue of long-life products and their implications for sustainable WEEE management policy.
- **Conclusion.** The report concludes (Chapter 7) with a summary of the key project findings, as well as the major recommendations and outputs generated by the research.

2 Literature Review

2.1 Electric Vehicle Batteries

This section of the literature review considers batteries used in EVs, specifically battery electric vehicle (BEV)-type applications. A BEV is a type of EV that exclusively uses chemical energy stored in rechargeable battery packs, with no secondary source of propulsion. An EVB is any battery used to power the propulsion system of such a BEV. These batteries are usually a secondary (rechargeable) battery, storage battery or secondary cell. It should be noted that these are distinct from traction batteries, which are specialised systems used for industrial (or recreational) vehicles. Traction batteries are specifically designed with a high ampere-hour capacity and are used in forklift trucks, electric golf carts, riding floor scrubbers, electric motorcycles, electric cars, trucks, vans and other EVs, and are outside the scope of this work.

2.1.1 Types/categories/composition of EVBs

Batteries for EVs can be characterised in a number of different ways, most commonly by their power-to-weight ratio, specific energy or energy density. Smaller, lighter batteries reduce the weight of the vehicle and improve its performance. The main categories of EVBs are nickel–metal hydride (NiMH) batteries and lithium-ion batteries (LIBs).

Nickel–metal hydride batteries

NiMH batteries were frequently used in early generation all-electric vehicles and plug-in hybrid vehicles; they have mostly been superseded by LIBs. NiMH batteries remain in use in some hybrid vehicles. For NiMH batteries, the working voltage and energy density is higher than lead–acid batteries and they can support over-charging and over-discharging; however, the memory effect is higher, they perform poorly in cold weather and their fixed shape means that they cannot be used for the smaller application (Fetcenko *et al*., 2007).

As NiMH batteries are a relatively mature technology, the majority of the research in the literature focuses on recycling issues associated with EOL processing of these batteries. For example, Meshram *et al*. (2017) present a two-stage intensified (baking and leaching) treatment process for selective metal dissolution of EOL NiMH batteries, focusing on leaching base metals and rare earth elements from the batteries. Overall, metal recovery rates using their process are 98.2% for nickel, 91.4% for cobalt, 98% for zinc, 97.8% for manganese and 96% for rare earth elements. The process outperforms direct sulfuric acid leaching of cathode powder because acid consumption is lower and it has better selectivity of metals.

Lithium-ion batteries

LIBs are rechargeable batteries that were initially developed and commercialised for use in laptops and consumer electronics. LIBs typically have a high energy density and long cycle life. Disadvantages of LIBs include sensitivity to temperature, poor low-temperature power performance and performance degradation with age (Wang *et al*., 2012). When LIBs are used in EVs, a battery management system is typically also installed to ensure battery safety and reliability (Lu *et al*., 2013).

LIB technology is moderately mature, with the first battery having appeared on the consumer electronics market in 1985. The research in the literature reflects this. For example, Mossali *et al*. (2020) discuss LIBs and their recycling with respect to the circular economy. The authors believe that the circular economy for LIBs is profitable due to the presence of valuable metals in the batteries; however, value-chain actors' integration will be key for future LIB recycling. Unsolved issues around pyrometallurgy will act as drivers for new LIB recycling solutions.

Variants of LIBs (using phosphates, titanates, spinels, etc.) have also been considered in the literature. These batteries sacrifice specific energy and specific power to provide fire resistance, environment-friendliness, rapid charging (as quickly as a few minutes) and longer lifespans. Typical figures predict lifespans of 10+ years and more than 7000 charge/discharge cycles (Hannan *et al*., 2018; Ushakov *et al*., 2019). Modelling (Hosseinzadeh *et al.*, 2018) and application of these technologies to EVs (Carrilero *et al.*, 2018) are also reported.

2.1.2 Directives and legislation

The EU Batteries and Accumulator Regulation[3] and report target waste batteries and accumulators, aiming to ensure that batteries placed on the EU market are sustainable and safe throughout their entire life cycle. The report (as well as providing a framing of the key aspects) and the impending regulation intend to contribute to the protection, preservation and improvement of the quality of the environment by minimising the negative impact of batteries and accumulators.

The End-of-Life Vehicles (ELV) Directive[4] is an EU directive that addresses the EOL processing of automotive products. Automobiles, etc., reaching EOL in the EU generate between 7 and 8 million tonnes of waste per annum, and should be managed according to this “ELV Directive”[5] (Konz, 2009).

The ELV Directive aims to make the dismantling and recycling of EOL vehicles more environmentally friendly. To do this, it sets clear and quantified targets for the reuse, recycling and recovery of EOL vehicles and their components. As of 1 January 2015, Ireland has been required to meet an EOL vehicle reuse, recycling and recovery target of 95%, with a minimum of 85% to be achieved through reuse/recycling. The balancing 10% can be met by recovery, which typically means processing through a waste-to-energy plant. The scope of the directive is limited to passenger cars and light commercial vehicles.

The directive also advocates that new vehicles be manufactured without using hazardous materials such as lead, mercury, cadmium and hexavalent chromium. This helps promote the reuse, recyclability and recovery of waste vehicles (see also Directive 2005/64/EC[6] on the type-approval of motor vehicles with regard to their reusability, recyclability and recoverability).

In Ireland, the ELV Directive was transposed into national law in 2006, as the European Union (End-of-Life Vehicles) Regulations 2014 (S.I. No. 281 of 2014)[7] as amended.[8,9,10] Under the EPR model, the Irish compliance scheme for EOL vehicles is operated by the ELV Environmental Services CLG (ELVES). ELVES was established in 2014 and represents automotive original equipment manufacturers in Ireland. The organisation was approved under the European Union (End-of-Life Vehicles) (Amendment) Regulations 2016 from 1 January 2017 as the compliance scheme for the vehicle sector in Ireland. ELVES also promotes, on behalf of its members, a network of public drop-off points (also known as authorised treatment facilities (ATFs) or scrapyards), providing free EOL vehicle takeback from the public.

When a vehicle reaches EOL, a “Certificate of Destruction” is issued. This document legally ends the owner’s responsibility for the vehicle from the time of issue and is issued by the ATF/permitted scrapyard where the vehicle is taken to become waste. The issuing of a Certificate of Destruction marks a vehicle as scrapped on the National Vehicle and Driver File.

For takeback of EVBs, ELVES has introduced the Electric ELVES Programme. This programme covers industrial batteries from hybrid, electric and mild hybrid vehicles. It provides ATFs with support such as dismantling information, training, free collection and recycling of the battery, and (if necessary) additional support in the event that the vehicle/battery is potentially damaged.

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[3] https://environment.ec.europa.eu/topics/waste-and-recycling/batteries-and-accumulators_en (accessed 11 January 2024).

[4] https://environment.ec.europa.eu/topics/waste-and-recycling/end-life-vehicles_en (accessed 11 January 2024).

[5] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02000L0053-20130611&qid=1405610569066&from=EN (accessed 11 January 2024).

[6] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32005L0064 (accessed 16 January 2024).

[7] http://www.irishstatutebook.ie/eli/2014/si/281/made/en/print (accessed 11 January 2024).

[8] https://www.irishstatutebook.ie/eli/2016/si/566/made/en/print (accessed 11 January 2024).

[9] https://www.irishstatutebook.ie/eli/2018/si/183/made/en/print (accessed 11 January 2024).

[10] https://www.irishstatutebook.ie/eli/2020/si/82/made/en/print (accessed 11 January 2024).

2.1.3 Environmental considerations for EVBs

Electric cars are better for the environment than conventional internal combustion engines (Wilson, 2013; Milev *et al*., 2019). In general, BEVs have lower life cycle greenhouse gas (GHG) emissions than vehicles with a traditional internal combustion engine (ICE) (Lattanzio and Clark, 2020). However, GHG emissions associated with the manufacturing process (including raw materials acquisition/processing) are higher for BEVs than for ICE vehicles. This is countered by the fact that BEVs typically have much lower emissions at the vehicle in-use stage, depending on the electricity generation source used to charge the vehicle batteries. The importance of the electricity generation source used to charge the vehicle batteries can be considerable; for example, Marmiroli *et al*. (2018) found that the carbon intensity of the electricity generation mix could explain up to 70% of the variability in published findings on this topic.

In addition to lower GHG emissions, BEVs offer local air quality benefits compared with ICE vehicles, due to the absence of vehicle exhaust emissions (Timmers and Achten, 2016). However, BEVs may be responsible for greater human toxicity and ecosystem effects than their ICE vehicle equivalents, attributed to factors such as the mining and processing of the metals/raw materials needed to produce batteries (Hawkins *et al*., 2013; De Souza *et al*., 2018).

While recycling processes continue to develop, reusing batteries offers an alternative to recycling. Many EVBs that are "spent" still have up to 70% of their capacity left – more than enough for other applications. After used EVBs have been broken down, tested and repackaged, they can be used for alternative second-use applications.

One second-use application for an EVB is to repurpose it to power a home/building by becoming part of a battery storage system (e.g. Weinstock, 2002; Li *et al*., 2017). Such systems store renewable energy, such as wind or solar energy, for use in powering homes. Other potential second-use applications include street lights, lifts, data centres, etc. Repurposing and reusing EVBs like this can create a closed-loop system for recycling.

2.1.4 Safety considerations

A number of specific safety considerations and associated standards need to be taken into account in EVB usage and recycling operations, including limiting chemical spillage from the batteries, ensuring that the batteries are securely mounted and able to withstand a crash, and isolating the car chassis from the high-voltage system to prevent the risk of electric shock.

EVBs, especially LIBs, are flammable; if cells are damaged, it is possible for the associated power circuits to be short-circuited, which can result in fires if the proper safety circuits and precautions are not present. EVBs can be recycled, but recycling them is a non-trivial task because of the sophisticated chemical procedures required, which present a further set of associated safety considerations. A recent case study describes a circular economy innovation demonstration project in Ireland. The project aims to identify damaged modules and to isolate them from existing waste lithium battery flows while also investigating the potential for refurbishment and reuse of undamaged modules.[11]

It is possible to recycle EVBs through smelting, direct recovery and other processes. LIBs are typically pulverised as part of the recycling process. If the battery is completely inert/without charge, then it can be shredded and the metal components easily sorted. If there is a risk that the battery still retains a charge and thus poses a safety risk, then the battery is frozen in liquid nitrogen before being pulverised.

Specific safety hazards for recycling EVBs include the risk of the batteries catching fire during recycling. Damage to the battery cell(s) can result in lithium metal being deposited on the anode. If the anode is then exposed to moisture, a violent reaction will occur. Thermal runaway or fire can also occur if the battery is disassembled incorrectly, as a result of extreme abuse such as that resulting from faulty battery operation or traffic accidents (e.g. Sun *et al*., 2020). Failure of the battery may then be accompanied by the release of toxic gas, fire, jet flames or explosion. Other risks include workplace exposure to hazardous fluorides or metals during recycling stages such as battery disassembly, shredding or smelting. Depending

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[11] https://wks.circuleire.ie/public/artefact/e032be78-f110-4b6f-a4a4-c0daa432f4a3 (accessed 11 January 2024).

on the battery type and composition, an inert or controlled environment may be required to handle recycling operations safely. As there are no known regulations providing specific guidelines for removing, discharging, disassembling and storing used EVBs, some authors, such as Gaines *et al*. (2018), argue that the increased costs associated with such safety regulations and standards could pose a barrier to the commercialisation of EVB recycling. The authors posit that there will be a need to balance cost efficiency, environmental sustainability, and worker health and safety in this regard.

2.2 PV Systems

This portion of the literature review considers PV systems. A PV system is a power system designed to supply usable solar power by means of PVs. It is composed of several components (as shown in Figure 2.1), including a solar panel, solar modules and solar cells to absorb and convert the sunlight into electricity. In addition, a solar inverter is used to convert the output from DC to AC voltage, as well as the physical fixture, cabling and other electrical accessories to allow the system to function. More advanced systems can also include a solar tracking system to improve performance and an integrated battery solution.

The PV cell (solar cell) is the basic building block of the PV system. It is an electrical device that converts the energy of light directly into electricity by the “photovoltaic effect”, allowing photons to knock electrons free from atoms, which in turn generates a flow of electricity. Individual solar cell devices are then combined to form modules, otherwise known as solar panels. The common single-junction silicon solar cell can produce a maximum open-circuit voltage of approximately 0.5 to 0.6 volts.

The majority of the research into PV cells in the literature focuses on improving the basic PV cell technology. Work such as that by Yoshikawa *et al*. (2017) focuses on improving the photo-conversion efficiency of silicon solar cells, arguing that this is crucial to further the deployment of this type of renewable electricity source. Device properties such as lifetime, series resistance and optical properties are considered essential in this respect, and must be improved simultaneously to reduce recombination, resistive and optical losses. Periodical publications by Green *et al*. (2018) provide a consolidated listing of the highest independently confirmed efficiencies for PV cell and module technologies over 6-month periods.

The PV/solar module is a single PV panel that is an assembly of connected solar cells. The solar cells absorb sunlight as a source of energy to

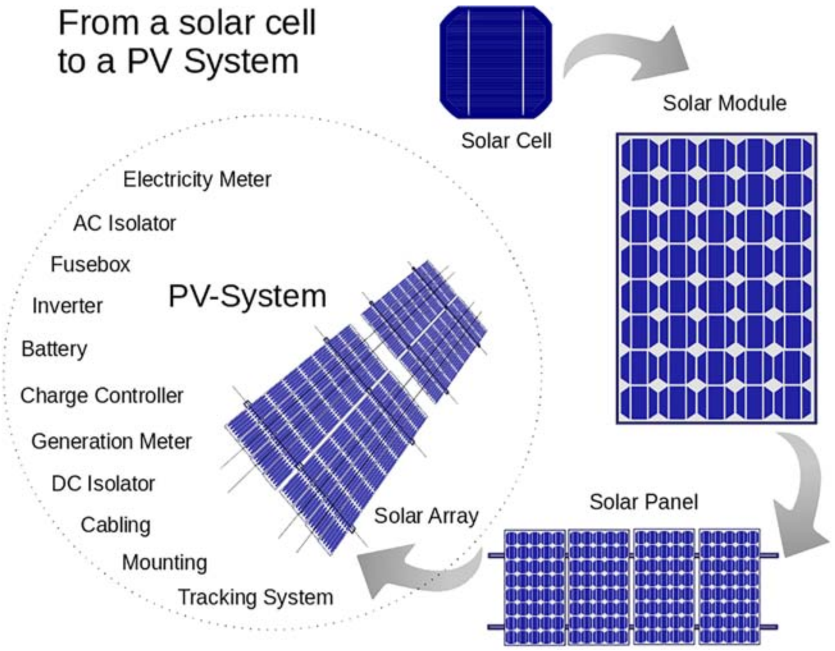

Figure 2.1. Solar panels, modules and cells. Image credit: Rfassbind/Wikipedia (https://commons.wikimedia.org/wiki/File:From_a_solar_cell_to_a_PV_system.svg?uselang=en#Licensing).

generate electricity. A PV module consists of multiple PV cells connected in series to provide a higher voltage output. The term solar panel is sometimes used interchangeably with solar module. The main difference is that some solar panel models are composed of multiple modules mounted together.

PV/solar panels are complete renewable energy solutions, comprising one or more PV modules with supporting technology and systems. PV systems range from small rooftop-mounted or building-integrated systems (≈70 kW capacity) to large utility-scale power stations (capacities of hundreds of megawatts). Nowadays, most PV systems are grid-connected, while off-grid or stand-alone systems account for only a small portion of the market.

The majority of research into PV systems focuses on either the PV cell technologies or the high-level management of the complete PV system. For example, Xu *et al*. (2018) present a review of the management and recycling technologies available for waste solar panels. While most research into solar cells focuses on improving cell efficiency and production capacity, their research looks at system-level concerns, such as the dismantling and recycling of EOL panels. The authors note that most solar panel recycling studies focus on silicon extraction and the recycling of rare metal elements. At present, there are three methods of processing waste solar panels: component repair, module separation, and the removal of silicon and other rare metal elements from among the components.

2.2.1 Types of PV cells

Current PV technologies use semiconductor materials as the basic element of the solar cells. There are two main types of PV technologies: crystalline silicon (c-Si) PV cells and thin-film PV cells.

2.2.1.1 Crystalline silicon PV cells

c-Si cells for PV systems are made by slicing high-purity silicon into thin wafers, the thickness of a human hair, and were first commercialised by Bell Labs in the 1950s. There are three types of c-Si used in PV cells: mono-c-Si cells, poly/multi-c-Si cells and ribbon silicon cells.

Mono-c-Si PV cells, using single-crystal wafer cells cut from cylindrical ingots, are the most efficient of the three types; however, this type of PV is also the most expensive, as the manufacturing process, which involves growing a single crystalline structure, is time-consuming. Mono-c-Si PV cells are the mainstay of the solar power industry, as they are extremely durable and have the highest commercial power conversion efficiencies.

Poly/multi-c-Si cells are made from square-cast ingots/blocks of silicon that contain multiple crystals and have a mosaic-like structure. Polycrystalline modules are much cheaper to produce due to their less stringent crystal structures; however, they are also less efficient than mono-c-Si modules.

Ribbon silicon cells are the third type of c-Si PV cells. This type is made by drawing flat thin films from molten silicon, creating a multi-crystalline structure. They are the least efficient of the three types, but manufacturing costs are significantly lower by saving on material waste.

2.2.1.2 Thin-film PV cells

Thin-film PV cells are the fastest growing sector of the PV manufacturing industry. Thin-film cells are manufactured by applying very thin layers of semiconductor material to inexpensive materials such as glass, plastic or metal. Thin-film semiconductors absorb light more easily than c-Si PV cells and require less semiconductor material, making them much more cost efficient than c-Si modules.

There are three main varieties of thin-film PV modules: cadmium–telluride thin film, amorphous silicon thin film and copper–indium–gallium–selenide (CGIS) thin film.

Cadmium—telluride thin film currently has the lowest Wp (watt peak) production cost because of the optimum balance between ease of production and cell efficiency (currently 6–11%; maximum 32.1–35.79% cell efficiency recorded to date under laboratory and simulation conditions (Kirk, 2024)).

Amorphous silicon thin film uses a well-proven, but slower, layer deposition manufacturing process, resulting in lower efficiencies (currently 6–8%: limited to 12% in the laboratory). Microcrystalline technology is used as an upgrading technology to boost the efficiency of amorphous silicon products to around 10%.

CGIS thin film has been able to reach the highest efficiencies in production: 13–14% maximum, averaging around 10%. However, there are difficulties in controlling the uniformity of the active layer on larger formats and this technology does not currently work on steel.

Presently, the vast majority of solar panels are made of c-Si, accounting for ≈95% of the total PV production in 2017. Of this, multi-crystalline technology dominates, accounting for ≈62% (compared with 70% in 2016) of total production (Philipps *et al.*, 2019). However, the manufacturing costs of thin-film PV cells are lower than those of c-Si cells, and thin film is expected to overtake c-Si as the main PV technology going forward. Current research, such as that presented in Lee and Ebong (2017), favours thin-film solar cells over their crystalline counterparts. Such research shows that thin-film cells have a number of advantages, including minimum material usage and rising efficiencies. However, all currently manufactured thin-film PV cells rely on certain critical raw materials, such as indium or tellurium, which are usually associated with supply problems due to finite global quantities, geopolitical concerns or export limitations. Despite the lower cost advantages of all the thin-film PV technologies, none of them can achieve commercially produced efficiencies over 17%. The combination of these factors restricts thin-film from achieving terawatt-scale global power production.

2.2.2 PV cells and the WEEE Directive

The WEEE Directive specifies targets, goals and procedures for PV-specific collection, recovery and recycling, requiring all producers supplying PV panels to the EU market (national, international or global) to finance the costs of collecting and recycling EOL PV panels put on the market in Europe (Weckend *et al.*, 2016).

The directive was revised (2012/19/EU) to include specifics on EOL management of PV panels. The revised WEEE Directive entered into force on 13 August 2012 and was implemented by EU Member States by 14 February 2014, thus introducing a new legal framework for PV panel waste, to be implemented individually in each of the 28 EU Member States. Currently, a focused amendment of the WEEE Directive is being proposed by the European Commission in response to a 2022 judgment from the Court of Justice of the European Union.[12]

Since the revised WEEE Directive is based on the EPR principle, producers are liable for the costs of collecting, treating and monitoring PV WEEE. From 2018, annual collection targets for WEEE (including PV WEEE) have been set to 65% (by mass) of the average of the POM total in the previous 3 years, or 85% of waste generated. The associated annual recycling/recovery targets are 85% recovered and 80% prepared for reuse and recycled. **Recovery** is defined as any operation the principal result of which is waste serving a useful purpose by replacing other materials that would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy. **Recycling** refers to any recovery operation by which waste materials are reprocessed into products, materials or substances, whether for the original or other purposes. In addition to these, producers also have to fulfil certain requirements and responsibilities regarding the financing, reporting and information responsibilities with respect to such PV WEEE.

The “high-value recycling” approach to PV recycling is the preferred option, ensuring that potentially harmful substances (e.g. lead, cadmium, selenium) are removed and properly treated, rare materials (e.g. silver, tellurium, indium) are recovered and recycled for future use, materials with high embedded energy value (e.g. silicon, glass) are also recycled, with consideration given to the quality of recovered material in this process.

The European Commission has requested that the European Committee for Electrotechnical Standardization[13] develop specific, qualitative treatment standards for different fractions of the waste stream to complement this high-value recycling approach. As part of this process, EN 50625-2-4:2017,

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[12] https://www.pv-magazine.com/2022/01/26/european-court-of-justice-solar-manufacturers-not-liable-for-waste-costs-for-panels-shipped-to-eu-before-aug-2012/ (accessed 11 January 2024).

[13] https://www.cenelec.eu/ (accessed 11 January 2024).

Collection, Logistics and Treatment Requirements For WEEE Treatment Requirements For Photovoltaic Panels,[14] and PD CLC/TS 50625-4:2017 Collection, Logistics & Treatment Requirements for WEEE Specification for the collection and logistics associated with WEEE,[15] have already been published.

In addition to these quotas and treatment requirements, the revised WEEE Directive also references measures specific to PV panels to prevent illegal shipments[16] and new obligations for trade (Directive 2012/19/EC, Art. 14[17]). One example of this is the need to provide information to the end user of the PV panels on the environmental impact of the product. Other provisions include proper collection mechanisms and the acceptance of old products free of charge if a replacement is bought.

Finally, the pan-European PV CYCLE initiative (Larsen, 2009) was set up in 2007. PV CYCLE is a voluntary association, established by leading PV manufacturers and fully financed by its member companies, that allows PV end-users to return defective panels at over 300 collection points around Europe. PV CYCLE manages the operation of the collection points, and has its own receptacles and collection, transport, recycling and reporting processes. Large quantities of panels (currently more than 40) can be picked up by PV CYCLE on request. In some countries, PV CYCLE has established co-operatives and it encourages research on panel recycling.

2.2.3 Environmental issues

The environmental and socioeconomic impacts of the different EOL waste management options for PV panels have been widely reviewed and discussed in the literature (Mueller *et al.*, 2008; Held, 2009; Wade *et al.*, 2017; Deng *et al.*, 2019).

PV systems generate clean, emission-free electricity. A typical PV system returns the energy invested in its manufacturing and installation within 0.7 to 2 years. From there, it then produces ≈95% net clean renewable energy over a 25- to 30-year service lifetime (Philipps *et al.*, 2019). For example, the typical energy payback time for concentrator PV systems in southern Europe is less than 1 year. A PV system located in Sicily with wafer-based Si modules has an energy payback time of just 1 year. Conservatively assuming a 20-year lifespan, this kind of system can produce 20 times the energy needed to produce it.

However, the PV system is not without drawbacks. The process of producing PV cells is energy intensive, and involves poisonous and environmentally toxic chemicals. Most PV manufacturing plants still do not use energy produced from PV cells, a measure that would reduce their manufacturing carbon footprint significantly.

