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Executive Summary

Photovoltaic (PV) Waste Management in Israel

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מכון ירושלים למחקרי מדיניות
מרכז מילקן לחדשנות

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About the Milken Innovation Center Fellows Program

The Milken Innovation Center Fellows Program accelerates Israel's economic growth through innovative, market-based solutions for long-term economic, social, and environmental challenges. Our goal is to accelerate Israel's transition from a Start-up Nation to a Global Nation with solutions that others can replicate.

The Program awards annual fellowships to outstanding Israeli graduate students. We train and deploy some of Israel's best and brightest young professionals to create pragmatic financing and economic policy solutions. Our applied research and Financial Innovations Labs® are a launching pad for transformative change, using innovative financing mechanisms, programs and policies to bridge social, regional, economic and productivity gaps within Israel and between Israel and the world.

In addition, Fellows craft their own projects during their internship aimed at barriers to job creation and capital formation in Israel. The Fellows' research, carried out under the guidance of an experienced academic and professional staff, support business and policy makers to shape economic reality in Israel. The program offers the ultimate training opportunity, combining real-life work experience with applied research.

Throughout the year, Fellows receive intensive training in economic and financial analysis, public policy and research methods. They acquire tools for communication and presentation, policy analysis, leadership and project management. The fellows participate in a weekly research training workshop where they work with senior economic and government professionals, business leaders, and top academic and financial practitioners from Israel and abroad. They also participate in an accredited MBA course, taught at the Hebrew University School of Business Administration by Prof. Glenn Yago.

Fellows Program alumni can be found in senior positions in the public and private sectors. Some serve in key positions in government ministries while others work at private-sector companies or go on to advanced graduates studies at leading universities in Israel, the United States and Great Britain.

The Fellows Program is a non-partisan. It is funded, in part, by the Milken Institute and other leading philanthropic organizations and individuals in the United