In terms of composition and materials, two-thirds of globally manufactured PV panels are c-Si, typically composed of ≈90% non-hazardous materials, such as glass, polymer and aluminium. However, they also include some hazardous trace materials such as silver, tin and lead traces. Thin-film panels, by comparison, are over 98% non-hazardous glass, polymer and aluminium, combined with around 2% copper and zinc (potentially hazardous), semiconductors or other hazardous materials. These include indium, gallium, selenium, cadmium, tellurium and lead (Weckend *et al.*, 2016).

At present, EOL PV panels are typically processed as separate batches in existing general recycling plants. This allows for material recovery of major components such as glass, aluminium and copper for c-Si panels (with cumulative yields greater than 85% of total panel mass possible).

Such concerns and considerations for PV systems also feature prominently in the academic research. Chaudhary and Vrat (2017), for example, consider the boom in solar panel installations in India and discuss the implications for the disposal of EOL solar panels in the future, assessing the lifetime energy payback time and carbon footprint of these PV panels. Estimating a

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[14] https://www.en-standard.eu/bs-en-50625-2-4-2017-collection-logistics-treatment-requirements-for-weee-treatment-requirements-for-photovoltaic-panels/ (accessed 11 January 2024).

[15] https://www.en-standard.eu/pd-clc-ts-50625-4-2017-collection-logistics-treatment-requirements-for-weee-specification-for-the-collection-and-logistics-associated-with-weee/ (accessed 11 January 2024).

[16] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32007R1418 (accessed 11 January 2024).

[17] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012L0019&from=EN (accessed 11 January 2024).

lifetime of 25 years for these solar panels, projected EOL will occur in the late 2030s onwards. The authors highlight problems associated with the disposal of EOL solar panels and predict that these PV panels will constitute a major portion of India's WEEE at that time. Analysing best practices for PV panel recycling and management globally, the authors make specific recommendations for effective PV panel waste management in India.

Heath and Engel-Cox (2020) also consider the question of PV EOL issues and their contribution to the global WEEE/e-waste situation. In 2014, global WEEE was estimated at 41.8 million metric tonnes, with PV WEEE contributing 0.1% of this. It is projected that, by 2050, PV panel waste could exceed 10% of global WEEE, with up to 78 million tonnes of PV panel waste being created globally. Heath and Engel-Cox (2020) propose a circular economy solution to the problem, and to preparing the policies, systems and technologies to manage the recycling and disposal of EOL PV waste. In this way, environmental impact and costs can be minimised while material recovery is maximised.

2.3 Projecting Future Volumes

Volume projections for future waste arising, of all kinds, rely on statistical modelling, regression analysis and Weibull function mapping to project future trends in WEEE streams (Huisman *et al.*, 2012; Johnson and Fitzpatrick, 2016; Parajuly *et al.*, 2017).

The majority of WEEE models described in the literature utilise the Weibull function to describe the lifetime of EEE, from when it is POM through retention phases to product EOL/WEEE. Weibull models and analyses can be used to model datasets (containing values greater than zero), such as failure data or EEE life cycle data.

The Weibull function is a probability density function, as shown in Figure 2.2. It uses values of the shape parameter, β, and the scale parameter, η, to vary the appearance or distribution characteristics/shape of the curve, the reliability and the failure rate of the Weibull function.

The Weibull distribution has the probability density function described by equation 2.1 for $x \geq 0$:

$$f(x) = (\beta/\alpha) \cdot (x/\alpha)^\wedge(\beta - 1) \cdot \exp\,[(-x/\alpha)^\wedge\beta] \qquad (2.1)$$

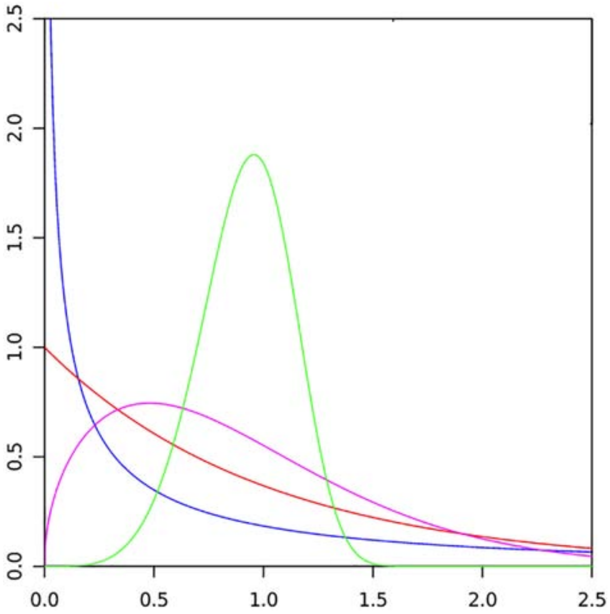

Figure 2.2. Weibull probability distribution functions.

In equation 2.1, $\beta > 0$ is the shape parameter and $\alpha > 0$ is the scale parameter. The corresponding cumulative distribution function is given by:

$$F(x) = 1 - \exp[-(x/\alpha)^\wedge\beta] \qquad (2.2)$$

Here, $1/\alpha$ can be viewed as the failure rate. If "*x*" represents "time to failure", then the Weibull distribution is characterised by the fact that the failure rate is proportional to a power of time, namely $\beta - 1$. Thus, β can be interpreted as follows:

- A value of $\beta < 1$ indicates that the failure rate decreases over time. This happens if there is significant "infant mortality" or if defective items fail early and the failure rate decreases over time as the defective items are weeded out of the population.
- A value of $\beta = 1$ indicates that the failure rate is constant over time. This might suggest that random external events are causing mortality or failure.
- A value of $\beta > 1$ indicates that the failure rate increases with time. This happens if there is an "ageing" process, for example if parts are more likely to wear out and/or fail as time goes on.

The Weibull function is used to model the WEEE lifetime for various product waste streams, as well as making predictions about a product's lifespan, comparing the reliability of competing product designs, statistically establishing warranty policies and proactively managing spare parts inventories. In academia, the Weibull analysis has been used to model diverse phenomena, such as tree diameters, drug release mechanisms and earthquakes (Cao, 2004; Papadopoulou *et al.*, 2006; Wang, 2016).

2.3.1 Volume projections for EVBs

The global EVB market (for battery and partial hybrid EVs) saw global sales figures reach 2.1 million in 2019, boosting global stock to 7.2 million electric cars.[18] Increased production of EVs is one of the primary factors underlying the growth of this market. The drive to reduce dependence on non-renewable energy sources has led to an increased demand for EVs and EVBs.

The Asia-Pacific market is anticipated to be the largest segment in the EVB market, owing to increasingly stringent government regulations to reduce carbon and GHG emissions. The market passed 5 million units in 2018, an increase of 63% from the previous year. Around 45% of electric cars on the road in 2018 were in China – a total of 2.3 million.[19] This was an increase from 39% in 2017. By comparison, Europe accounted for 24% of the global fleet (3.1 million batteries in 2018) and the USA produced 22% of the global EVBs manufactured.[20] Richa *et al.* (2014) predict that between 0.33 and 4 million metric tonnes of LIBs will be produced in the USA in the next 20 years, and, of this, only 42% of these expected materials (by weight) are currently recyclable in the USA.

Globally, the total EV stock is expected to rise to 548 million by 2040, equating to approximately 32% of the world's passenger vehicles. Projections are for more than half of new-car sales and one-third of the global fleet (≈559 million vehicles) to be EVs.

2.3.2 Financing EOL proposals for EVBs

EVBs typically have to be replaced every 7–10 years in the case smaller vehicles and every 3–4 years in the case of larger ones, such as buses and vans. The global stockpile of such batteries is expected to exceed 3.4 million by 2025, compared with about 55,000 last year.[6]

Batteries can be recycled through smelting, direct recovery and other, newer, processes. Smelting processes are used to recover metals and minerals (e.g. lithium, cobalt, nickel) but the process is not financially sustainable at present; for example, the cost of recycling a LIB is ≈€1 per kilogramme, but the value of the lithium reclaimed during such a process is only ≈€0.33, or one-third of the recycling cost. Using current processes and technology, it is still five times more expensive to extract lithium from recycled EVBs than it is to mine the lithium ore (Pinegar and Smith, 2019).

As previously mentioned (see section 2.1.3), battery reuse/second use is a promising value creation mechanism for EVBs that have reached EOL and potentially provides additional revenue to EVB manufacturers (Reinhardt *et al.*, 2019). Patten *et al.* (2011) discuss the repurposing of EV batteries as a means to store wind energy to increase wind energy capacity factor. The authors describe a 200-MW wind farm that can charge a battery farm consisting of rejected and post-consumer EVBs. Ahmadi *et al.* (2017) describe another reuse potential for LIB packs recovered from EOL EVs. The authors argue that such second-life/reuse batteries present potential technological, economic and environmental opportunities for improving energy systems and material efficiency. The authors describe an application whereby these battery packs are reused in stationary applications as part of a "smart grid", providing energy storage systems for load levelling or residential or commercial power.

2.3.3 Volume projections for PV waste

PVs and PV systems are fast-growing markets – the compound annual growth rate of PV installations was 36.8% between year 2010 and 2018 (Philipps *et al.*, 2019). Worldwide, around 400 GW of PV was installed in 2017 and this is expected to reach 4500 GW by 2050.

In 2017, China and Taiwan accounted for 70% of worldwide PV module production, with the rest of

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[18] https://www.iea.org/reports/global-ev-outlook-2020 (accessed 11 January 2024).

[19] https://about.bnef.com/electric-vehicle-outlook/#toc-viewreport (accessed 11 January 2024).

[20] https://www.iea.org/reports/global-ev-outlook-2019 (accessed 11 January 2024).

Asia-Pacific and Central Asia producing 14.8% of the global supply. Europe contributed 3.1% (compared with 4% in 2016), while USA/Canada produced 3.7%. In terms of PV installations, in 2018, 25% of the global total cumulative PV installations were located in Europe and 36% were located in China. In 2017, installations in Europe stood at 26%, with China accounting for 32% of all installations that year.

Global installed PV capacity reached 222 GW at the end of 2015 and is projected to reach 4500 GW by 2050 (Weckend *et al.*, 2016), as shown in Figure 2.3. In 2050, high cumulative deployment rates are predicted for China (1731 GW), India (600 GW), the USA (600 GW), Japan (350 GW) and Germany (110 GW).

According to the same report (Weckend *et al.*, 2016), in 2016, cumulative global PV waste streams reached 0.1–0.6% of the cumulative mass of all installed panels (4 million metric tonnes). By 2030, this figure will have increased to the equivalent of 4% of installed PV panels at that time, with waste amounts by the 2050s (5.5–6 million tonnes) almost matching the mass contained in new installations (6.7 million tonnes). Recycling or repurposing these PV panels at EOL in a circular economy fashion by 2050, the estimated value of the material recovered from PV panels could exceed US$15 billion.

PV systems comprise more than just the PV cells – other major components in any PV system include the inverter, battery, transformer, balance of system (BOS), the control electronics, fixtures and mounting fixtures. For example, Domínguez and Geyer (2017) report that, in Mexico, physical PV modules account for only 55% of the material contained in PV systems, the remainder being made up by the inverters, batteries and BOS. They also estimated that close to 1 million metric tonnes of different metals will be contained in this PV waste stream over the next 30 years, broken down into 42% iron, 26% aluminium, 26% silicon and 5% copper. The same authors carried out a similar comparison for the USA and projected that 9.8 million metric tonnes of PV waste will be generated between 2030 and 2060, of which physical PV modules will make up only 67% (6.6 metric tonnes), with the remainder being 2.7 metric tonnes of BOS, 0.3 metric tonnes of inverters and 0.2 metric tonnes of transformers.

2.3.4 *Financing end-of-life proposals for PVs*

Preliminary research (Weckend *et al.*, 2016) suggests that the raw materials technically recoverable from PV systems could cumulatively yield up to US$450 million by 2030, equivalent to the raw materials currently needed to produce approximately 60 million new

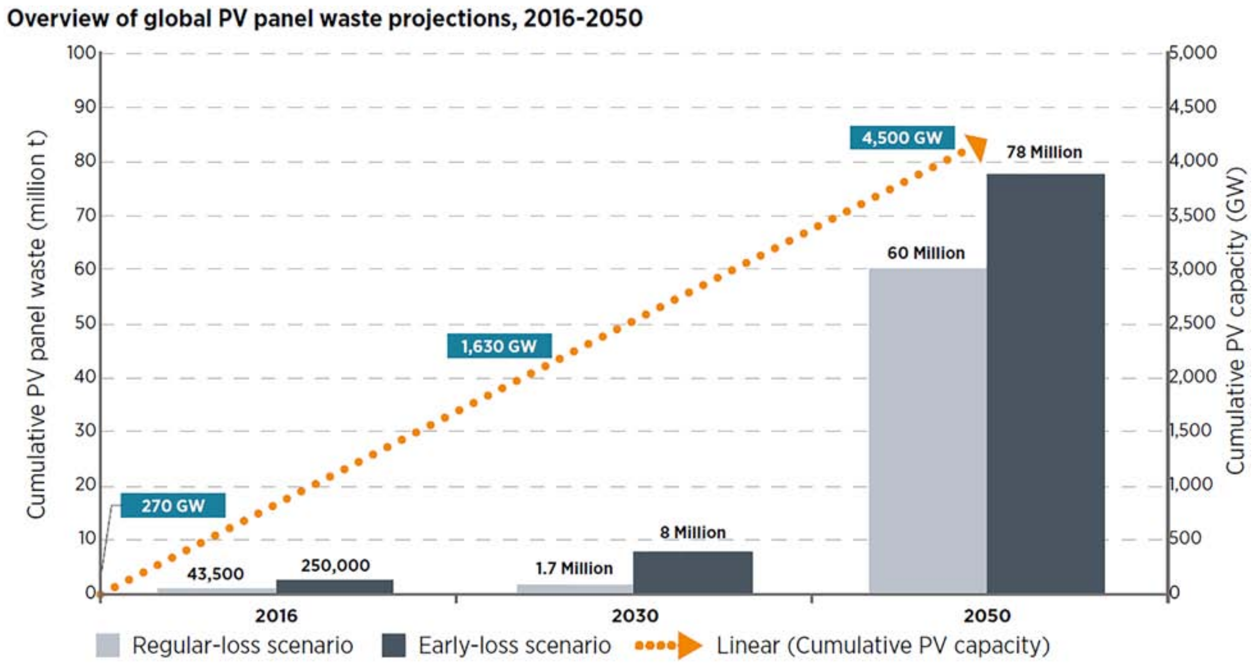

Figure 2.3. PV panel global projects. Reproduced with permission from Weckend *et al.* (2016).

panels, or 18 GW of power generation capacity. By 2050, the recoverable value could cumulatively exceed US$15 billion, equivalent to 2 billion panels or equating to 630 GW of power generation capacity.

Two financing approaches for PV systems can be distinguished from the WEEE Directive – individual pre-funding or collective joint-and-several liability schemes or contractual arrangements between producer and customer (dependent on the nature of the transactions, i.e. whether they are business to consumer (B2C) or business to business (B2B)).

Pre-funding approaches have been found to be practicable only for WEEE sold in very low quantities (e.g. specialised appliances such as custom-made fridges). Pre-funding schemes for collecting and recycling high-volume WEEE, such as projected PV returns, have not proven to be very cost-effective (Weckend *et al.*, 2016).

There are several options when it comes to collective joint-and-several liability schemes or contractual arrangements. The pay-as-you-go approach sees collection and recycling costs covered by market participants when WEEE occurs. A pay-as-you-put approach involves setting aside an upfront payment for estimated collection and recycling costs when the product is POM. Last-man-standing insurance is an insurance product that covers a producer compliance scheme based on a pay-as-you-go approach if all producers were to disappear from the market. In such a situation, the insurance would cover the costs of collection and recycling. Under a joint-and-several liability scheme, producers of a product/product group agree to jointly accept the liabilities for waste collection and recycling for that specific product or product group.

For mainstream WEEE such as PV panels, producer pay-as-you-go approaches combined with last-man-standing insurance and joint-and-several liability producer schemes are more commonplace, although the revised WEEE Directive still supports the prefunding scheme option.

3 EVB Modelling

This chapter of the report presents the modelling and projections for the levels of EVBs that will be reaching their EOL phase in the timeframe 2021–2050. Section 3.1 describes the approach used to develop the EVB model used in this respect. Section 3.2 discusses the data sources used to gather data for this modelling task, as well as reviewing some of the considerations and choices made in populating the dataset for the model. Finally, section 3.3 presents the model predictions for the EOL EVB levels in both tabular and graphical formats for the period 2021–2050.

3.1 Modelling Methodology/Approach

Figure 3.1 depicts the modelling approach adopted to project the number of EOL EVBs arising in Ireland for the timeframe 2021–2050. The methodology is divided into two main sections. In the first section, the level of EV adoption in Ireland is projected. The second section, based on this projection, estimates the volume of EOL EVs over the same timeframe – allowing us to project the potential scale of the recycling/second-hand market for EVBs in Ireland. In Figure 3.1, the “primary market” section represents the model for the Irish EV adoption rates and the ensuing “second-hand market” section shows the volume of EOL EVBs.

In the first part, the annual sale of EVs is predicted in two steps: (1) developing a customer choice model for vehicle market diffusion and (2) predicting the vehicle demand in the Irish automobile market (car stock model). The market diffusion model is fed through the life cycle cost of vehicle technologies and considers

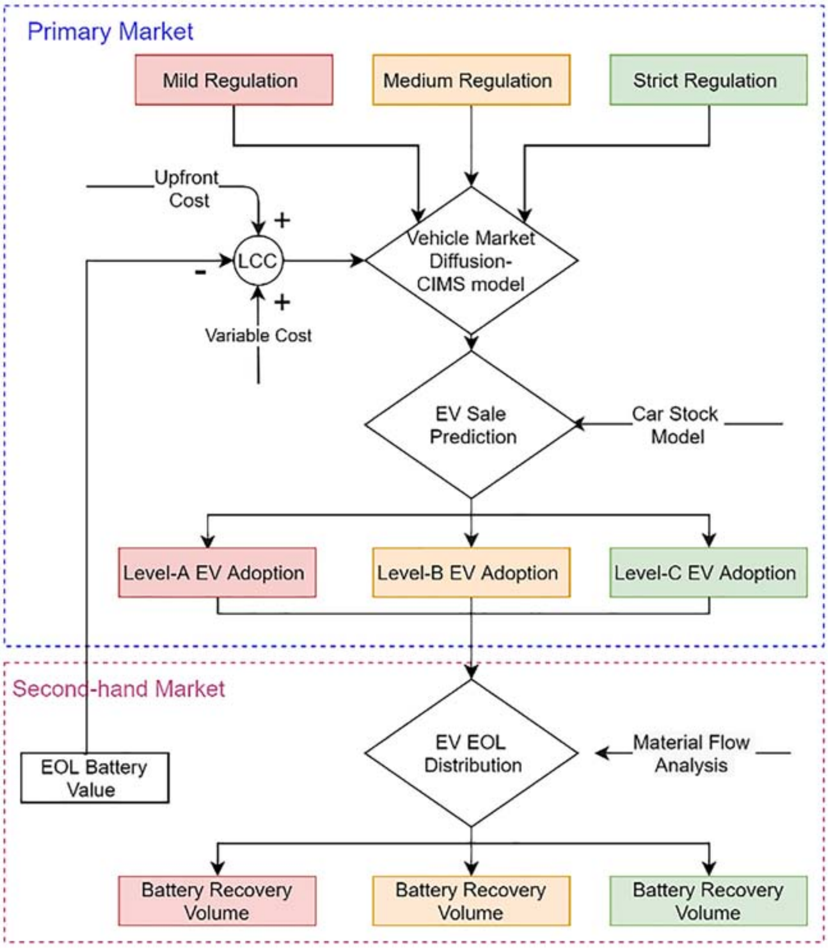

Figure 3.1. Methodology flow chart. LCC, life cycle cost.

three scenarios in compliance with different degrees of changes in regulations and policies regarding carbon dioxide emission reduction.

For the “primary market” model, the annual sale of EVs is predicted using a two-stage process. First, a customer choice model is developed for vehicle market diffusion, represented as the “vehicle market diffusion – CIMS model” in the figure. The CIMS energy–economy model (Rivers and Jaccard, 2005) has been selected for modelling vehicle technology share in this work. CIMS is a “technology vintage model” that has been developed for tracing the evolution of a certain technology through sequential decisions by providers and consumers over time. In the second stage of the “primary market” model, the output of the first stage is used to predict the vehicle demand in the Irish automobile market (car stock model) – the “EV sale prediction”. This market diffusion model is fed through the life cycle cost of vehicle technologies to consider different potential scenarios, representing different degrees of changes in regulations and policies regarding carbon dioxide emission reduction in Ireland. The EV sales estimates for these scenarios are then computed using the market share and the estimated total vehicle demand arising from these scenarios.

For the “second-hand market” model, the number of EOL EVs is estimated by first finding the survival rate of EVs, and, second, by calculating the available and reusable capacity of the removed battery units from these EOL vehicles.

Multiple financial and non-financial components are included in the model, resulting in a number of tangible and intangible inputs for the system. The future trend of tangible inputs is discovered to be driven mainly by environmental fuel standards, fuel economy, battery technology development and mass of economy for every technology. A scenario-based projection approach is carried out for tax-related inputs – considering factors such as motor tax, Vehicle Registration Tax exemptions, grants and/or the presence of a future ban on ICE vehicles. The projection for intangible cost, however, depends on the European growth of the automotive market for every technology followed by their distribution in the Irish automobile market, which is also influenced by government policies. This has been encapsulated into a low, medium or high supply of EV types to the market. These different scenarios are therefore defined based on tax-related inputs (low, medium and high) and potential market availability (low, medium and high availability).

3.2 Data Collection for EVBs

To model the use-phase for vehicles in Ireland, the EOL data for the Irish passenger fleet were acquired from the Driver and Vehicle Computer Services Division of the Department of Transport.[21] The statistical distribution of vehicle survival age is modelled using a Weibull function, with the parameters obtained by fitting the model to the historical data. However, the fleet EOL dataset in Ireland mainly comprises the EOL data for traditional (ICE) vehicles, as shown in Figure 3.2. According to this dataset, the maximum lifespan of traditional vehicles is 17 years. Research such as that by Ai *et al.* (2019) has shown that the expected lifespan for comparable EVs is in the range of 10–12 years.

To address the shortage of EV car sales on the Irish market, the EOL distribution pattern for the sale of EVs in a larger/more established market may be used to predict the behaviour of EVs in the Irish setting. The most suitable candidate available was the EOL dataset for EVs in the United Kingdom (Department for Transport, n.d.), as shown in Figure 3.3. This dataset was deemed to be the most appropriate given the similarities between the two countries – similar vehicle models, environmental conditions and EOL vehicle legislation. The distribution of EOL vehicles for every registration year since 1996 was extracted from this dataset and the Weibull distribution parameters were determined for these distributions. These distribution curves are illustrated in Figures 3.2 and 3.3 for Irish and UK data, respectively. The average values of these parameters have been considered for the EVB EOL distribution in this case.

There are certain discrepancies in the dataset that also need to be accounted for in the model. For example, 2005 was determined as the starting point for modelling EVB distribution; however, EOL data in the UK dataset are valid for vehicles sold as far back as 1996. As a result of technological developments in

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[21] https://www.gov.ie/en/policy-information/1ba443-motor-taxvehicle-registration/ (accessed 11 January 2024).

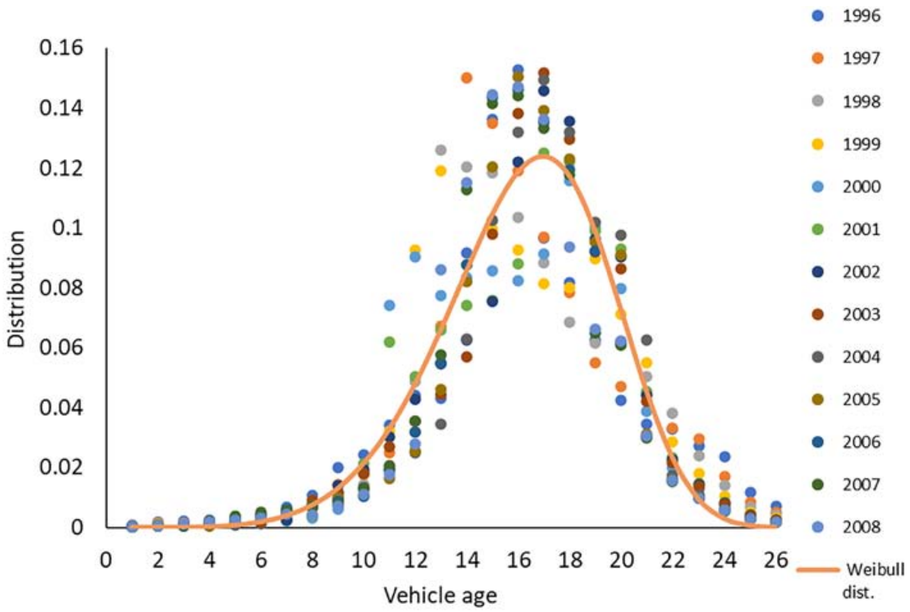

Figure 3.2. Historical dataset for vehicles in Ireland.

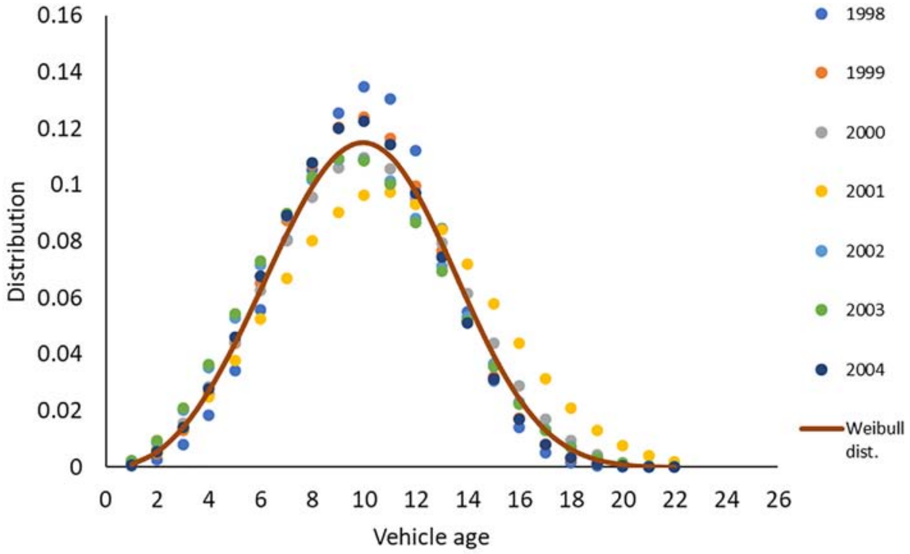

Figure 3.3. Historical dataset for vehicles in the UK.

EVB manufacturing, the performance and capacity of EVBs have improved/increased in recent years; for example, the average capacity of the batteries in EV passenger fleets in Ireland has increased from 16 kWh in 2014 to 65 kWh in 2020. This increase in battery capacity suggests that newer EVs will have a longer life distribution/curve than older EV models.

The EVB prediction/curve for each year is therefore a weighted average of all the Weibull distributions for vehicles registered from the record start to that year. This means that vehicles for every registered year will have a distribution for reaching EOL, as shown in Figure 3.4. The general curve for EVBs is constructed by averaging these individual curves, as described in the next section.

To include factors such as the technical advancement of EVs and the relatively young age of EVs in the EOL distribution model, a series of evolved distribution curves have been used. For these curves, the α parameter has been varied to represent the peak life of an EV and the shape parameter β varied to include the increasing upper lifespan limit for these EVs. It has been assumed that the EOL peak distribution for EVs increases towards the end of the 17-year lifespan

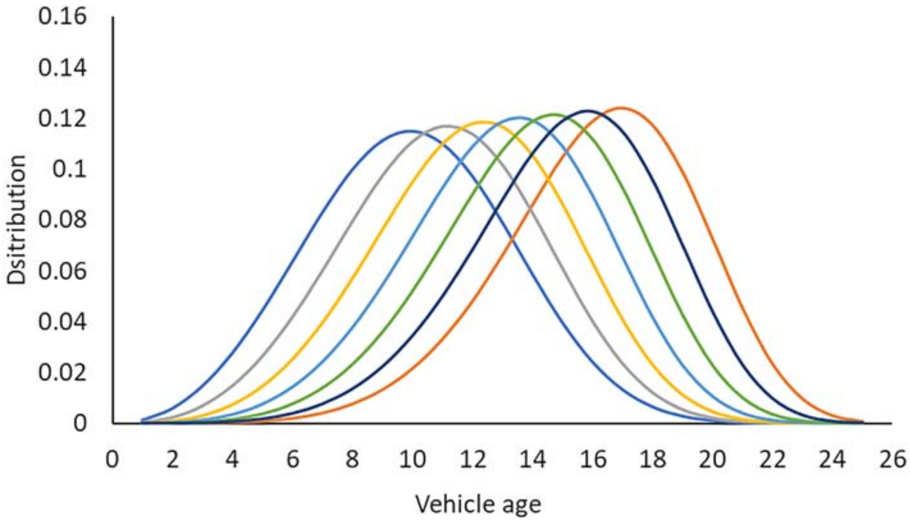

Figure 3.4. Predicted evolution of EV survival rate.

of conventional vehicles. The evolution of these EOL distribution curves is shown in Figure 3.5.

3.3 EVB Model, 2020 to > 2050

Results for modelling the EVB distribution curve for the Irish market are obtained by fitting the model to the historical dataset by minimising the mean absolute error. Projection results for the vehicle market shares using the model with optimised parameters are shown in Figure 3.5. For modelling the EVB market share and subsequent EOL EVBs arising to 2050, a matrix of nine different scenarios was constructed. This matrix considered three different levels (low, medium and high) across two parameters of importance for the EVB market: “AFV (alternative fuel vehicle) model availability” and “changes in regulations”. “AFV model availability” is a measure of the availability of EVs on the market to meet the projected demand. “Changes in regulations” refers to market incentives to enable motorists to purchase/afford EVs and how far into the projected future such subsidies and incentives will last. Further information, tabular data and graphs on these scenarios are available in Appendix 1 of this report or from Fallah *et al.* (2021).

From these scenarios, it can be seen that the vehicle market is dominated by ICE vehicles until 2025, at which point they are overtaken by hybrid vehicles, which then account for the major market share for the next 5 years. Hybrid EVs gradually decline from the vehicle market after 2030. The plug-in hybrid EV share does not grow considerably when there is a hybrid EV alternative in the market. The BEV share is projected to dominate the vehicle market by 2040, with EV uptake until 2030 mainly driven by the degree of regulations rather than by market availability.

The number of EVBs that will be retired/present in the waste stream up until the year 2050 was determined from a materials flow analysis of the distribution of these EOL EVBs. Data for the nine different scenarios are presented in Figure 3.6. Again, more detailed information is available in Appendix 1 of this report.

As can be seen, projections for numbers of EOL EVBs show that, by 2050, between 14,000 and 81,000 EVBs per annum (depending on the scenario considered) could reach the end of their use-phase in the automobile industry. It should be noted that these figures assume a 100% collection rate for EOL EVBs. Furthermore, the model does not consider outflows from the system, such as leakage, vehicle export, second use or battery repurposing by the user before it becomes waste. It is, therefore, very much an upper-bound estimate given medium regulation support for the introduction of EVs and an adequate supply/availability of such EVs to meet the demands of the market.

Chapter 5 of this report discusses some of the financial implications of these projections in terms of predicted recycling costs, etc. Chapter 6 will present the study findings and recommendations in the light of these figures and interviews/discussions with stakeholders in the EV automotive and recycling sectors.

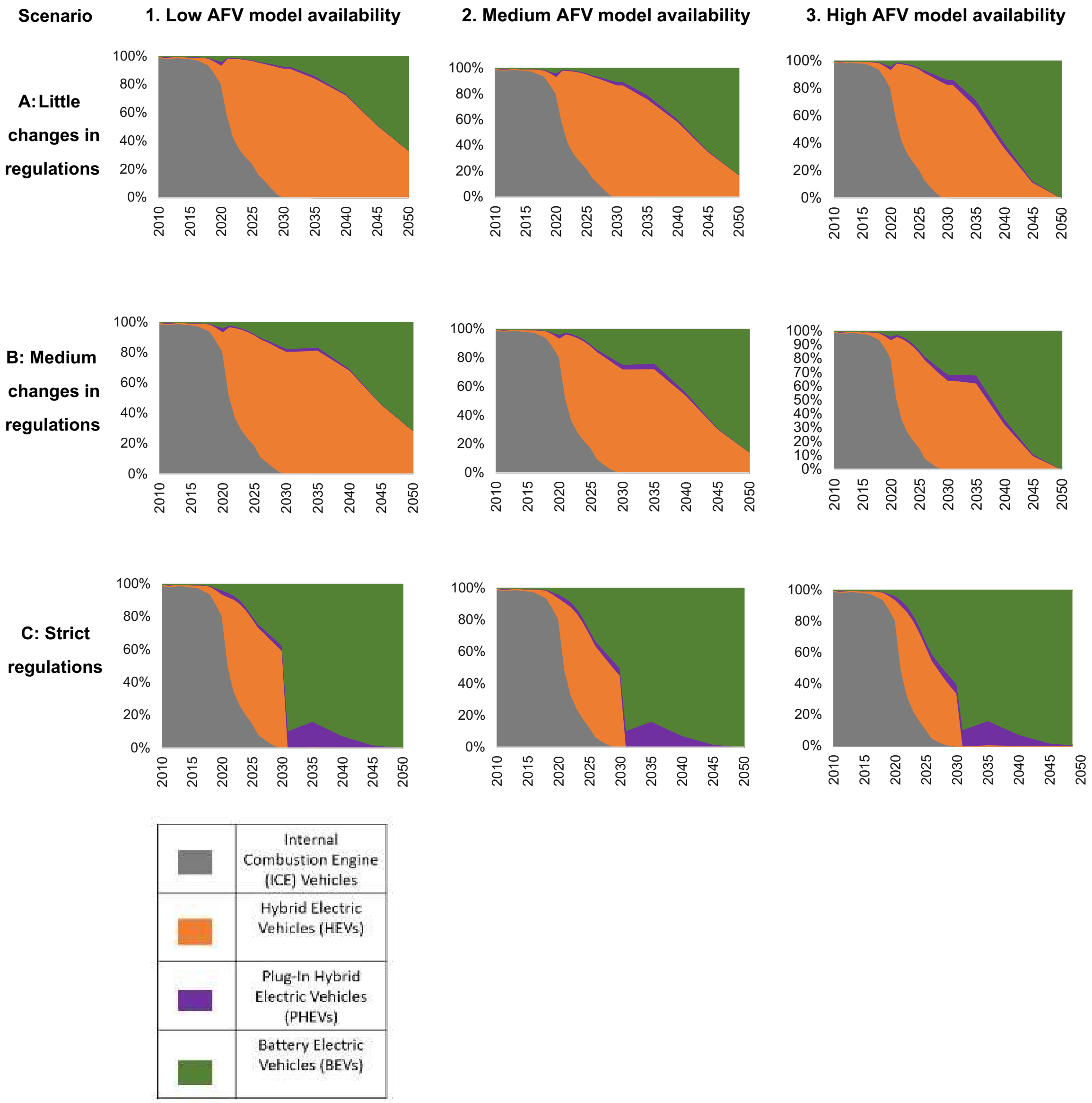

Figure 3.5. EVB forecasting scenarios for various models of regulation supports and vehicle availability.

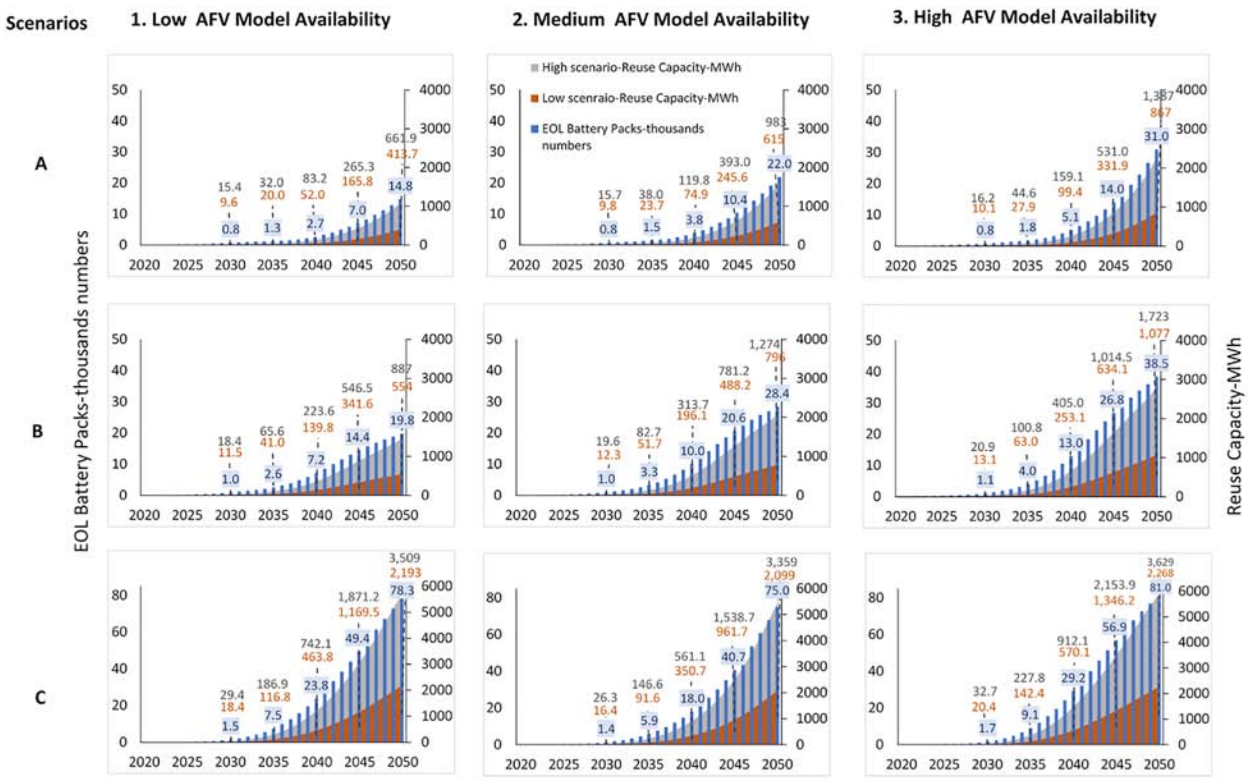

Figure 3.6. EVB EOL projections, 2021–2050.

4 PV Modelling

EEE products have different use-phase/life cycles, and this must be taken into account when planning the associated EOL/waste operations for those products when they become WEEE. Products with long life cycles currently include solar PV panels, which typically have use-phases of 20–25 years.[22] As a whole new product category, coupled with significantly longer lifetimes than other EEE products, this creates a need to plan for waste management at the end of their life cycles.

In this chapter, the specific example of solar PV as a long-life WEEE product is considered. As a result of a combination of policies and price reductions, producers are now starting to place solar PV products on the Irish market in significant quantities, but the manner in which recycling will be funded and arranged in the future is, as yet, unconsidered. Ensuring that the WEEE collection system is capable of handling the mandatory collection and recycling obligations for these products presents a series of new and distinct challenges to producers, EPR schemes and policymakers.

This chapter first looks at the data collected by the LongWEEE project to forecast PV stock for the period of interest, 2020–2050. Data sources used and the types of data collected are discussed here. In section 4.2, the methodology adopted and approach used for future modelling of the solar PV EEE is described and illustrated. The model results are then presented in the section 4.3, which projects solar PV WEEE until 2050.

4.1 Data Collection for PV

For the purposes of forecasting/modelling solar PV, we have used sources that roadmap the power generation to come from PV from 2021 to 2030. The first is the *Shaping Our Electricity Future* report, by the Irish Transmission System Operator (TSO) Eirgrid (2021). This report was the result of an extensive public consultation on how best to achieve the renewable ambitions for Ireland and considers PV projections for domestic ("microgeneration") and commercial/solar farm ("utility") settings. The second source is *Ireland's Solar Future*, a report by the Irish Solar Energy Association (ISEA) (ISEA, 2021). Here, "utility" is again used to refer to commercial/solar farm PV figures, with domestic PV figures presented as "behind the meter" data. This report has modelled three scenarios for the growth of solar energy in Ireland based on different levels of ambition for the sector. In order of increasing volume projections, the three scenarios are "business as usual" (BAU), "moderate ambition" and "high ambition". A summary of the key projections for power generation to come from PV in 2030 from the various sources is shown in Table 4.1. It is worth noting that the projections of the industry association are significantly higher than those of the TSO.

For each of these scenarios, a linear level of installation between 2021 and 2030 was assumed, with a conversion factor of 4000 panels per MW (ISEA, 2021) and a mass of 17 kg per panel (from discussions with industry experts and Mahmoudi *et al.*, 2019) to find the total mass of PV panels being POM annually (PV POM data).

Table 4.1. A summary of the key projections for PV power generation in Ireland, 2021–2030

***Shaping Our Electricity Future* (Eirgrid, 2021)**		***Ireland's Solar Future* (ISEA, 2021)**					
		BAU		**Moderate ambition**		**High ambition**	
Microgeneration	**Utility**	**Behind the meter**	**Utility**	**Behind the meter**	**Utility**	**Behind the meter**	**Utility**
500 MW	1000 MW	245 MW	2495 MW	510 MW	3450 MW	1023 MW	5055 MW

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[22] https://www.seai.ie/publications/SEAI-Solar-PV-Guide-For-Business.pdf (accessed 11 January 2024).

4.2 Modelling Methodology/Approach

The methodologies used to model/project the future volumes of solar PV WEEE in Ireland are presented in this section of the report. This model for predicting these solar PV WEEE figures for Ireland is shown in Figure 4.1.

The model was applied to all sets of solar PV data described in the preceding section. It is derived from the standard WEEE life cycle model. It should be noted that the analysis of flows of solar PV WEEE in Ireland is simplified by a number of factors. First, in the case of the solar PV output flow, there is negligible export of second-hand/used solar PV panels from the country for remanufacture or reuse. Second, at present, there is no reuse market within Ireland for second-hand solar PV panels. Both of these factors simplify the flows analysis for the modelling, but future work will be required to correct for this if these practices emerge. Likewise, incorrect disposal through scrap collections will need to be carefully monitored.

Once the solar PV POM figures for both residential and commercial installations in Ireland had been established, the next step was the projection of future volumes of solar PV panels using a lifespan distribution model. For this, a Weibull model was used to model the expected lifetime of the products. The Weibull parameters determined from the "IE WEEE Calc Tool" available from the European Commission (European Commission, n.d.) were a scale (lifetime index) of 25 years and a shape parameter of 3.5. Again, future work would need to monitor the accuracy of this curve to allow for Irish-specific conditions and technological change.

WEEE projections for B2C and B2B solar PV numbers were calculated separately, using the POM data described in the preceding section. For B2C projections, POM projections up to 2030 are used in conjunction with individual Weibull return rates to generate projected WEEE across each year for the period 2021–2050. By summing these cumulative projections across the relevant years, a total projection of solar PV WEEE for each year (2030–2050) was obtained, as shown in section 4.3.

A similar operation was carried out for the B2B solar PV WEEE projections. Taking the Renewable Electricity Support Scheme[23]/Sustainable Energy Authority of Ireland[22] data and converting them to individual solar PV panel(s) from MWp predictions, these POM figures from 2020 to 2030 were used as the input(s) for the Weibull modelling operation. Using these figures, WEEE amounts were calculated across the timeframe 2030–2050 and predicted levels of solar PV WEEE were determined, which is also presented in section 4.3.

By combining these predictions for both residential (B2C) and commercial (B2B) solar PV figures, an overall model for the level(s) of solar PV in Ireland

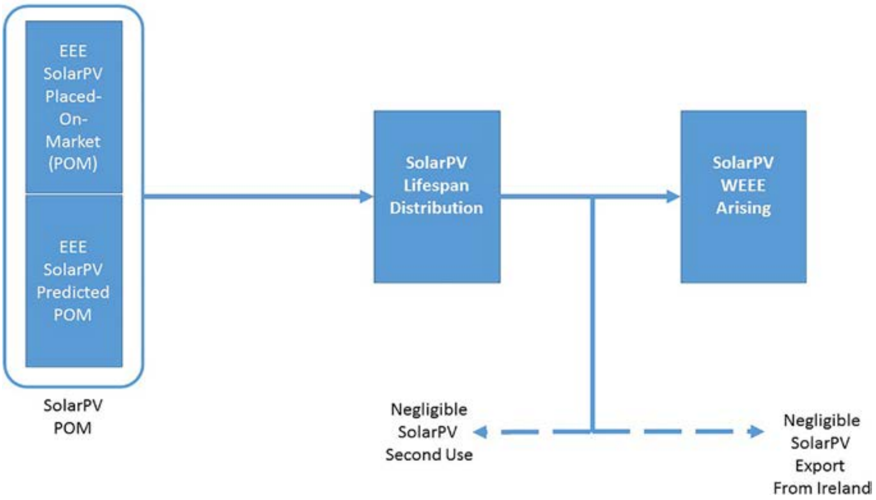

Figure 4.1. Modelling the solar PV life cycle for Ireland.

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[23] https://www.gov.ie/en/publication/36d8d2-renewable-electricity-support-scheme/ (accessed 15 January 2024).

going forward is obtained. These model findings are presented next.

4.3 PV Model, 2020 to >2050

In this section, we present projections of solar PV WEEE arising up to mid-century for the four scenarios considered. Under all scenarios, the amount of waste being generated remains negligible until 2030, at which time it begins to grow at different rates under different scenarios. The extent to which waste will be generated will obviously depend on the extent to which PV is employed in power generation. Highlighting this, the figure for 2050 PV WEEE forecast ranges from just below 5,000,000 to over 20,000,000 kg. It should be noted that these projections do not consider complementary flows through scrapyards or export for reuse.

The predicted levels of WEEE arising for solar PV panels have been presented as residential (B2C), commercial (B2B) and total (i.e. the sum of both residential and commercial) WEEE. Figure 4.2 shows the solar PV WEEE predictions for the commercial (B2B) Irish market until the year 2050, while Figure 4.3 shows the comparable solar PV WEEE predictions for the residential (B2C) sector in Ireland for the years up to 2050. Figure 4.4 presents the total solar PV WEEE predictions for the Irish market for the same timeframe, achieved by combining the B2C and B2B predictions

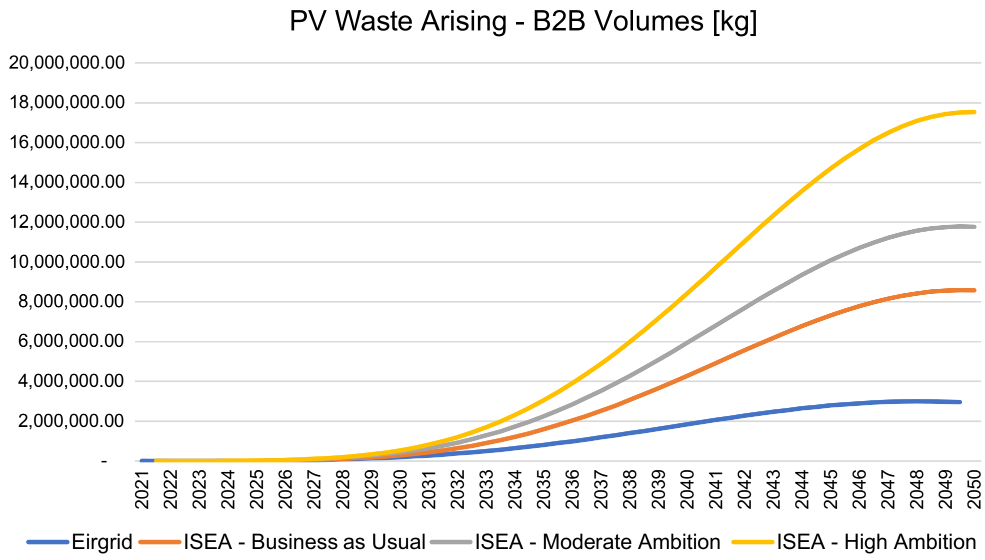

Figure 4.2. Commercial solar PV WEEE predictions, up to 2050.

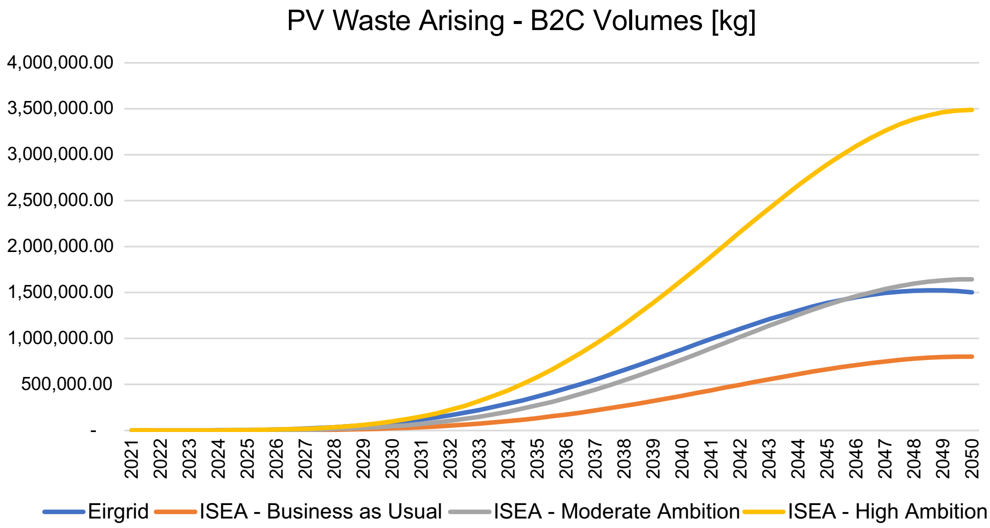

Figure 4.3. Residential solar PV WEEE predictions, up to 2050.

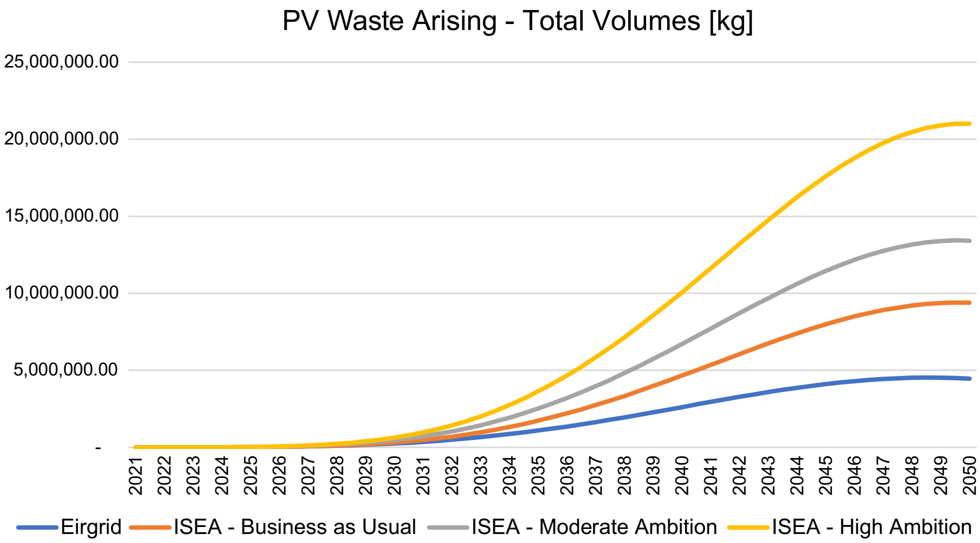

Figure 4.4. Total solar PV WEEE predictions, up to 2050.

for each year. As can be seen from the diagrams, projections range from approximately 5,000,000 to 20,000,000 kg of solar PV WEEE being generated by the year 2050, depending on the POM data used. Further information on the data used in these projections can be found in Appendix 2 of this report.

5 Financing

It is imperative that those involved in developing and implementing an EPR system ensure that the WEEE collection system is adequately financed if it is to achieve its mandatory collection and recycling obligations. This is especially important in the case of long-life products such as EVBs and solar PV panels, given the quantities of these products that will be returning to the recycling stream in the future.

A number of approaches are available when placing such products on the market, but their suitability to fund recycling for products returning as EOL/ WEEE 10–25 years into the future has not yet been considered. It is essential to consider the financial flows associated with these options to ensure that the recycling system is adequately financed but at the same time does not add unnecessary costs to the relevant sectors.

This chapter presents some of these financial considerations and costings associated with the recycling of EVB and solar PV WEEE in the future. In the next section, two distinct options for financing the collection and recycling of such long-life products are discussed: "pay when placed" and "pay when collected". Subsequently, the EVB and solar PV situation(s) are considered in isolation, and the financial costs of recycling the projected quantities of EOL EVBs/WEEE in each stream are estimated.

5.1 EVB Financial Considerations

Based on the EVB EOL modelling and projections presented in Chapter 3, a series of scenarios for EOL EVB predictions for the period 2021–2050 can be determined. These scenarios are based on the impact of government regulations on the sales of EVs in conjunction with the market availability of such EVs. A 3 × 3 matrix of scenarios featuring low, medium and high regulation impacts against low, medium and high market results in nine different scenarios.

Based on the figures predicted from this matrix, a financial costing/analysis of EVB recycling costs was carried out. For this analysis, a nominal scenario representing medium government regulations and medium market availability of EVs in Ireland was used. For the analysis, costings for scenario 5, featuring medium availability and medium support, were used. Costings for this scenario took into account the costs of collecting, packaging and exporting EVBs for recycling (as EVBs currently cannot be processed/ recycled on the island), as well as a management fee. Three distinct cases were considered for EVBs, namely EOL batteries, defective (non-critical) batteries and defective (critical) batteries. EOL batteries are batteries that have naturally reached the end of their use-phase/life cycle and have been replaced in the EV. Defective batteries are batteries that have had to be replaced before they have reached EOL, e.g. batteries from vehicles that have been involved in an accident. Defective batteries can generally be classified as defective/critical or defective/non-critical, e.g. accidents involving EVs, and batteries are classified as NF-S (no fire – safe), NF-D (no fire – damaged), F-ND (fire – no damage) or F-D (fire – damaged), as per Wöhrl *et al.* (2021). Under this system, NF-S and F-ND would be considered defective/non-critical batteries, whereas NF-D and F-D batteries would be considered defective/critical. The cost of processing and handing defective batteries will be much higher than the cost of processing EOL batteries, as more procedures, safety restrictions and specialised equipment, etc., will be required to process these batteries when they enter the waste stream.

For the considered cases, a BEV weight of 700 kg was used. Table 5.1 shows estimates of the handling/ processing costs associated for these batteries when they reach EOL for the three different cases considered: (normal) EOL, defective/non-critical and defective/critical. Note that this figure assumes no pre-processing or treatment of the battery prior to shipping. If an operating battery-dismantling programme were put in place in Ireland, then pre-processing to remove

Table 5.1. Considered handling/processing costs for EVBs

Battery handling case	EOL	Defective/ non-critical	Defective/ critical
Total cost (€) per battery	3017	5776	5776
Total cost (€) per kg	4	8	8

casing, cables, etc., before shipping would reduce battery weight(s) and associated costs before the batter is sent abroad for final treatment and recycling.

At present, the processing costs for defective/critical and defective/non-critical batteries are identical, primarily due to the lack of battery-dismantling programmes/disassembly facilities for EVBs in Ireland. Data on the breakdown of batteries in each category, e.g. the number of EVs involved in road traffic accidents in Ireland and the associated fire damage to batteries, were not readily available for the purposes of this financial costing.

To address this, two scenarios are considered in lieu of this. In scenario 1, it is assumed that 80% of all EOL EVBs arising are normal (undamaged) EOL batteries, while the remaining 20% are defective (critical and non-critical) batteries. In scenario 2, the breakdown is assumed to be 90% EOL batteries and 10% defective batteries. Nine scenarios for EVB market penetration and associated EOL figures have been presented in Chapter 3. For the purposes of this financial costing, the medium AFV model availability/medium changes in regulations (scenario 5) case was used for projecting the quantities and associated costing figures presented here. A similar exercise can be repeated for any of the other forecasting scenarios to realise a financial costing for that use case.

Applying the processing costs described in Table 5.1 to these two scenarios, the projected costs for scenario 1 (80% EOL batteries, 20% defective batteries) are as shown in Table 5.2. However, it should be noted that efficiencies of scale or changes in practices are not factored into this analysis.

Table 5.3 shows the equivalent projected costs for EVB recycling under scenario 2 (90% EOL batteries, 10% defective batteries).

Figure 5.1 shows these financial projections for scenarios 1 and 2 in graphical form.

Table 5.2. EVB processing costs for scenario 1

Year	EOL cost (€)	Defective cost (€)	Total cost (€)
2021	127	61	188
2022	1620	775	2395
2023	7578	3627	11,204
2024	23,454	11,225	34,678
2025	57,874	27,698	85,572
2026	123,716	59,209	182,926
2027	239,350	114,551	353,901
2028	429,782	205,689	635,472
2029	727,245	348,052	1,075,298
2030	1,170,840	560,352	1,731,192
2031	1,805,160	863,932	2,669,092
2032	2,678,414	1,281,862	3,960,277
2033	3,841,037	1,838,282	5,679,319
2034	5,345,503	2,558,304	7,903,807
2035	7,246,964	3,468,325	10,715,288
2036	9,602,561	4,595,690	14,198,250
2037	12,466,001	5,966,104	18,432,105
2038	15,875,508	7,597,860	23,473,368
2039	19,838,208	9,494,368	29,332,576
2040	24,704,646	11,823,397	36,528,043
2041	29,736,603	14,231,641	43,968,243
2042	35,175,604	16,834,693	52,010,297
2043	40,970,339	19,607,995	60,578,334
2044	47,041,933	22,513,799	69,555,733
2045	53,252,056	25,485,902	78,737,957
2046	59,254,718	28,358,716	87,613,434
2047	64,718,821	30,973,781	95,692,602
2048	69,553,983	33,287,842	102,841,825
2049	73,811,639	35,325,513	109,137,152
2050	78,410,928	37,526,687	115,937,614

5.2 Solar PV Financial Considerations

A similar financial analysis/costing exercise was conducted for solar PV panels, based on the solar PV market. For this analysis, financing costing/models were necessarily limited/confined to recycling costs and other readily available datasets. Additional overheads and commercially sensitive information that would have provided information on other costs, such as the cost of environmental management (including reporting, administration, project management, communications, contingency funding and system management), as well as supporting systems and enforcement programmes, were not available for consideration and therefore cannot be included.

According to the PV projections in Chapter 4 (and using the ISEA "BAU" figures), approximately 13,500,000 kg of PV panels will be returned as WEEE for recycling by 2050. Taking this quantity as the input for the financial modelling of the solar PV WEEE

Table 5.3. EVB processing costs for scenario 2

Year	EOL cost (€)	Defective cost (€)	Total cost (€)
2021	143	30	174
2022	1823	388	2210
2023	8525	1813	10,338
2024	26,385	5612	31,998
2025	65,109	13,849	78,958
2026	139,181	29,605	168,786
2027	269,269	57,275	326,544
2028	483,505	102,845	586,350
2029	818,151	174,026	992,177
2030	1,317,195	280,176	1,597,371
2031	2,030,805	431,966	2,462,771
2032	3,013,216	640,931	3,654,147
2033	4,321,166	919,141	5,240,307
2034	6,013,691	1,279,152	7,292,843
2035	8,152,834	1,734,162	9,886,997
2036	10,802,881	2,297,845	13,100,725
2037	14,024,252	2,983,052	17,007,304
2038	17,859,947	3,798,930	21,658,877
2039	22,317,984	4,747,184	27,065,168
2040	27,792,727	5,911,698	33,704,425
2041	33,453,678	7,115,820	40,569,498
2042	39,572,555	8,417,346	47,989,901
2043	46,091,631	9,803,998	55,895,629
2044	52,922,175	11,256,900	64,179,075
2045	59,908,562	12,742,951	72,651,513
2046	66,661,558	14,179,358	80,840,916
2047	72,808,673	15,486,891	88,295,564
2048	78,248,231	16,643,921	94,892,152
2049	83,038,094	17,662,757	100,700,851
2050	88,212,294	18,763,343	106,975,637

recycling exercise, this section considers two distinct possibilities for recycling of solar PV WEEE:

- Recycling solar PV WEEE in Ireland (case 1). This scenario assumes that the necessary recycling facilities will exist in Ireland, and therefore considers the cost of recycling this solar PV WEEE *in situ* in Ireland.
- Recycling solar PV WEEE in Europe (case 2). This scenario assumes that recycling facilities for solar PV will not exist in Ireland, and therefore considers the financial implications of collecting, pre-processing and then shipping the solar PV WEEE to mainland Europe for recycling and processing.

The remainder of this section considers each of these two cases in isolation.

5.2.1 Case 1: recycling solar PV WEEE in Ireland

The first financial case considers the situation that solar PV WEEE could be recycled nationally on the island of Ireland. To analyse the financial cost of recycling the solar PV WEEE, a materials composition/breakdown was required. After considering several possible sources, the materials composition for solar PV panels presented in Mahmoudi *et al.* (2019) was used. The primary components of a typical solar PV panel and the contribution to the panel and recycling yield of each component are shown in Table 5.4.

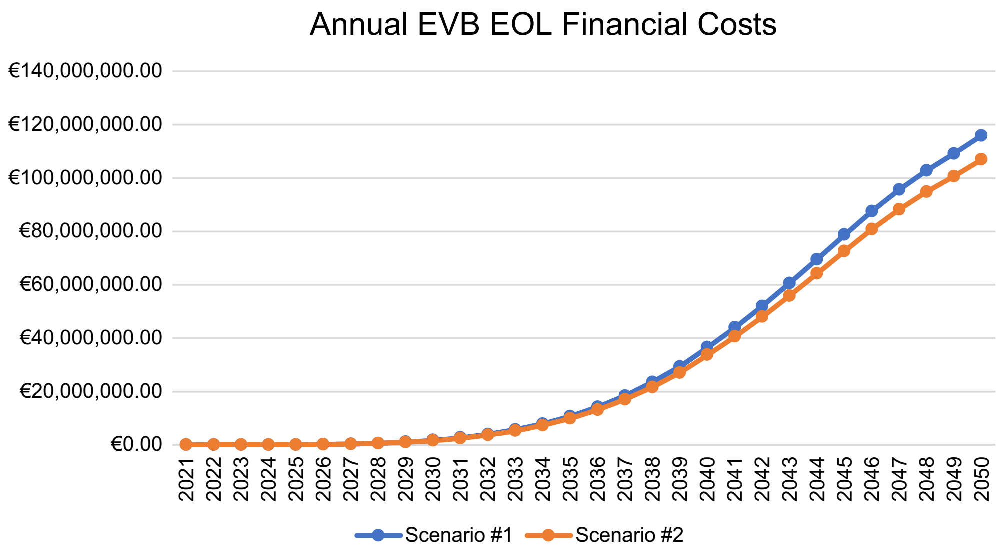

Figure 5.1. EVB EOL financial costs (per year).

Table 5.4. Solar PV panel composition and recycling yields

Materials and substances	Mass (tonnes)	%	Recycling yield (%)
Glass	18,610,039.00	68.10	95.00
Aluminium	3,823,857.96	13.99	99.70
Steel	2,179,785.90	7.98	95.00
Ethylene vinyl acetate	1,624,719.63	5.94	100.00
Nickel	359,799.72	1.32	41.00
Copper	248,105.03	0.91	100.00
Silicon	185,716.22	0.68	99.90
Iron	137,428.58	0.50	90.00
Magnesium	120,391.49	0.44	33.00

The main constituent elements of a solar PV panel are glass, aluminium, steel, ethylene vinyl acetate, nickel, copper, silicon, iron and magnesium. Next, using these elements as a starting point, and from discussions with WEEE recyclers in Ireland, an adjusted recycling list, values (per tonne) and yields for these materials was determined, as shown in Table 5.5. Here, recycling costs are shown as positive if the material worth/recycling value is greater than the cost of recovery; a negative value in the table means that the recycling of that material currently incurs a larger overhead/cost than the value of the recycled element. Note also that these figures do not consider factors such as natural wastage, warranty returns, etc.

Note that ethylene vinyl acetate is not currently recycled in significant quantities in Ireland and silicon was deemed to have net zero recycling value; for this reason, neither of these elements is included in Table 5.5. Based on these recycling values, and assuming a recycling yield of 80%, the WEEE predictions for solar PV presented in the ISEA BAU scenario in Chapter 4 were calculated.

Recycling costs and overheads (per tonne) for the collection, transport and pre-processing of this solar PV WEEE on site in Ireland (if such an option existed) were estimated at €1050 per tonne for this study. Applying these overheads and the material yields from the PV panel recycling operations to the recycling material value(s), the solar PV financial recycling model is as shown in Table 5.6.

Table 5.5. Recycling values (per tonne) for solar PV panel elements

Materials and substances	Recycling value (€/tonnes)
Glass	–80
Aluminium	375
Steel	150
Nickel	1200
Copper	1550

Figure 5.2 shows this projected solar PV WEEE financial model in graphical format.

Note that these projected figures assume the existence of a PV recycling facility in Ireland that can recycle/be modified to recycle solar PV panels. Currently, no such facility capable of recycling solar PV panels exists in Ireland. The set-up costs for such

Table 5.6. Projected WEEE recycling dividends for solar PV WEEE recycled in Ireland

Year	Recycling revenue (€)	– Recycling overheads (€)	= Net total (€)
2021	0	0	0
2022	259	107	153
2023	4348	1786	2562
2024	19,620	8060	11,560
2025	56,801	23,334	33,467
2026	130,463	53,594	76,869
2027	259,607	106,646	152,961
2028	466,847	191,780	275,067
2029	778,207	319,686	458,521
2030	1,222,396	502,158	720,238
2031	1,830,700	752,048	1,078,652
2032	2,636,696	1,083,150	1,553,546
2033	3,664,877	1,505,525	2,159,353
2034	4,929,125	2,024,875	2,904,249
2035	6,434,924	2,643,455	3,791,469
2036	8,179,180	3,359,992	4,819,188
2037	10,149,568	4,169,423	5,980,144
2038	12,323,836	5,062,609	7,261,227
2039	14,669,273	6,026,110	8,643,163
2040	17,142,512	7,042,112	10,100,400
2041	19,689,819	8,088,541	11,601,278
2042	22,248,003	9,139,438	13,108,565
2043	24,746,022	10,165,619	14,580,402
2044	27,107,330	11,135,640	15,971,690
2045	29,252,953	12,017,058	17,235,895
2046	31,105,166	12,777,944	18,327,222
2047	32,591,627	13,388,579	19,203,048
2048	33,649,668	13,823,220	19,826,447
2049	34,230,464	14,061,810	20,168,654
2050	34,302,687	14,091,479	20,211,208

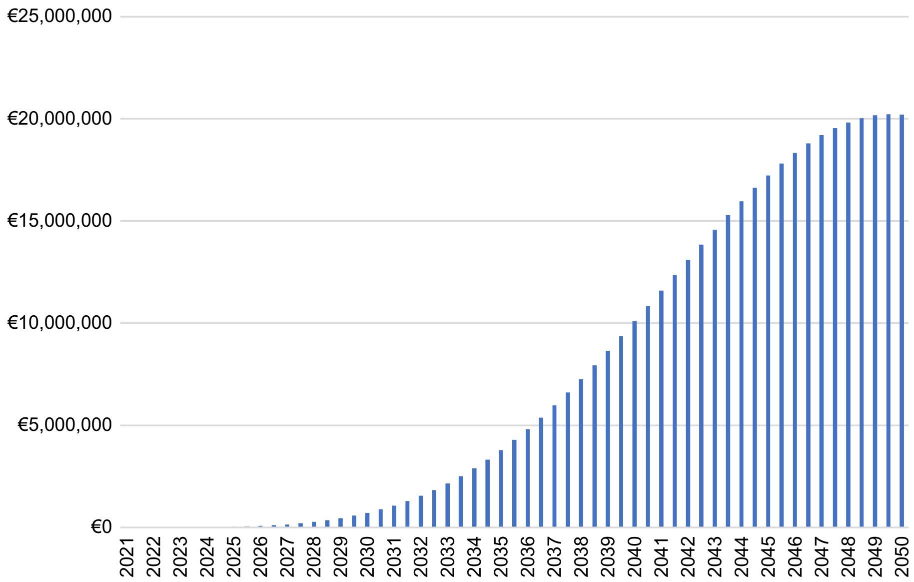

Figure 5.2. Projected revenue from domestic recycling of solar PV WEEE returns, 2021–2050.

a facility are not included in this financial modelling. Factors such as the cost of exports, hazardous waste export challenges and amber list Transfrontier Shipments requirements should also be considered.

5.2.2 Case 2: recycling solar PV WEEE in Europe

The second financial case considers the situation that solar PV WEEE cannot be recycled nationally and instead is shipped to mainland Europe for processing and recycling. Under this scenario, costs associated with the operation include collection, pre-processing, transportation and recycling gate fee costs. From discussions with industry recyclers and actors in this field, the total cost of recycling solar PV panels, assuming that all these operations are required, is estimated to be €1850 per tonne.

Using this figure and the ISEA BAU solar PV WEEE predictions, as per Chapter 4, a breakdown of recycling costs for solar PV panels over the timeframe 2021–2050 was calculated. This breakdown of recycling costs (assuming shipping of PV panels to Europe for recycling and with no natural wastage and warranty returned factors considered) is shown in Table 5.7.

5.2.3 Note on developing a domestic EVB/PV panel recycling facility in Ireland

Based on the financial costings considered in this report, an investigation into the feasibility of development of a recycling facility on the island of Ireland for both EVBs and solar PV panels is warranted. In the case of solar PV panels, further exploration to consider capital costs and minimum quantities required would be necessary. In the case of EVBs, shipping and treatment costs for the volume of batteries projected in this report will be very significant. The pre-treatment of EVBs on the island of Ireland could significantly reduce the overall costs of treating batteries. The case for a recycling facility on the island to recycle both PV panels and EVBs appears strong, particularly when key risks associated with export (including political and currency risks) are taken into account. Considering national policy on expanding the use of both PV panels and EVs, exploration into the development of such facilities is recommended.

The most obvious solution would be the issuance of a bond in accordance with either (or ideally both) of the International Capital Market Association's Green Bond Principles[24] and the EU Green Bond Standard,[25] which is currently in development. Both the Green Bond Principles and the Green Bond Standard are

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[24] https://www.icmagroup.org/sustainable-finance/the-principles-guidelines-and-handbooks/green-bond-principles-gbp/ (accessed 11 January 2024).

[25] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021SC0181 (accessed 11 January 2024).

Table 5.7. Projected WEEE recycling costs for solar PV WEEE recycled in Europe

Year	Total weight (kg)	Projected annual recycling cost (€)
2021	–	0
2022	101	188
2023	1701	3147
2024	7676	14,200
2025	22,223	41,112
2026	51,042	94,427
2027	101,568	187,901
2028	182,648	337,898
2029	304,463	563,256
2030	478,246	884,754
2031	716,236	1,325,037
2032	1,031,571	1,908,407
2033	1,433,833	2,652,591
2034	1,928,452	3,567,637
2035	2,517,576	4,657,516
2036	3,199,992	5,919,986
2037	3,970,879	7,346,127
2038	4,821,532	8,919,834
2039	5,739,152	10,617,432
2040	6,706,773	12,407,530
2041	7,703,372	14,251,238
2042	8,704,227	16,102,819
2043	9,681,542	17,910,853
2044	10,605,372	19,619,938
2045	11,444,817	21,172,912
2046	12,169,470	22,513,520
2047	12,751,028	23,589,401
2048	13,164,972	24,355,198
2049	13,392,200	24,775,571
2050	13,392,200	24,775,571

voluntary frameworks with which issuers of bonds – in this case the Irish government – can choose to comply. They provide transparency to investors and support to the Irish government as issuer, because eligible green bonds are recognised in the market as meeting key criteria of sustainability, and thus attract a specific investor clientele. The Irish government issued its first Green Bond in 2019, supporting the work of the ESB Group, and a framework was established for its use. The Green Bond Principles recognise seven possible categories of eligibility for the issuance of a Green Bond, and a bond issued to finance a facility to recycle EVBs would qualify under the category “pollution prevention and control” or the category “clean transportation”. Under the emerging EU Green Bond Standard, four additional criteria would apply: a substantial contribution to environmental objectives, an avoidance of harm to any of the EU taxonomy’s environmental objectives, social safeguards and technical screening criteria. Again, meeting these objectives should be relatively straightforward for such a facility.

Green Bonds are attractive to investors because of enhanced transparency deriving from compliance with the appropriate Green Bond Principles, and most significantly because they can help funds to achieve or enhance their environmental, social and governance ratings. The Green Bond market, as noted by the European Commission, has doubled in size annually over a 5-year period to 2020. As environmental, social and governance considerations also grow in significance on the capital markets, there is no indication that this momentum will slow in the near term. With this level of demand, the issuance of a Green Bond is the clearly favoured mode of financing an EVB recycling facility.

6 Stakeholder Inputs

As part of the LongWEEE project, Work Package 3 focused on gathering input from all relevant stakeholders in the EVB and solar PV industry and recycling concerns regarding their current thinking about these long-life products within the context of target setting, recycling and EPR finance.

As an emerging topic, various stakeholders will have different perspectives on the issue of long-life products and their implications for sustainable WEEE management policies. It is important to capture these in a structured way so that they can inform the scenario development during the modelling work described in Chapters 3 and 4. These perspectives were captured through a series of semi-structured interviews with relevant stakeholders. These interviews were recorded and transcribed. After being reviewed by the interviewees, the interviews were then analysed and common themes identified across the different conversations. All interviews took place through videoconference calls using MS Teams and Otter AI transcription software.

The researchers would like to thank the following stakeholders for their assistance in this regard, for taking the time to participate in the interview process and contributing their viewpoints and perspectives to the process:

- Colin Walsh, Society of the Irish Motor Industry;
- Paudy O’Brien, FPD Recycling;
- Olivia Brennan and Kevin Thornton, KMK Recycling;
- Dominic Henry, The Producer Register Ltd;
- Leo Donovan, Elizabeth O’Reilly, Laurence Kieran and Conor Leonard, WEEE Ireland;
- ISEA representatives Bill Senior (Power Capital) and Gerhard Heyl (PV Green);
- Matteo Bonanno, European Recycling Platform Austria;
- Graham Brennan, Transport Programme Manager, Sustainable Energy Authority of Ireland;
- Patrick Chan, Financial Provisions Team, Environmental Protection Agency (EPA).

6.1 Stakeholder Inputs for EVBs

Analysing the themes and content from the stakeholder interviews regarding EVB recycling and financing, a number of common themes and topics are evident across the range of these interviews. These recommendations are broadly grouped under the headings of plans, transportation, second life and general recommendations.

6.1.1 Plans

EVB recycling roadmap/plan

A formal roadmap or plan for the national transition to EVs is needed. Such a plan should outline how this transition should progress, detailing the milestones and goals. Such a plan should also detail how it will contribute and fit into the international/EU-level battery roadmap, potentially as part of the European goals and objectives regarding the recycling or recovery of EVB materials for the future. The need to see these plans or roadmaps explicitly spelt out/disseminated to interested parties was also highlighted here.

6.1.2 Transportation

Shipping

The biggest challenge in recycling EVBs from Ireland is the extremely high cost and complex nature of shipping EVBs to mainland Europe. The cost of such an operation is typically €8000–10,000 per battery. The majority of this cost arises from transporting damaged/EVB cells in bomb-proof containers that meet ADR[26] requirements/regulations.

Need for standardised transport requirements for batteries

There is a need for a standardised definition of transport requirements for the movement and transport

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[26] https://unece.org/about-adr (accessed 11 January 2024).

of old or damaged batteries. For example, there is no lithium-specific six-digit HS code for transport.

6.1.2 Second life

Disassembly operation for long-life LIBs

The need for an on-island EVB disassembly plant was highlighted in a number of interviews conducted. Such a plant/operation would allow for the discharge and safe disassembly of damaged/EOL EVBs going forward. This would facilitate reuse of good cells from these batteries in second-life applications. Damaged or worn-out cells could be discharged, collected and held for shipping to mainland Europe for recycling in a more cost-effective and streamlined fashion than is currently available.

Liability/reuse concerns

At present, there is a lot of uncertainty and varying standards regarding ownership and reuse potential for EVBs at EOL. For example, some car manufacturers claim ownership of batteries after their use-phase and want them to be returned while others want batteries to be recycled when their initial use-phase has expired. A clear path and identified roles under EPR for reuse of EVBs in second-life applications, such as power banks, is needed to clarify the situation regarding reuse of EVBs in this regard and set the precedent for reusing these batteries in other applications.

6.1.2 Other

Education

Educating the general public/Irish population about the recycling of EVBs at their EOL was also identified as one of the key factors needed in the successful recycling of EVBs as they reach EOL. In the first instance, this may take the form of education and information dissemination activities to the general public on the need to recycle EVBs in a responsible fashion, where they can go to recycle these batteries, what is expected of them, etc.

Norway

From discussions with a number of stakeholders, Norway was identified as the forerunner in terms of EV roll-out in Europe. Therefore, stronger ties and links with the EVB recycling industry in Norway are recommended. Where applicable, Norway should be used as the model for future EV-related matters and EVB recycling in Ireland. From sustainable, circular economy production of EVBs[27] to success stories such as Li-Cycle[28] and Northvolt/Hydro,[29] Norway is leading the way in the recycling and reuse of EVBs at the European and global levels. One key recommendation to be taken from the Norwegian model is the development of an EVB disassembly plant in Ireland, and recently piloted in the CIRCULÉIRE-funded Long-Life Lithium Battery (LLLB) reuse demonstration pilot.[30]

Stakeholder forum

The formation of a regular stakeholder forum to review EPR models has been suggested. This would enable Ireland to keep pace with technology developments and support the "futureproofing" of the Irish system. This has been highlighted as being of particular interest ahead of battery regulation implementation and the WEEE Directive revision.

Other long-life WEEE

Some interviewees were interested in finding out if other WEEE appliances fall into the same dynamic or long-life product bracket as EVBs and solar PV panels. Again, this could fall within the remit of an education programme informing the general public/interested parties about this classification of WEEE and how they will vary from the standard WEEE life cycle.

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[27] https://businessnorway.com/articles/nordic-cooperation-powers-up-green-battery-ecosystem (accessed 11 January 2024).

[28] https://www.businesswire.com/news/home/20220126005345/en/Li-Cycle-Strategic-Partners-to-Build-New-Lithium-ion-Battery-Recycling-Facility-in-Norway (accessed 11 January 2024).

[29] https://www.mr-sustainability.com/stories/2021/battery-recycling-northvolt (accessed 11 January 2024).

[30] https://circuleire.ie/10-things-we-learnt-from-the-long-life-lithium-battery-lllb-re-use-pilot/ (accessed 11 January 2024).

6.2 Stakeholder Inputs for Solar PV Panels

From the interviews and discussions conducted regarding the recycling of solar PV panels, these long-life products and associated concerns, a number of recurring themes were identified. These themes centred around the topics of assistance, information and equipment with regard to the solar PV panels and industry. Each theme is discussed in more detail in this section.

6.2.1 Assistance

Subsidies

To promote renewable solar energy in Ireland, there is a need to continue to subsidise renewable energy projects and schemes utilising solar PV panels in a fashion similar to that used to encourage the development of wind energy in Ireland over the past 20 years. Furthermore, it is recommended that factors such as subsidies, planning permission and connection to the electricity grid are linked back to EPR requirements for companies and entrants into the market. Examples from other Member States have shown a favourable link between such benefits and evidence of Producer Registration and EPR obligations (such as finance/subsidies, takeback solutions). Such a link would help drive compliance and engagement by the industry with the recycling initiatives.

PV recycling costs

Recommendations from discussions with stakeholders on recycling of solar PV panels include keeping recycling costs fixed, low and transparent to all customers. Lower recycling costs/overheads will allow greater penetration/uptake of solar PV panels, especially in the domestic market. By ensuring that these costs are fixed and transparent to all parties involved, clarity and understanding of the costs and requirements are more readily guaranteed.

Simplicity

Stakeholders recommend that any incentive or tax break offered in the solar PV field should be something that is easily understood by the solar PV panel buyer and/or the general public. Overly complex or convoluted incentives or schemes will not motivate the same degree of uptake of solar PV panels within the residential/B2C market.

Government policy for tariffs for renewable energy

Clarity is required regarding the proposed government policy regarding tariffs for renewable energy into the future, in particular solar energy. This would allow the stakeholders and parties operating in the solar PV market to plan their future operations and undertakings with greater certainty and assist in ensuring the existence of these actors in the marketplace for longer periods of time – something that would benefit the financial planning for the recycling industry in this space.

6.2.2 Information

Information widely available

Information on solar PV panel recycling should be widely advertised and available to the general public. Information regarding the recycling process, the responsibilities of all parties involved, what should happen to solar PV panels when they are taken down from residential roofs and where the panels should be taken for recycling, etc., are all key points regarding the recycling of solar PV WEEE that need to be disseminated and advertised to the general public.

National recycling guidelines

National recycling guidelines for both roof- and ground-mounted solar PV panels should be drawn up and disseminated. These guidelines should differentiate between the different types of panel mountings and the different requirements for the recycling of these panels. Such information should again feature in any general public education programme informing people what to do with their solar PV panels that have reached the end of their life.

6.2.3 Equipment

Non-panel equipment

Clear and simple guidelines for the recycling of all non-panel components of a solar PV system should also be readily available and disseminated to panel owners, installers and the general public. Elements such as the PV panel inverters, wiring, batteries, etc., should all be identified, and information on how each element can be recycled should be included in such guidelines.

Panel recycling drop-off points

Dedicated return/drop-off/collection points for solar PV panels for recycling should be designated nationally. These locations should be advertised, and installers/building contractors removing PV panels from domestic residences should know about them. This will mean that PV panels immediately enter the recycling stream on removal at their EOL and do not end up as metal scrap or accumulating in storage for long periods of time. This requires investment/planning now, as well as an agreed national approach to management of this waste stream.

Solar panels versus solar thermal

An education/information dissemination programme for end-users and the general public should distinguish between solar PV panels and solar thermal products. Such information should also distinguish between the EOL/recycling considerations for both products, with solar PV panels being treated as WEEE for recycling versus recycling provisions for solar thermal products.

B2B (PV solar farms) versus B2C (PV home panels)

Collection and recycling will need to be different for the B2B and B2C markets for solar PV panels, to accommodate the differences in scale and scope of the two markets. For example, many B2C panels will present at scrap metal recyclers, and diverting these into the proper recycling channel must be addressed (Ryan-Fogarty *et al.*, 2021). With B2B solar PV products aggregating ~85% of the market share, according to projections, considerations such as on-site collection of solar PV panels from B2B installations should be facilitated to streamline the recycling of this section of the market.

7 Conclusions

7.1 Financing Considerations

To process long-life WEEE product streams such as EVBs and solar PV panels and finance the environmentally sound recycling of these long-life products, two distinct financing options are considered. These options are (1) charge current producers as they place products on the market (here referred to as the "pay when placed" model) or (2) defer the charges until the products present for recycling (referred to as the "pay when collected" model). The authors believe that, of these, the "pay when placed" model better suits the long-life WEEE products such as the solar PV panels discussed in this report.

The implications of charging current producers as they place long-life EEE products on the market or deferring the charges until these products present for recycling need to be fully considered. Impacts such as the projected increased future volumes of these long-life WEEE products and the costs of collection and recycling them are discussed in the EVB financial considerations and solar PV financial considerations sections of this chapter (see sections 7.2.1 and 7.2.2). In addition, general financial recommendations based on these considerations are presented in Chapter 5. A failure to adequately plan for the recycling of these long-life products now may lead to an inadequately financed recycling system, or one that becomes prohibitively expensive for new market entrants to join.

Both the "pay when placed" and the "pay when collected" financing schemes for long-life WEEE have associated advantages and disadvantages. The main advantage of the "pay when placed" financing scheme is that it is fair and ensures the existence of a recycling fund for the future. A "pay when placed" scheme collects the recycling costs for the long-life product "up front" in a fair and equitable fashion. Collecting the recycling fee in this way provides a monetary fund that can be used to finance the correct and responsible collection and recycling of long-life WEEE products when they become waste. These are the main reasons why this method is recommended for solar PV panels and other long-life WEEE products in Ireland.

Disadvantages or drawbacks of the "pay when placed" financing option for these products include uncertainties about the size of fund necessary in the future and the need to manage this fund. Forecasting the number of long-life EEE products, such as solar PV panels or EVBs, that will present at EOL for recycling in the future has a significant degree of uncertainty associated with it. If the number of EOL products that are to be recycled is larger or collection and recycling costs are higher than the predicted levels the fund was designed to finance, there will be a shortfall. Likewise, an overly conservative approach could see current producers bear unnecessary costs if collection rates are low or recycling costs/revenues for these products change substantially in the future, and the fund may be larger than required. Financing options considered now can account only for the present values and costs associated with the collection and recycling operation. They cannot consider how changes in the material values and costs of recycling in 10–25 years will affect the financial cost of recycling this quantity of long-life WEEE.

In the case of the "pay when collected" model, advantages include the fact that producers pay only when actually recycling the product/WEEE, and the recycling cost they pay is based on current market share, and therefore directly covers the actual costs of recycling. However, this model depends somewhat on there being a balance between new products coming on the market and the waste being generated. That is, it is assumed that for every item to be recycled an approximately equivalent number of items are POM and therefore a producer is to be billed for the recycling. This method of financing waste management depends on new products replacing old products. This might not occur for solar panels as when they reach EOL it is not inevitable that the homeowner will replace the entire system (in the same way they would when their washing machine breaks). When the current wave of PV panels reaches EOL, the electric grid will have been completely decarbonised so the "green" incentive to spend so much money won't still be there.

A potential disadvantage of the "pay when collected" financing system is that such a balance may not achievable. The market for the products in question is heavily influenced by policy and for long-life EEE such as these the policy could potentially change drastically over the 10- to 25-year lifetime of the products. For example, off-shore wind and hydrogen-generated electricity could be prioritised by policy, and therefore new installations of solar PV panels may not replace EOL PV farms. Likewise, the current push for sales of EVs could be replaced by a policy to promote active and public transport, leading to a large decline in car ownership. Or, perhaps, circular business models based on access to services such as car sharing or leasing could dominate in the future, which would also lead to a reduction in the absolute number of vehicles reaching EOL. In each of these scenarios, there would not be an equivalent market for new products to fund the recycling of the retired ones.

The question of how these cash reserves (whenever they are accumulated) should be managed and the impacts on future new market entrants is considered next. For the responsible recycling of long-life WEEE at EOL, financial provision must be put in place to cover the costs needed to implement the plan. The three requirements for any financial provision are that it must be secure, sufficient and available when needed.

Based on feedback from stakeholders in the solar PV and EVB markets, consideration of the four methods of financial guarantee outlined in S.I. No. 149 (2014) and discussions with members of the financial provisions team in the EPA,[31] five main types of financial provision/secured fund plan(s) are currently in use in the market: (1) on-demand performance bonds, (2) secured accounts, (3) parental company guarantee, (4) mortgages/other resources and (5) accident insurance. Of these, the secured funds, parental company guarantee and mortgages/other resources options are hard to manage, and all incur high administration overheads. As insurance cannot be put in place for a known liability such as the recycling of long-life WEEE products, this leaves on-demand performance bonds as the preferred financial provision option recommended by experts for this scenario.

Perpetual and on-demand performance bonds are suitable financial provision for all liabilities. An on-demand performance bond is a financial instrument issued by a financial institution, such as a bank or a specialist provider (the “surety”), acceptable to the company or organisation that will be responsible for the recycling of the WEEE products. It is essentially a promise on the part of the surety to immediately pay the cost of complying with the company’s/organisation’s recycling obligations if it fails to do so. The bond is issued by the surety and is a direct obligation of the surety in favour of the recycler. The surety’s promise to pay the recycler is activated if the licensee fails to meet its obligations.

Bonds are usually valid for a fixed period of time and so they need to be renewed. Failure by a licensee to renew a bond, or agree an alternative financial provision with the recyclers, in itself constitutes a failure of the licensee to meet its obligations. Prior to the expiry of a bond, if a licensee fails to agree an alternative financial provision with the recycler, then the recycler would be entitled to immediately call on the bond. A perpetual bond or an on-demand bond that can be drawn down in full if not replaced by a particular date is suitable for covering all liabilities, including the costs of inevitable recycling of all the long-life WEEE.

Some factors to consider when using bonds include timeframe, inflation and templates. Where used, bonds are typically put in place for timeframes of 2–3 years. This allows them to be renewed or revalued if costs have changed in the intervening times or over the lifetime of the PV/EVB product – thereby ensuring that the amount at EOL of the product is sufficient to facilitate the recycling of the product(s). Bonds typically have a 2% default inflationary cost associated with them, compound interest style, to ensure that they keep up with changes in the recycling costs in the market over the lifetime of the product. Most bonds used for purposes such as those considered here provide a template for companies to use when setting them up. The wording of such a bond and the legal terminology used is very important to get right for when the bond may be needed in the future.

7.2 Recommendations

This report has presented considerations and identified challenges and modelling scenarios for the waste management of long-life WEEE or batteries going

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[31] https://www.epa.ie/enforcement/financialprovisionforenvironmentalliabilities/ (accessed 11 January 2024).

forward. Specifically, two separate cases have been considered: solar PV panels and EVBs.

The report has provided a concise analysis of this long-life WEEE, projecting future volumes and considering the financial flows related to these long-life emerging technologies, such as solar PV panels and EVBs. Such information will support the decision-making process for sustainable waste management, providing an evidential basis for the short- and long-term implications of decisions.

7.2.1 EVBs

For the case of EVBs, modelling the number of EOL vehicles that will present over the next 30 years is extremely difficult, given the large number of parameters that are input to any such model. Given the two key scenario inputs considered in this report (tax-related inputs and potential market availability), this research has assumed a medium level of changes in the regulations going forward, coupled with a medium supply of EV types on the market. Modelling this situation suggests that up to ≈32,000 EVBs per annum will present for recycling by the year 2050.

To calculate the recycling costs for all of these vehicles, certain assumptions needed to be made, namely no second-life or reuse potential, zero market leakage and 10% of the returning batteries being damaged in road traffic accidents and having to be considered defective for recycling purposes. Based on such a scenario, recycling costs for these ≈32,000 EVBs based on today's costings could rise as high as €115,000,000 by the year 2050. However, it must be stressed that this figure is a projection based on a continuation of current conditions without intervention to drive efficiencies into this process or changes in transport policy. This means that this is essentially an upper bound on the potential future cost. However, it serves as a warning that action is needed in this space and investigating the development of pre-treatment facilities for EVBs in Ireland is warranted.

7.2.2 Solar PV panels

Modelling the amount of WEEE generated by solar PV panels must consider both residential (B2C) and commercial (B2B) installations of these panels. Modelling both waste streams separately using residential and commercial/solar farm projections (using the projected quantity figures for the Eirgrid projections presented in Chapter 4), the WEEE generated by residential solar PV panels is expected to reach a minimum quantity of ≈60,000 panels per year by the year 2050. For commercial solar PV panels, the projected return figure is a minimum of ≈235,000 panels per year by 2050. This would yield a total minimum expected quantity of ≈295,000 panels per year (≈5000 tonnes taking a weight of 17 kg/panel, on average) returning as WEEE in Ireland by the year 2050.

Two recycling scenarios for the solar PV WEEE were considered in this report: recycling of solar panels in Ireland and shipping these panels to Europe for dedicated processing. Recycling the panels in Ireland would be dependent on the existence of a recycling facility capable of processing solar PV panels in Ireland – at present, no such facility exists. Recycling of waste solar PV panels shipped to Europe could incur very expensive recycling fees by 2050 for the PV levels projected in this report. Value retention in Ireland should be considered. Note that these scenarios consider only basic recycling fees and do not consider the associated overheads or costs incurred for environmental management, etc., under such a system.

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Abbreviations

AFV	Alternative fuel vehicle
ATF	Authorised treatment facility
B2B	Business to business
B2C	Business to consumer
BAU	Business as usual
BEV	Battery electric vehicle
BOS	Balance of system
CGIS	copper–indium–gallium–selenide
c-Si	Crystalline silicon
EEE	Electrical and electronic equipment
ELV	End-of-life vehicle
ELVES	ELV Environmental Services CLG
EOL	End of life
EPA	Environmental Protection Agency
EPR	Extended Producer Responsibility
EU	European Union
EV	Electric vehicle
EVB	Electric vehicle battery
F-D	Fire – damaged
F-ND	Fire – no damage
GHG	Greenhouse gas
ICE	Internal combustion engine
ISEA	Irish Solar Energy Association
LIB	Lithium-ion battery
LongWEEE	Long-life Waste Electrical and Electronic Equipment
NF-D	No fire – damaged
NF-S	No fire – safe
NiMH	Nickel–metal hydride
POM	Placed on the market
PV	Photovoltaic
TSO	Transmission System Operator
WEEE	Waste electrical and electronic equipment

Appendix 1 Electric Vehicle Market Share Projections

This appendix contains the market share projections for the EV market up to the year 2050. These projections are derived based on a series of nine different market scenarios, considered across two different parameters of interest. For each parameter, three different levels of uptake/engagement were considered, namely low, medium and high levels. The two parameters considered for the EVB market are “AFV model availability” and “changes in regulations”. “AFV market availability” is a measure of the availability of EVs on the market to meet the projected demand. “Changes in regulations” refers to market incentives to enable motorists to purchase/afford EVs and how far into the projected future such subsidies and incentives will last.

Table A1.1. Relationship between “AFV model availability” and “changes in regulations”, levels of uptake and the different scenarios

Scenario no.	Changes in regulation	AFV model availability
1	Low	Low
2	Low	Medium
3	Low	High
4	Medium	Low
5	Medium	Medium
6	Medium	High
7	High	Low
8	High	Medium
9	High	High

Table A1.1 summarises the relationship between these two parameters, levels of uptake and the different scenarios presented in this appendix.

Figures A1.1–A1.9 present the projected vehicle market share for the ICE, hybrid EV, partial hybrid EV and BEV categories, forecast to the year 2050.

For the same nine scenarios, Tables A1.2–A1.10 and Figures A1.10–A1.18 present the forecasted numbers of EVBs that will reach EOL between now and 2050 under the various scenario conditions. In each case, a table and graph of the projected figures is provided for each scenario.

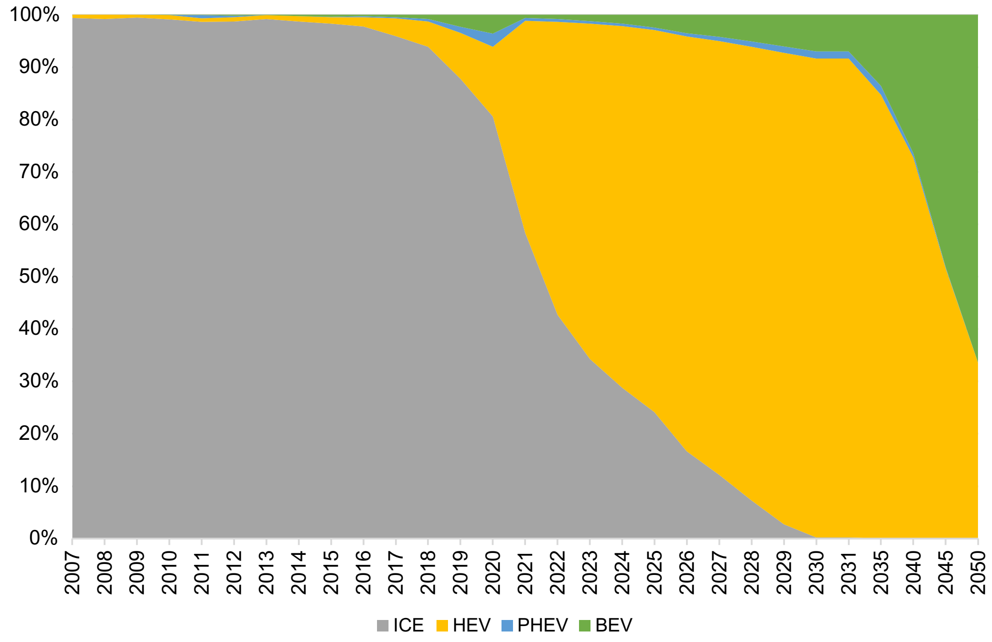

Figure A1.1. Projected market share under scenario 1, low AFV, low change in regulations. HEV, hybrid electric vehicle; PHEV, partial hybrid electric vehicle.

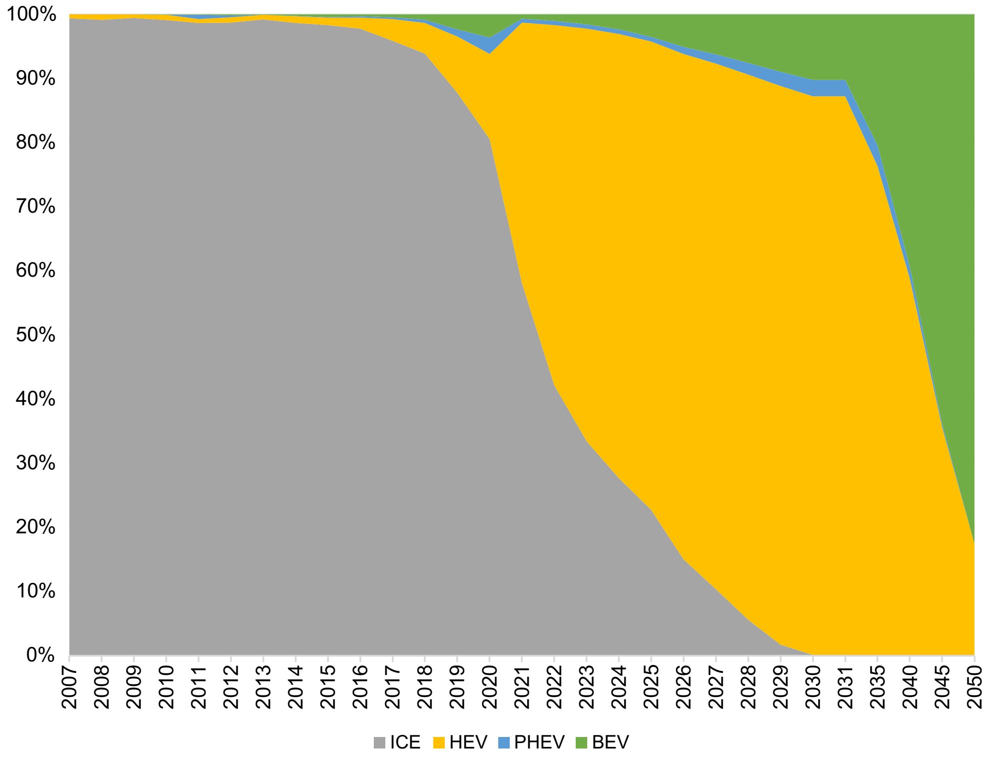

Figure A1.2. Projected market share under scenario 2, low AFV, medium change in regulations. HEV, hybrid electric vehicle; PHEV, partial hybrid electric vehicle.

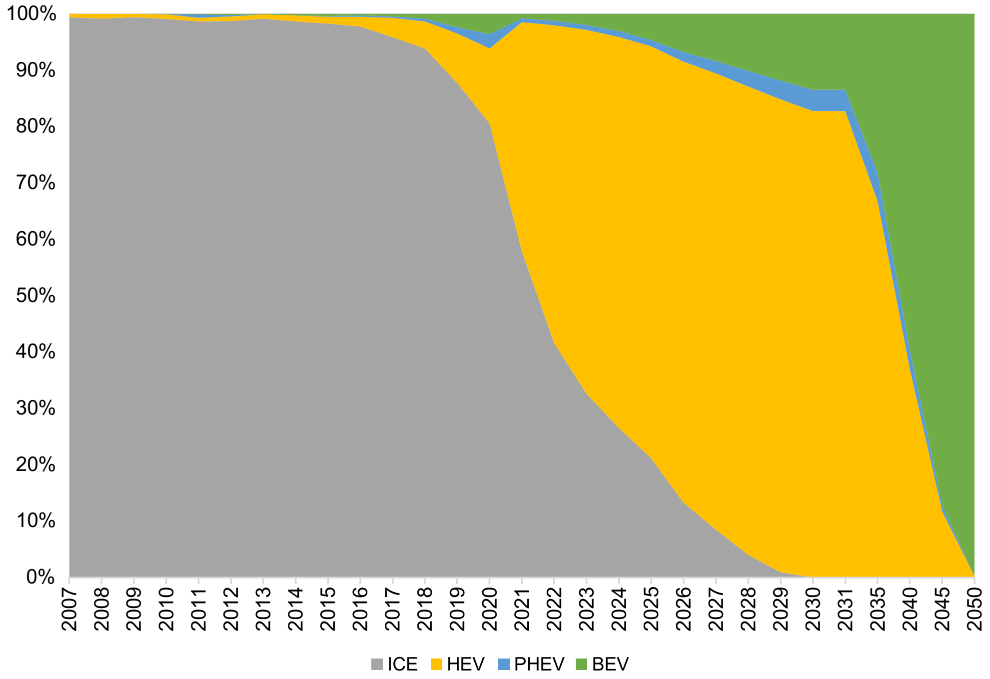

Figure A1.3. Projected market share under scenario 3, low AFV, high change in regulations. HEV, hybrid electric vehicle; PHEV, partial hybrid electric vehicle.

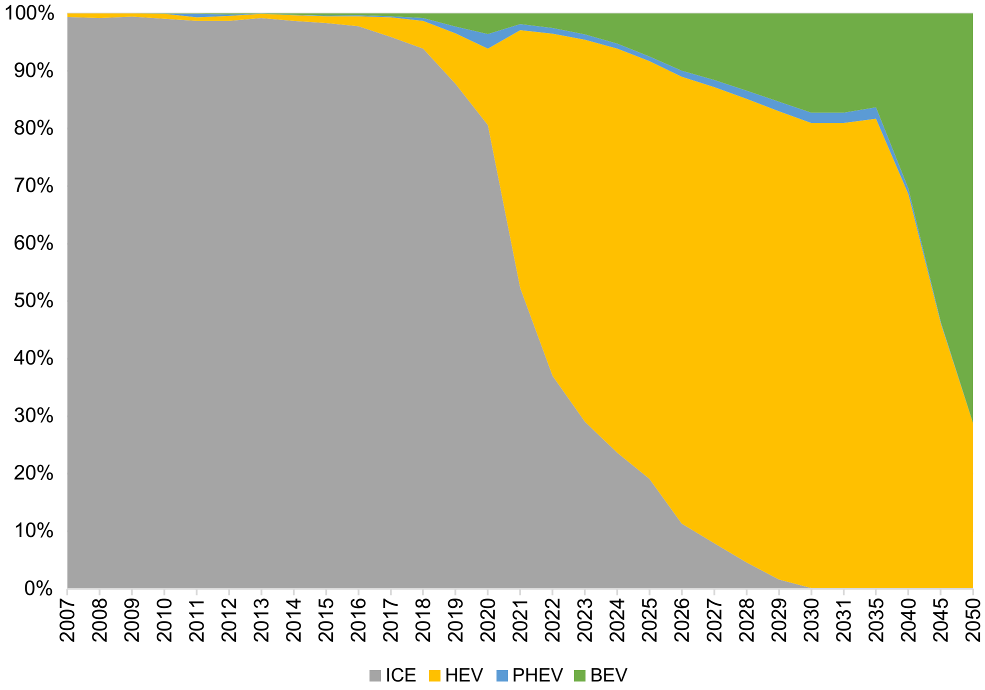

Figure A1.4. Projected market share under scenario 4, medium AFV, low change in regulations. HEV, hybrid electric vehicle; PHEV, partial hybrid electric vehicle.

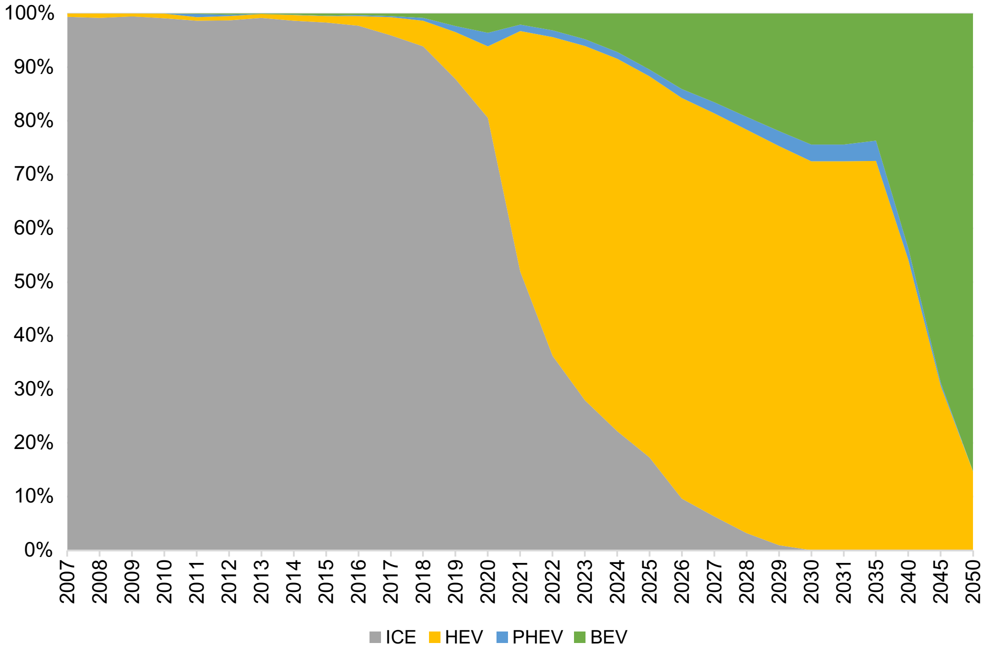

Figure A1.5. Projected market share under scenario 5, medium AFV, medium change in regulations. HEV, hybrid electric vehicle; PHEV, partial hybrid electric vehicle.

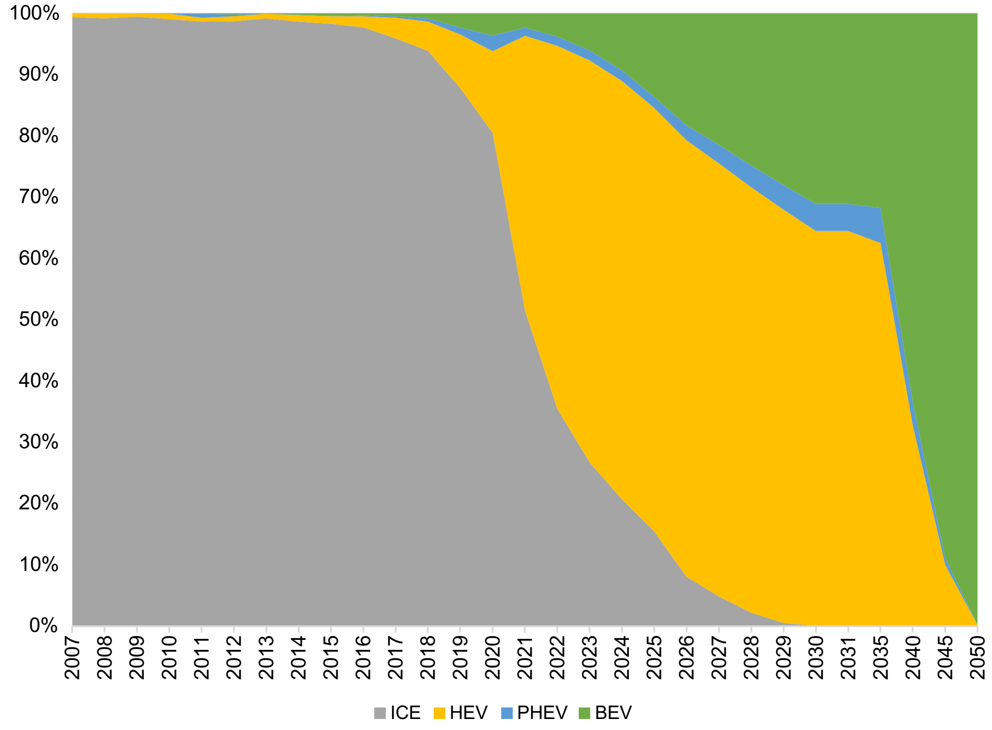

Figure A1.6. Projected market share under scenario 6, medium AFV, high change in regulations. HEV, hybrid electric vehicle; PHEV, partial hybrid electric vehicle.

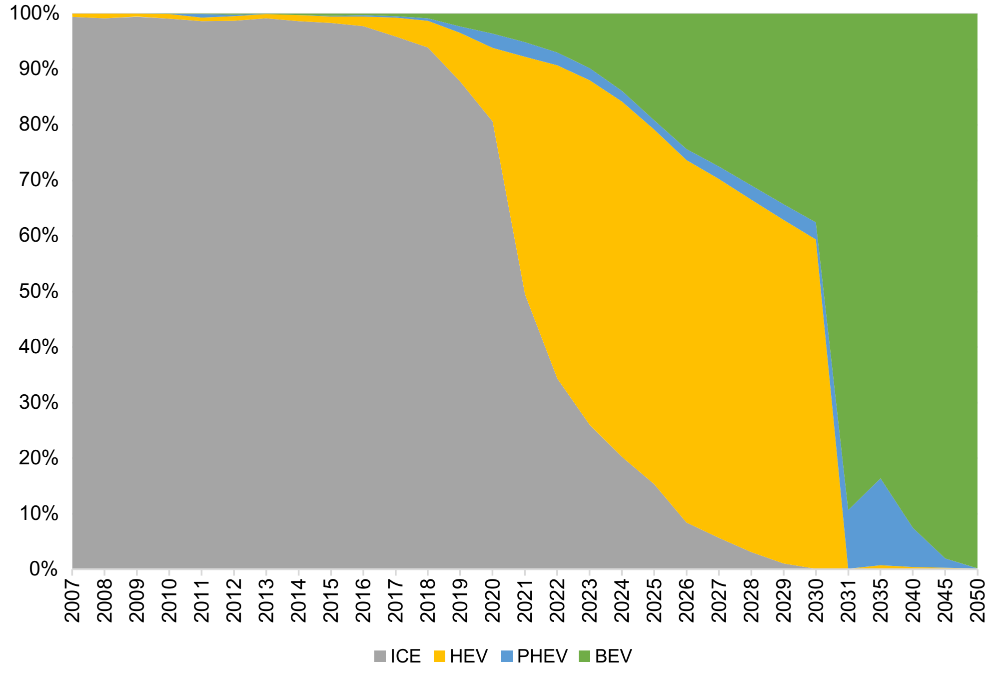

Figure A1.7. Projected market share under scenario 7, high AFV, low change in regulations. HEV, hybrid electric vehicle; PHEV, partial hybrid electric vehicle.

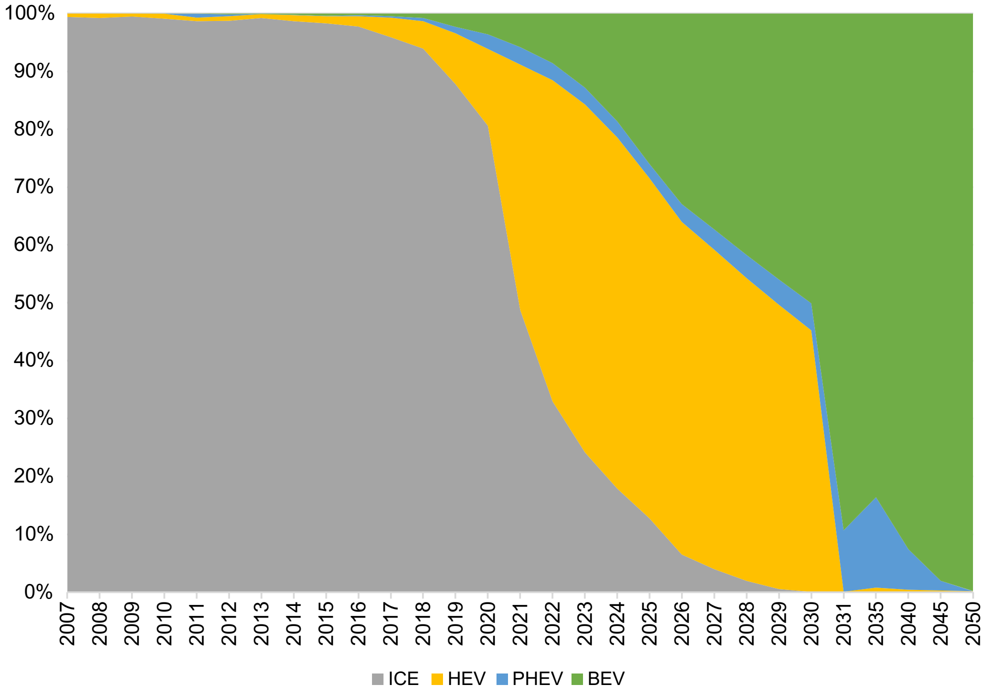

Figure A1.8. Projected market share under scenario 8, high AFV, medium change in regulations. HEV, hybrid electric vehicle; PHEV, partial hybrid electric vehicle.

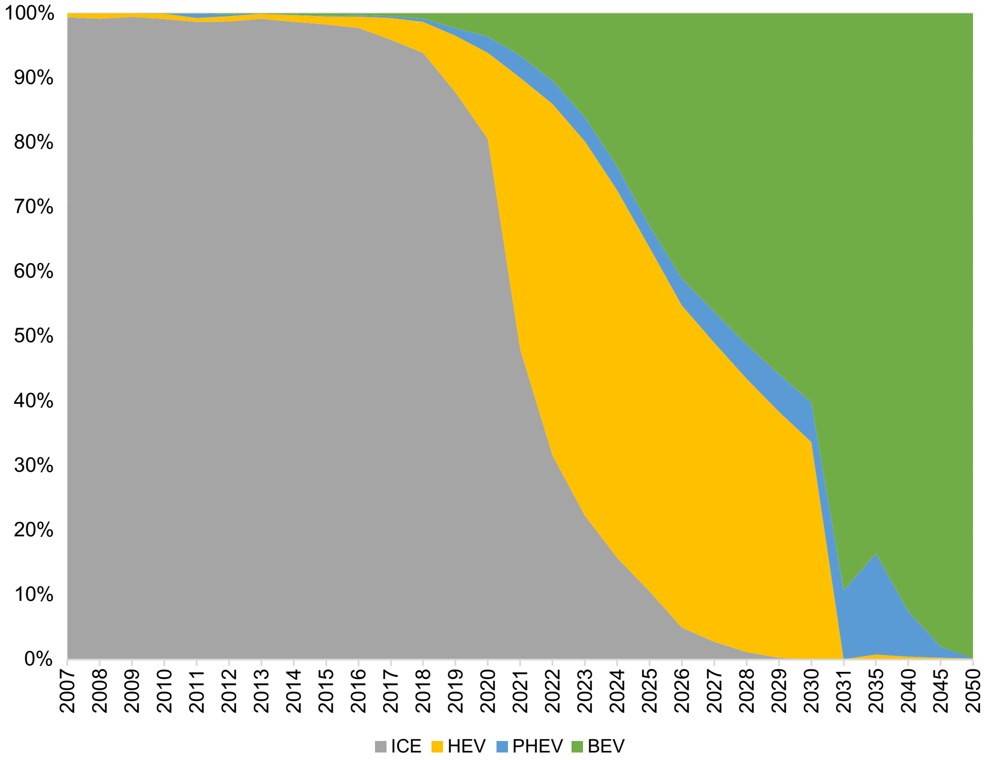

Figure A1.9. Projected market share under scenario 9, high AFV, high change in regulations. HEV, hybrid electric vehicle; PHEV, partial hybrid electric vehicle.

Table A1.2. Projected EOL EVBs under scenario 1, low AFV, low change in regulations

Year	Projected EOL EVBs	Year	Projected EOL EVBs
2011	0	2031	925
2012	0	2032	1033
2013	1	2033	1123
2014	1	2034	1200
2015	3	2035	1279
2016	6	2036	1388
2017	11	2037	1559
2018	18	2038	1818
2019	29	2039	2177
2020	44	2040	2662
2021	64	2041	3302
2022	93	2042	4049
2023	132	2043	4911
2024	184	2044	5898
2025	252	2045	7011
2026	336	2046	8255
2027	436	2047	9657
2028	551	2048	11,199
2029	676	2049	12,874
2030	803	2050	14,775

Table A1.3. Projected EOL EVBs under scenario 2, low AFV, medium change in regulations

Year	Projected EOL EVBs	Year	Projected EOL EVBs
2011	0	2031	962
2012	0	2032	1095
2013	1	2033	1226
2014	1	2034	1360
2015	3	2035	1520
2016	6	2036	1739
2017	11	2037	2053
2018	18	2038	2494
2019	29	2039	3078
2020	44	2040	3836
2021	64	2041	4801
2022	93	2042	5926
2023	132	2043	7225
2024	184	2044	8711
2025	252	2045	10,385
2026	337	2046	12,252
2027	438	2047	14,347
2028	556	2048	16,647
2029	686	2049	19,139
2030	823	2050	21,951

Table A1.4. Projected EOL EVBs under scenario 3, low AFV, high change in regulations

Year	Projected EOL EVBs	Year	Projected EOL EVBs
2011	0	2031	1002
2012	0	2032	1165
2013	1	2033	1338
2014	1	2034	1536
2015	3	2035	1784
2016	6	2036	2122
2017	11	2037	2589
2018	18	2038	3224
2019	29	2039	4047
2020	44	2040	5091
2021	64	2041	6395
2022	93	2042	7919
2023	132	2043	9686
2024	184	2044	11,719
2025	252	2045	14,034
2026	338	2046	16,653
2027	441	2047	19,641
2028	562	2048	22,991
2029	698	2049	26,709
2030	846	2050	30,964

Table A1.5. Projected EOL EVBs under scenario 4, medium AFV, low change in regulations

Year	Projected EOL EVBs	Year	Projected EOL EVBs
2011	0	2031	1197
2012	0	2032	1466
2013	1	2033	1782
2014	1	2034	2160
2015	3	2035	2625
2016	6	2036	3211
2017	11	2037	3946
2018	18	2038	4850
2019	29	2039	5919
2020	44	2040	7159
2021	64	2041	8554
2022	93	2042	10,029
2023	132	2043	11,541
2024	185	2044	13,306
2025	255	2045	14,424
2026	346	2046	15,731
2027	459	2047	16,914
2028	599	2048	17,939
2029	767	2049	18,810
2030	965	2050	19,803

Table A1.6. Projected EOL EVBs under scenario 5, medium AFV, medium change in regulations

Year	Projected EOL EVBs	Year	Projected EOL EVBs
2011	0	2031	1307
2012	0	2032	1652
2013	1	2033	2082
2014	1	2034	2622
2015	3	2035	3309
2016	6	2036	4184
2017	11	2037	5284
2018	18	2038	6631
2019	29	2039	8218
2020	44	2040	10,043
2021	64	2041	12,076
2022	93	2042	14,225
2023	132	2043	16,427
2024	185	2044	18,600
2025	256	2045	20,643
2026	348	2046	22,515
2027	466	2047	24,231
2028	614	2048	25,719
2029	799	2049	26,992
2030	1027	2050	28,428

Table A1.7. Projected EOL EVBs under scenario 6, medium AFV, high change in regulations

Year	Projected EOL EVBs	Year	Projected EOL EVBs
2011	0	2031	1426
2012	0	2032	1853
2013	1	2033	2404
2014	1	2034	3115
2015	3	2035	4032
2016	6	2036	5207
2017	11	2037	6678
2018	18	2038	8469
2019	29	2039	10,568
2020	44	2040	12,964
2021	64	2041	15,611
2022	93	2042	18,406
2023	132	2043	21,270
2024	186	2044	24,109
2025	257	2045	26,811
2026	351	2046	29,349
2027	473	2047	31,759
2028	631	2048	33,984
2029	834	2049	36,056
2030	1094	2050	38,451

Table A1.8. Projected EOL EVBs under scenario 7, high AFV, low change in regulations

Year	Projected EOL EVBs	Year	Projected EOL EVBs
2011	0	2031	2163
2012	0	2032	3013
2013	1	2033	4143
2014	1	2034	5612
2015	3	2035	7478
2016	6	2036	9790
2017	11	2037	12,579
2018	18	2038	15,850
2019	29	2039	19,580
2020	44	2040	23,755
2021	64	2041	28,305
2022	93	2042	33,918
2023	133	2043	38,392
2024	189	2044	48,838
2025	267	2045	49,448
2026	379	2046	55,280
2027	538	2047	61,333
2028	764	2048	67,305
2029	1086	2049	72,877
2030	1538	2050	78,319

Table A1.9. Projected EOL EVBs under scenario 8, high AFV, medium change in regulations

Year	Projected EOL EVBs	Year	Projected EOL EVBs
2011	0	2031	1879
2012	0	2032	2542
2013	1	2033	3401
2014	1	2034	4495
2015	3	2035	5865
2016	6	2036	7552
2017	11	2037	9587
2018	18	2038	11,991
2019	29	2039	14,773
2020	44	2040	17,961
2021	64	2041	21,551
2022	93	2042	25,580
2023	133	2043	30,087
2024	188	2044	35,113
2025	265	2045	40,662
2026	371	2046	46,820
2027	519	2047	53,611
2028	722	2048	60,749
2029	1000	2049	67,866
2030	1376	2050	74,982

Table A1.10. Projected EOL EVBs under scenario 9, high AFV, high change in regulations

Year	Projected EOL EVBs	Year	Projected EOL EVBs
2011	0	2031	2463
2012	0	2032	3505
2013	1	2033	4912
2014	1	2034	6759
2015	3	2035	9114
2016	6	2036	12,032
2017	11	2037	15,533
2018	18	2038	19,601
2019	29	2039	24,176
2020	44	2040	29,917
2021	64	2041	34,530
2022	93	2042	40,082
2023	133	2043	45,747
2024	189	2044	51,408
2025	270	2045	56,920
2026	387	2046	62,352
2027	588	2047	67,690
2028	810	2048	72,636
2029	1178	2049	76,916
2030	1710	2050	81,008

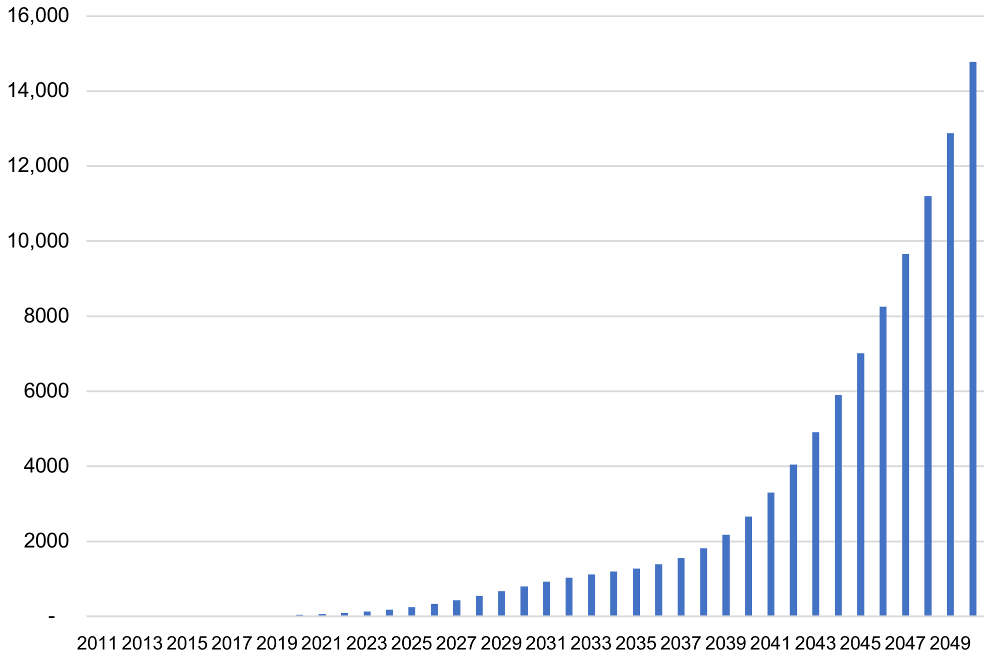

Figure A1.10. Projected EOL EVBs under scenario 1, low AFV, low change in regulations.

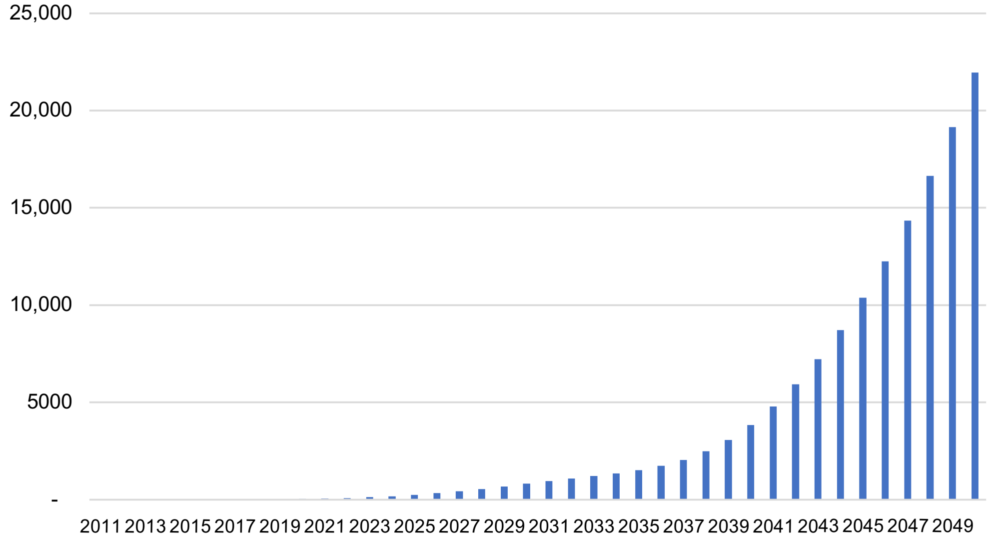

Figure A1.11. Projected EOL EVBs under scenario 2, low AFV, medium change in regulations.

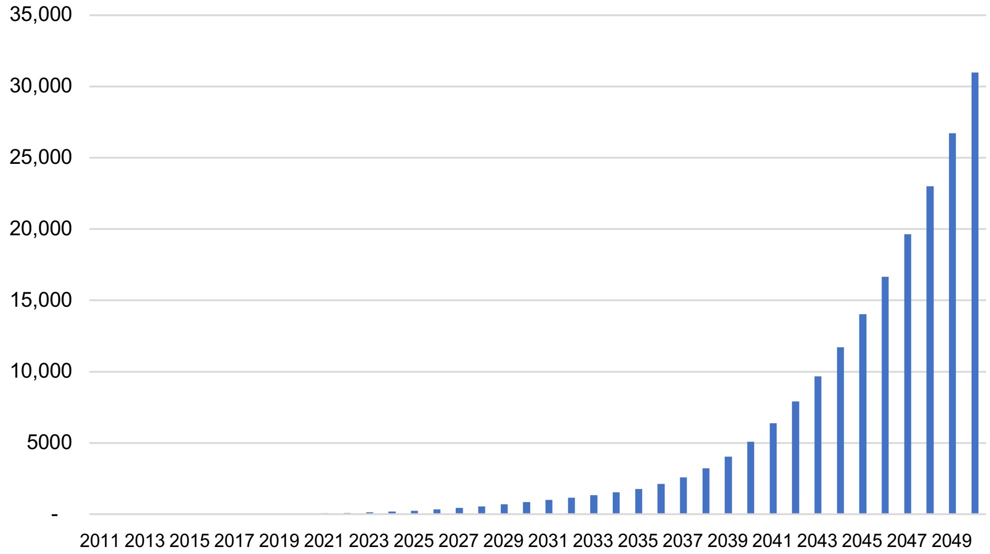

Figure A1.12. Projected EOL EVBs under scenario 3, low AFV, high change in regulations.

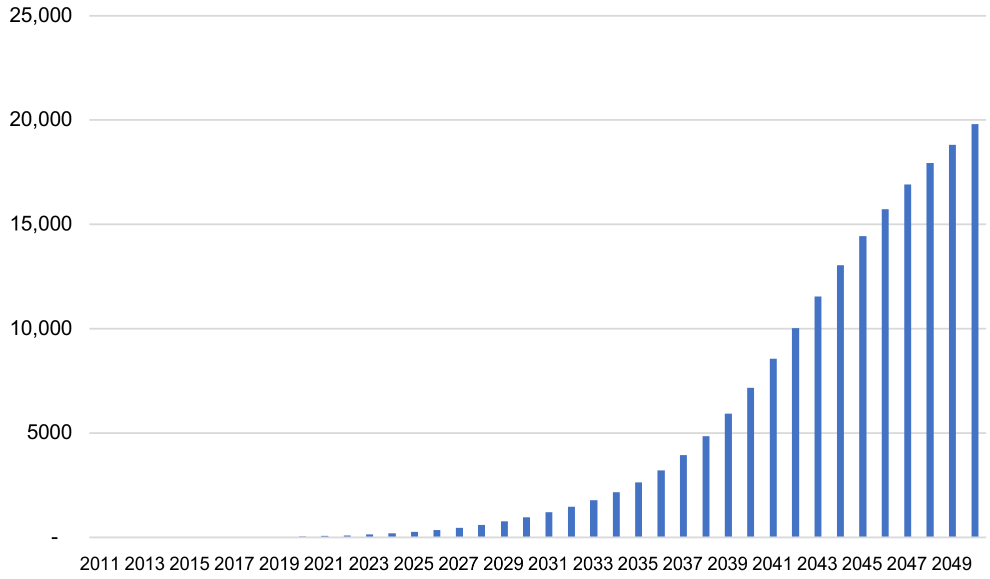

Figure A1.13. Projected EOL EVBs under scenario 4, medium AFV, low change in regulations.

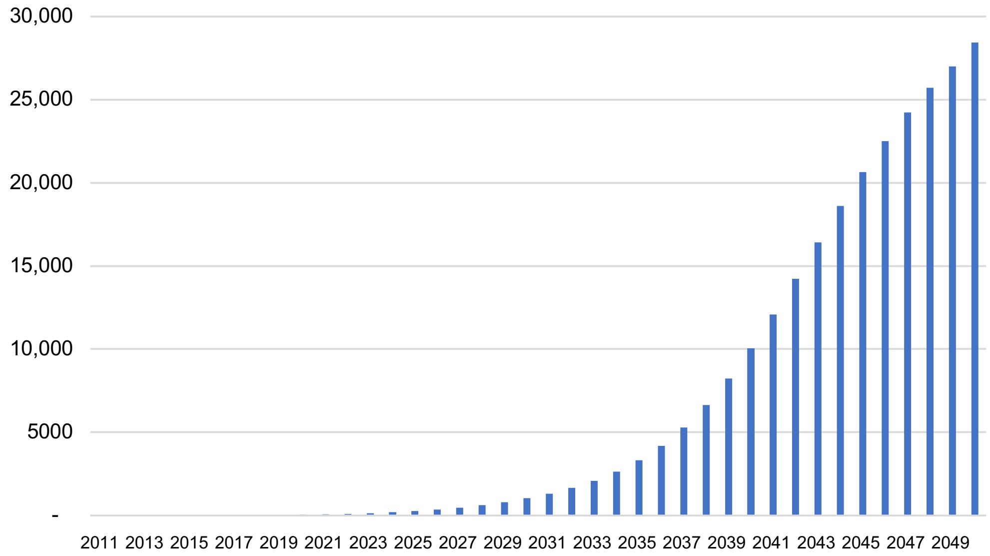

Figure A1.14. Projected EOL EVBs under scenario 5, medium AFV, medium change in regulations.

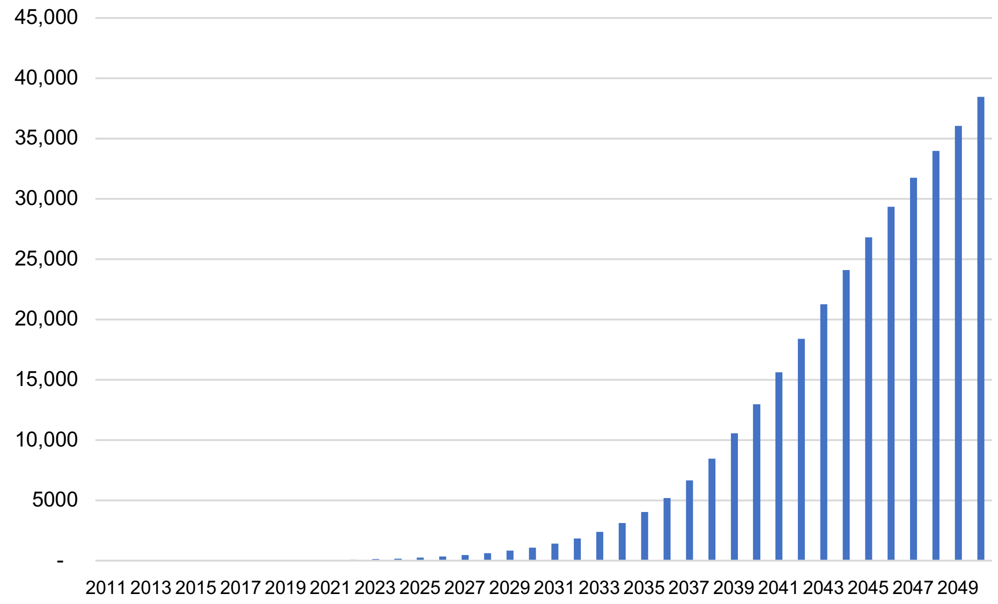

Figure A1.15. Projected EOL EVBs under scenario 6, medium AFV, high change in regulations.

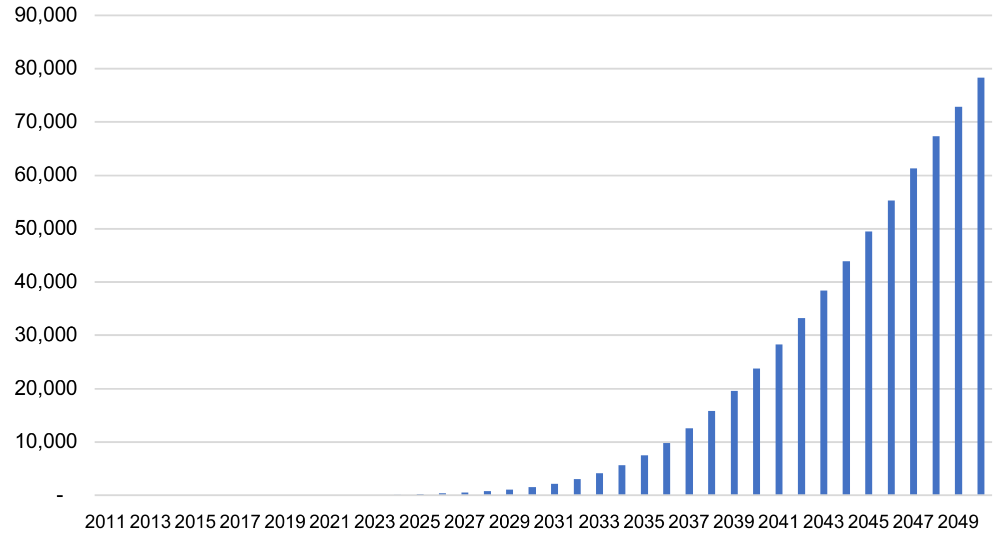

Figure A1.16. Projected EOL EVBs under scenario 7, high AFV, low change in regulations.

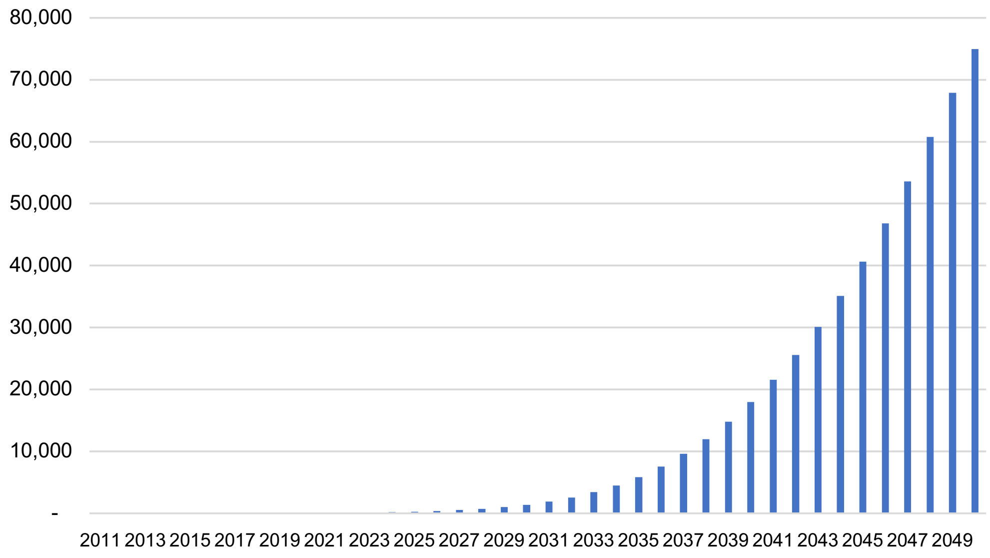

Figure A1.17. Projected EOL EVBs under scenario 8, high AFV, medium change in regulations.

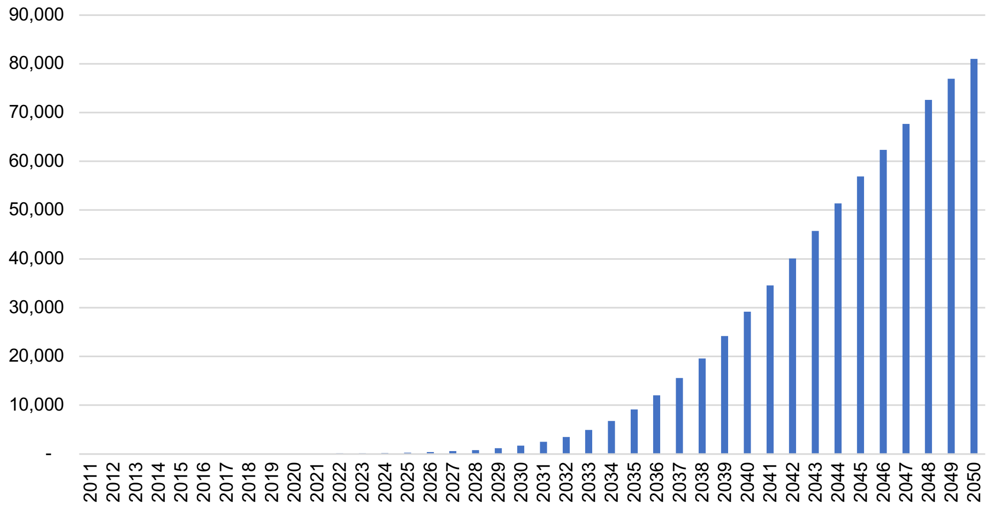

Figure A1.18. Projected EOL EVBs under scenario 9, high AFV, high change in regulations.

Appendix 2 PV WEEE Projections

Table A2.1. Total (domestic + commercial) PV WEEE projection amounts, in kg, for all four projected scenarios

		ISEA (2021)		
Year	Eirgrid (2021)	BAU	Moderate ambition	High ambition
2021.5	0.00	0.00	0.01	0.01
2022	71.43	48.65	101.45	120.17
2022.5	404.07	275.19	573.91	679.77
2023	1185.05	816.46	1700.97	2003.45
2023.5	2690.59	1885.51	3922.34	4582.03
2024	5179.32	3769.00	7675.91	8905.77
2024.5	8988.75	6961.53	13,573.46	15,658.72
2025	14,432.44	11,910.36	22,222.54	25,634.54
2025.5	21,897.37	19,188.18	34,442.57	40,052.34
2026	31,741.54	29,352.18	51,041.85	60,049.87
2026.5	44,391.62	43,124.99	73,086.12	87,087.32
2027	60,240.47	61,235.10	101,567.86	122,631.29
2027.5	79,744.67	84,651.37	137,704.52	168,633.78
2028	103,321.76	114,222.65	182,647.52	226,933.98
2028.5	131,447.34	150,913.69	237,803.17	299,823.03
2029	164,551.89	195,659.07	304,462.72	389,433.52
2029.5	203,117.32	249,606.34	384,141.72	498,339.15
2030	247,573.30	313,758.63	478,245.53	628,903.97
2030.5	298,393.15	389,217.72	588,429.16	783,904.35
2031	355,990.14	477,045.43	716,236.46	965,874.17
2031.5	420,813.12	578,529.95	863,512.96	1,177,747.07
2032	493,169.40	694,592.33	1,031,571.17	1,421,664.13
2032.5	573,273.20	825,943.79	1,221,418.31	1,699,309.79
2033	661,261.13	973,138.53	1,433,833.10	2,012,026.11
2033.5	757,195.67	1,136,588.18	1,669,387.56	2,360,845.34
2034	861,064.99	1,316,565.22	1,928,452.47	2,746,498.06
2034.5	972,781.33	1,513,201.30	2,211,195.62	3,169,409.86
2035	1,092,178.55	1,726,482.75	2,517,575.98	3,629,691.64
2035.5	1,219,009.59	1,956,244.79	2,847,335.92	4,127,126.47
2036	1,352,943.81	2,202,164.81	3,199,992.23	4,661,154.41
2036.5	1,493,564.84	2,463,755.69	3,574,827.09	5,230,856.74
2037	1,640,368.77	2,740,359.28	3,970,879.44	5,834,940.53
2037.5	1,792,763.20	3,031,140.73	4,386,937.36	6,471,724.45
2038	1,950,067.04	3,335,083.79	4,821,532.13	7,139,126.77
2038.5	2,111,511.42	3,650,987.69	5,272,934.29	7,834,656.13
2039	2,276,241.80	3,977,465.77	5,739,152.32	8,555,406.11
2039.5	2,443,321.27	4,312,946.19	6,217,934.29	9,298,054.14
2040	2,611,735.36	4,655,675.17	6,706,772.93	10,058,865.55
2040.5	2,780,398.29	5,003,722.80	7,202,914.55	10,833,703.31
2041	2,948,160.71	5,354,991.93	7,703,371.96	11,618,044.16

Table A2.1. Continued

		ISEA (2021)		
Year	Eirgrid (2021)	BAU	Moderate ambition	High ambition
2041.5	3,113,819.10	5,707,230.04	8,204,941.84	12,407,001.49
2042	3,276,126.56	6,058,044.43	8,704,226.56	13,195,355.43
2042.5	3,433,805.20	6,404,920.78	9,197,660.71	13,977,590.30
2043	3,585,559.82	6,745,244.95	9,681,542.10	14,747,939.67
2043.5	3,730,092.92	7,076,328.12	10,152,067.39	15,500,438.82
2044	3,866,120.66	7,395,434.96	10,605,371.79	16,228,984.42
2044.5	3,992,389.75	7,699,814.70	11,037,572.80	16,927,400.94
2045	4,107,694.87	7,986,734.59	11,444,817.18	17,589,513.22
2045.5	4,210,896.30	8,253,515.57	11,823,330.80	18,209,224.27
2046	4,300,937.63	8,497,569.30	12,169,470.44	18,780,597.15
2046.5	4,376,862.86	8,716,436.21	12,479,776.79	19,297,939.91
2047	4,437,832.88	8,907,823.73	12,751,027.62	19,755,891.77
2047.5	4,483,140.65	9,069,643.95	12,980,290.21	20,149,509.31
2048	4,512,224.89	9,200,050.04	13,164,971.77	20,474,350.52
2048.5	4,524,681.84	9,297,470.35	13,302,866.84	20,726,555.24
2049	4,520,274.80	9,360,639.67	13,392,200.44	20,902,919.75
2049.5	4,498,941.08	9,388,626.52	13,431,665.94	21,000,963.87
2050	4,460,796.19	9,380,855.89	13,420,456.51	21,018,988.55

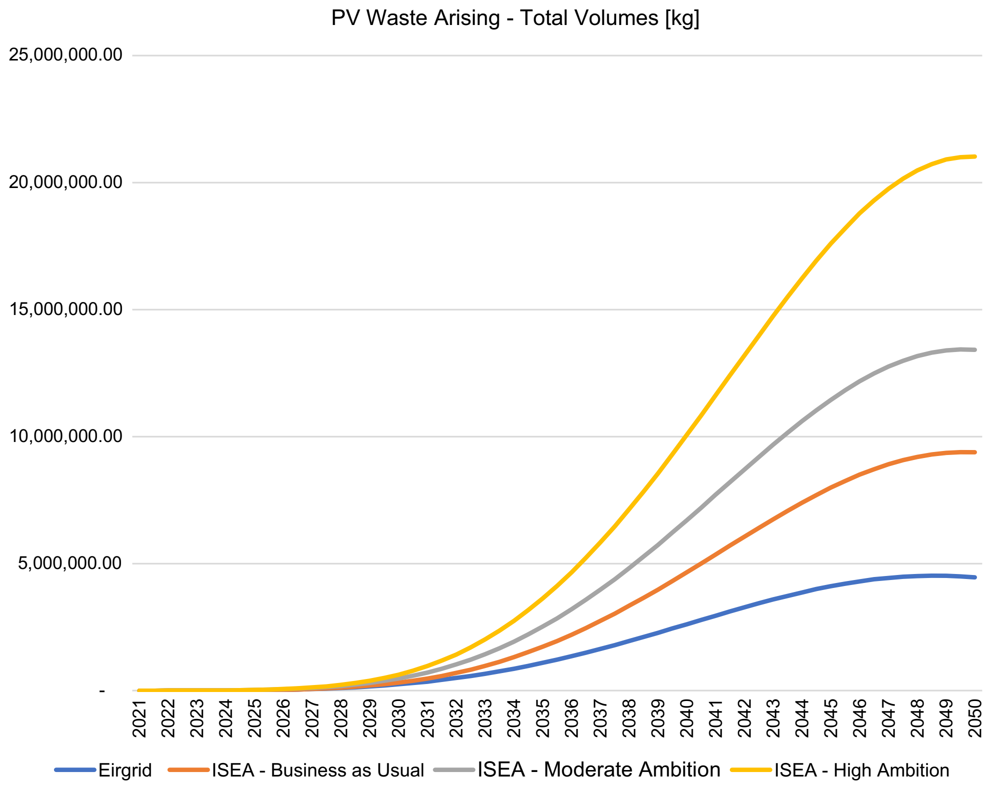

Figure A2.1. Total (domestic+commercial) PV WEEE projection amounts, in kg, for all four projected scenarios.

Table A2.2. Domestic PV WEEE projection amounts, in kg, for all four projected scenarios

		ISEA (2021)		
Year	Eirgrid (2021)	BAU	Moderate ambition	High ambition
2021.5	0.00	0.00	0.00	0.00
2022	24.23	3.77	7.96	16.80
2022.5	137.09	21.32	45.02	95.03
2023	402.18	63.07	135.90	284.48
2023.5	913.57	144.99	321.65	665.45
2024	1758.96	286.98	637.50	1315.61
2024.5	3052.41	521.85	1126.13	2341.27
2025	4899.81	882.45	1834.84	3860.48
2025.5	7431.66	1414.81	2832.23	6048.42
2026	10,768.68	2162.02	4199.05	9081.10
2026.5	15,054.59	3178.80	6060.41	13,199.86
2027	20,421.74	4518.54	8534.74	18,635.64
2027.5	27,023.83	6249.79	11,776.56	25,685.03
2028	35,001.41	8436.19	15,931.81	34,644.45
2028.5	44,514.48	11,154.62	21,183.64	45,904.71
2029	55,707.84	14,478.38	27,700.98	59,823.21
2029.5	68,743.54	18,497.32	35,686.20	76,828.96
2030	83,765.98	23,299.13	45,327.09	97,324.77
2030.5	100,934.20	28,994.66	56,846.38	121,797.38
2031	120,387.32	35,685.28	70,446.49	150,680.79
2031.5	142,276.86	43,491.65	86,360.62	184,466.78
2032	166,706.39	52,500.69	104,760.21	223,517.94
2032.5	193,747.99	62,780.56	125,781.27	268,122.14
2033	223,447.52	74,385.83	149,533.40	318,511.24
2033.5	255,825.81	87,358.98	176,102.34	374,866.49
2034	290,878.59	101,730.90	205,550.64	437,319.94
2034.5	328,575.98	117,520.83	237,917.44	505,953.90
2035	368,861.64	134,736.07	273,217.67	580,799.37
2035.5	411,651.92	153,371.53	311,441.04	661,833.84
2036	456,835.02	173,409.13	352,550.78	748,978.75
2036.5	504,270.17	194,817.29	396,482.43	842,096.77
2037	553,787.12	217,550.30	443,142.50	940,989.20
2037.5	605,185.78	241,547.77	492,407.35	1,045,393.47
2038	658,236.16	266,734.19	544,122.10	1,154,980.95
2038.5	712,678.71	293,018.58	598,099.88	1,269,355.33
2039	768,225.01	320,294.17	654,121.24	1,388,051.43
2039.5	824,558.89	348,438.45	711,933.95	1,510,534.78
2040	881,338.10	377,313.15	771,253.18	1,636,202.08
2040.5	938,196.37	406,764.69	831,762.13	1,764,382.47
2041	994,746.06	436,624.63	893,113.10	1,894,339.93
2041.5	1,050,581.34	466,710.56	954,929.17	2,025,276.73
2042	1,105,281.81	496,827.11	1,016,806.36	2,156,338.11
2042.5	1,158,416.69	526,767.36	1,078,316.44	2,286,618.18
2043	1,209,549.47	556,314.45	1,139,010.27	2,415,167.02
2043.5	1,258,242.92	585,243.49	1,198,421.84	2,540,999.16
2044	1,304,064.51	613,323.78	1,256,072.74	2,663,103.12

Table A2.2. Continued

		ISEA (2021)		
Year	**Eirgrid (2021)**	**BAU**	**Moderate ambition**	**High ambition**
2044.5	1,346,592.07	640,321.21	1,311,477.33	2,780,452.26
2045	1,385,419.70	666,001.01	1,364,148.33	2,892,016.58
2045.5	1,420,163.70	690,130.58	1,413,602.87	2,996,775.51
2046	1,450,468.48	712,482.57	1,459,368.91	3,093,731.40
2046.5	1,476,012.41	732,838.05	1,500,991.92	3,181,923.63
2047	1,496,513.27	750,989.79	1,538,041.71	3,260,442.99
2047.5	1,511,733.43	766,745.41	1,570,119.25	3,328,446.11
2048	1,521,484.40	779,930.71	1,596,863.48	3,385,169.68
2048.5	1,525,630.81	790,392.61	1,617,957.77	3,429,944.09
2049	1,524,093.59	798,002.11	1,633,135.97	3,462,206.29
2049.5	1,516,852.30	802,656.86	1,642,187.96	3,481,511.34
2050	1,503,946.55	804,283.44	1,644,964.47	3,487,542.57

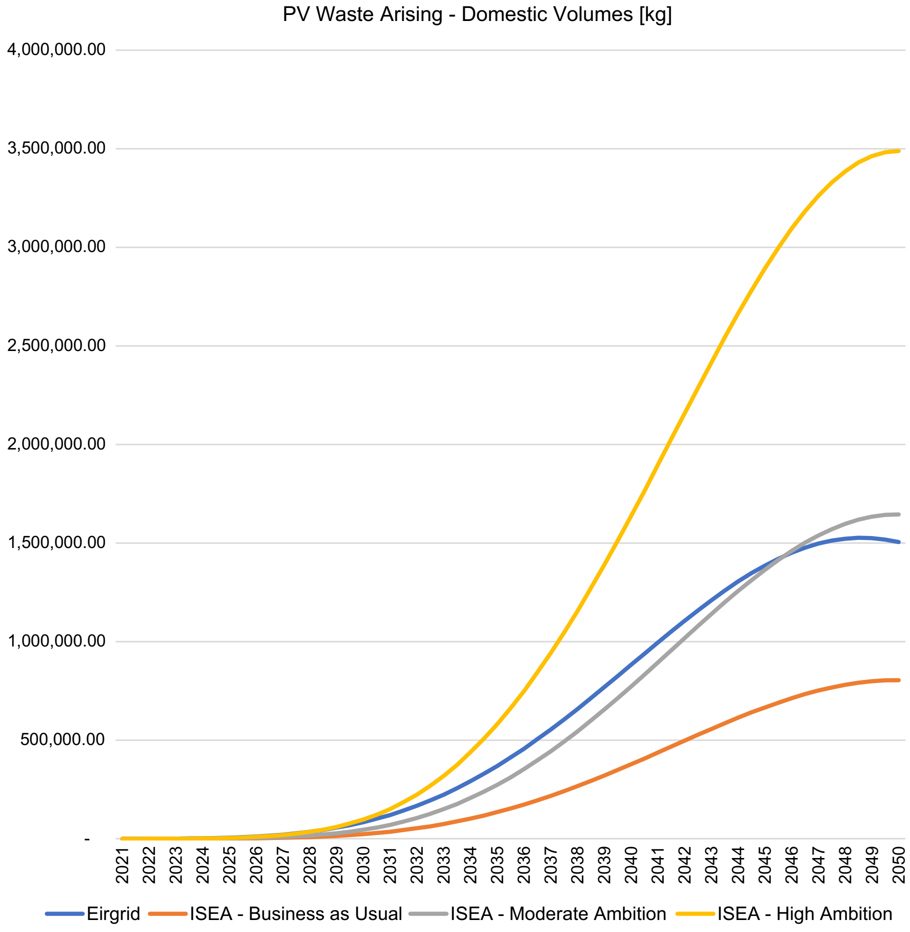

Figure A2.2. Domestic PV WEEE projection amounts, in kg, for all four projected scenarios.

Table A2.3. Commercial PV WEEE projection amounts, in kg, for all four projected scenarios

		ISEA (2021)		
Year	Eirgrid (2021)	BAU	Moderate ambition	High ambition
2021.5	0.00	0.00	0.01	0.01
2022	47.20	44.88	93.50	103.37
2022.5	266.98	253.87	528.89	584.74
2023	782.87	753.39	1565.08	1718.97
2023.5	1777.03	1740.52	3600.69	3916.59
2024	3420.36	3482.02	7038.41	7590.16
2024.5	5936.34	6439.67	12,447.34	13,317.45
2025	9532.63	11,027.91	20,387.70	21,774.06
2025.5	14,465.71	17,773.38	31,610.35	34,003.92
2026	20,972.87	27,190.17	46,842.80	50,968.77
2026.5	29,337.03	39,946.19	67,025.71	73,887.46
2027	39,818.73	56,716.57	93,033.12	103,995.65
2027.5	52,720.84	78,401.58	125,927.96	142,948.74
2028	68,320.36	105,786.46	166,715.71	192,289.53
2028.5	86,932.87	139,759.07	216,619.53	253,918.32
2029	108,844.05	181,180.69	276,761.74	329,610.31
2029.5	134,373.79	231,109.02	348,455.52	421,510.19
2030	163,807.32	290,459.51	432,918.44	531,579.20
2030.5	197,458.95	360,223.06	531,582.78	662,106.97
2031	235,602.82	441,360.15	645,789.97	815,193.38
2031.5	278,536.26	535,038.30	777,152.34	993,280.29
2032	326,463.02	642,091.64	926,810.97	1,198,146.19
2032.5	379,525.21	763,163.23	1,095,637.04	1,431,187.66
2033	437,813.61	898,752.70	1,284,299.70	1,693,514.87
2033.5	501,369.86	1,049,229.19	1,493,285.22	1,985,978.84
2034	570,186.41	1,214,834.32	1,722,901.83	2,309,178.12
2034.5	644,205.35	1,395,680.46	1,973,278.18	2,663,455.96
2035	723,316.92	1,591,746.68	2,244,358.31	3,048,892.27
2035.5	807,357.66	1,802,873.26	2,535,894.88	3,465,292.63
2036	896,108.79	2,028,755.68	2,847,441.44	3,912,175.67
2036.5	989,294.67	2,268,938.40	3,178,344.66	4,388,759.97
2037	1,086,581.65	2,522,808.99	3,527,736.94	4,893,951.32
2037.5	1,187,577.42	2,789,592.96	3,894,530.01	5,426,330.99
2038	1,291,830.88	3,068,349.59	4,277,410.03	5,984,145.81
2038.5	1,398,832.71	3,357,969.12	4,674,834.41	6,565,300.79
2039	1,508,016.79	3,657,171.60	5,085,031.08	7,167,354.68
2039.5	1,618,762.38	3,964,507.75	5,506,000.34	7,787,519.36
2040	1,730,397.26	4,278,362.01	5,935,519.75	8,422,663.47
2040.5	1,842,201.92	4,596,958.11	6,371,152.42	9,069,320.84
2041	1,953,414.65	4,918,367.30	6,810,258.86	9,723,704.23
2041.5	2,063,237.76	5,240,519.48	7,250,012.67	10,381,724.77
2042	2,170,844.75	5,561,217.32	7,687,420.20	11,039,017.32
2042.5	2,275,388.50	5,878,153.42	8,119,344.27	11,690,972.12
2043	2,376,010.35	6,188,930.50	8,542,531.83	12,332,772.65
2043.5	2,471,850.00	6,491,084.63	8,953,645.55	12,959,439.66
2044	2,562,056.15	6,782,111.19	9,349,299.05	13,565,881.30

Table A2.3. Continued

Year	Eirgrid (2021)	ISEA (2021)		
		BAU	Moderate ambition	High ambition
2044.5	2,645,797.69	7,059,493.48	9,726,095.47	14,146,948.67
2045	2,722,275.17	7,320,733.58	10,080,668.85	14,697,496.64
2045.5	2,790,732.61	7,563,384.99	10,409,727.93	15,212,448.76
2046	2,850,469.15	7,785,086.73	10,710,101.53	15,686,865.76
2046.5	2,900,850.45	7,983,598.16	10,978,784.86	16,116,016.28
2047	2,941,319.61	8,156,833.94	11,212,985.91	16,495,448.78
2047.5	2,971,407.22	8,302,898.54	11,410,170.96	16,821,063.20
2048	2,990,740.49	8,420,119.33	11,568,108.29	17,089,180.85
2048.5	2,999,051.03	8,507,077.74	11,684,909.07	17,296,611.15
2049	2,996,181.21	8,562,637.56	11,759,064.47	17,440,713.46
2049.5	2,982,088.78	8,585,969.66	11,789,477.98	17,519,452.53
2050	2,956,849.64	8,576,572.45	11,775,492.04	17,531,445.98

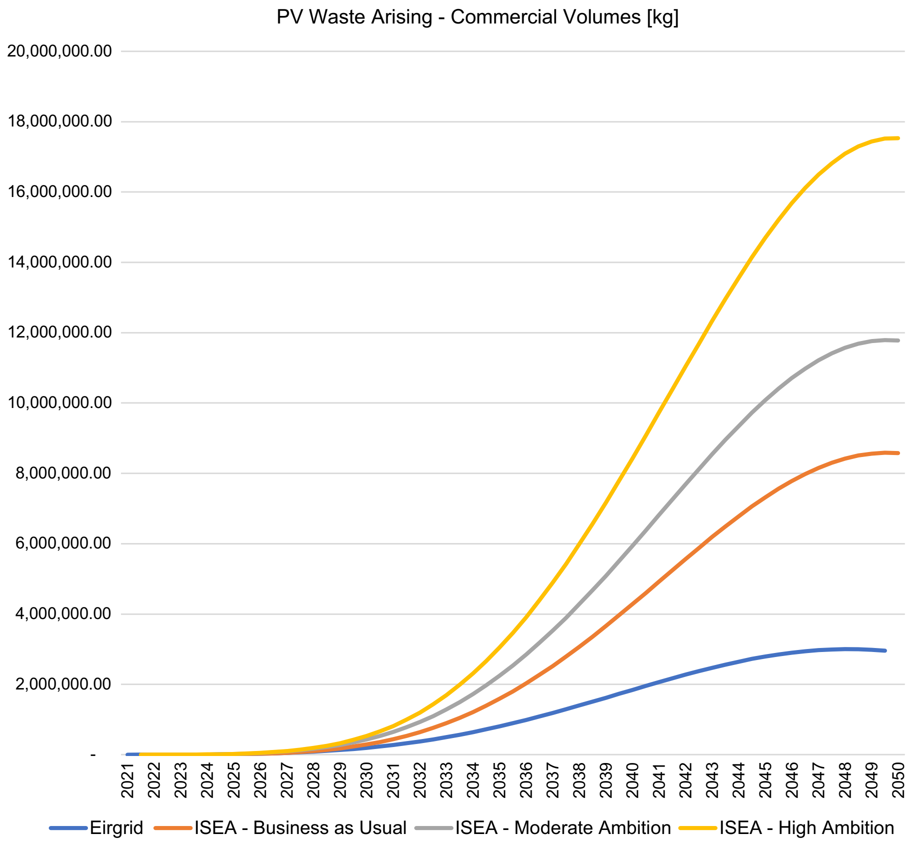

Figure A2.3. Commercial PV WEEE projection amounts, in kg, for all four projected scenarios.

An Ghníomhaireacht Um Chaomhnú Comhshaoil

Tá an GCC freagrach as an gcomhshaol a chosaint agus a fheabhsú, mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ar thionchar díobhálach na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialáil: Rialáil agus córais chomhlíonta comhshaoil éifeachtacha a chur i bhfeidhm, chun dea-thorthaí comhshaoil a bhaint amach agus díriú orthu siúd nach mbíonn ag cloí leo.

Eolas: Sonraí, eolas agus measúnú ardchaighdeáin, spriocdhírithe agus tráthúil a chur ar fáil i leith an chomhshaoil chun bonn eolais a chur faoin gcinnteoireacht.

Abhcóideacht: Ag obair le daoine eile ar son timpeallachta glaine, táirgiúla agus dea-chosanta agus ar son cleachtas inbhuanaithe i dtaobh an chomhshaoil.

I measc ár gcuid freagrachtaí tá:

Ceadúnú

- Gníomhaíochtaí tionscail, dramhaíola agus stórála peitril ar scála mór;
- Sceitheadh fuíolluisce uirbigh;
- Úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe;
- Foinsí radaíochta ianúcháin;
- Astaíochtaí gás ceaptha teasa ó thionscal agus ón eitlíocht trí Scéim an AE um Thrádáil Astaíochtaí.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

- Iniúchadh agus cigireacht ar shaoráidí a bhfuil ceadúnas acu ón GCC;
- Cur i bhfeidhm an dea-chleachtais a stiúradh i ngníomhaíochtaí agus i saoráidí rialáilte;
- Maoirseacht a dhéanamh ar fhreagrachtaí an údaráis áitiúil as cosaint an chomhshaoil;
- Caighdeán an uisce óil phoiblí a rialáil agus údaruithe um sceitheadh fuíolluisce uirbigh a fhorfheidhmiú
- Caighdeán an uisce óil phoiblí agus phríobháidigh a mheasúnú agus tuairisciú air;
- Comhordú a dhéanamh ar líonra d'eagraíochtaí seirbhíse poiblí chun tacú le gníomhú i gcoinne coireachta comhshaoil;
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Dramhaíola agus Ceimiceáin sa Chomhshaol

- Rialacháin dramhaíola a chur i bhfeidhm agus a fhorfheidhmiú lena n-áirítear saincheisteanna forfheidhmithe náisiúnta;
- Staitisticí dramhaíola náisiúnta a ullmhú agus a fhoilsiú chomh maith leis an bPlean Náisiúnta um Bainistíocht Dramhaíola Guaisí;
- An Clár Náisiúnta um Chosc Dramhaíola a fhorbairt agus a chur i bhfeidhm;
- Reachtaíocht ar rialú ceimiceán sa timpeallacht a chur i bhfeidhm agus tuairisciú ar an reachtaíocht sin.

Bainistíocht Uisce

- Plé le struchtúir náisiúnta agus réigiúnacha rialachais agus oibriúcháin chun an Chreat-treoir Uisce a chur i bhfeidhm;
- Monatóireacht, measúnú agus tuairisciú a dhéanamh ar chaighdeán aibhneacha, lochanna, uiscí idirchreasa agus cósta, uiscí snámha agus screamhuisce chomh maith le tomhas ar leibhéil uisce agus sreabhadh abhann.

Eolaíocht Aeráide & Athrú Aeráide

- Fardail agus réamh-mheastacháin a fhoilsiú um astaíochtaí gás ceaptha teasa na hÉireann;
- Rúnaíocht a chur ar fáil don Chomhairle Chomhairleach ar Athrú Aeráide agus tacaíocht a thabhairt don Idirphlé Náisiúnta ar Ghníomhú ar son na hAeráide;
- Tacú le gníomhaíochtaí forbartha Náisiúnta, AE agus NA um Eolaíocht agus Beartas Aeráide.

Monatóireacht & Measúnú ar an gComhshaol

- Córais náisiúnta um monatóireacht an chomhshaoil a cheapadh agus a chur i bhfeidhm: teicneolaíocht, bainistíocht sonraí, anailís agus réamhaisnéisiú;
- Tuairiscí ar Staid Thimpeallacht na hÉireann agus ar Tháscairí a chur ar fáil;
- Monatóireacht a dhéanamh ar chaighdeán an aeir agus Treoir an AE i leith Aeir Ghlain don Eoraip a chur i bhfeidhm chomh maith leis an gCoinbhinsiún ar Aerthruailliú Fadraoin Trasteorann, agus an Treoir i leith na Teorann Náisiúnta Astaíochtaí;
- Maoirseacht a dhéanamh ar chur i bhfeidhm na Treorach i leith Torainn Timpeallachta;
- Measúnú a dhéanamh ar thionchar pleananna agus clár beartaithe ar chomhshaol na hÉireann.

Taighde agus Forbairt Comhshaoil

- Comhordú a dhéanamh ar ghníomhaíochtaí taighde comhshaoil agus iad a mhaoiniú chun brú a aithint, bonn eolais a chur faoin mbeartas agus réitigh a chur ar fáil;
- Comhoibriú le gníomhaíocht náisiúnta agus AE um thaighde comhshaoil.

Cosaint Raideolaíoch

- Monatóireacht a dhéanamh ar leibhéil radaíochta agus nochtadh an phobail do radaíocht ianúcháin agus do réimsí leictreamaighnéadacha a mheas;
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha;
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta;
- Sainseirbhísí um chosaint ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Ardú Feasachta agus Faisnéis Inrochtana

- Tuairisciú, comhairle agus treoir neamhspleách, fianaise-bhunaithe a chur ar fáil don Rialtas, don tionscal agus don phobal ar ábhair maidir le cosaint comhshaoil agus raideolaíoch;
- An nasc idir sláinte agus folláine, an geilleagar agus timpeallacht ghlan a chur chun cinn;
- Feasacht comhshaoil a chur chun cinn lena n-áirítear tacú le hiompraíocht um éifeachtúlacht acmhainní agus aistriú aeráide;
- Tástáil radóin a chur chun cinn i dtithe agus in ionaid oibre agus feabhsúchán a mholadh áit is gá.

Comhpháirtíocht agus Líonrú

- Oibriú le gníomhaireachtaí idirnáisiúnta agus náisiúnta, údaráis réigiúnacha agus áitiúla, eagraíochtaí neamhrialtais, comhlachtaí ionadaíocha agus ranna rialtais chun cosaint chomhshaoil agus raideolaíoch a chur ar fáil, chomh maith le taighde, comhordú agus cinnteoireacht bunaithe ar an eolaíocht.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

Tá an GCC á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóir. Déantar an obair ar fud cúig cinn d'Oifigí:

1. An Oifig um Inbhunaitheacht i leith Cúrsaí Comhshaoil
2. An Oifig Forfheidhmithe i leith Cúrsaí Comhshaoil
3. An Oifig um Fhianaise agus Measúnú
4. An Oifig um Chosaint ar Radaíocht agus Monatóireacht Comhshaoil
5. An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tugann coistí comhairleacha cabhair don Ghníomhaireacht agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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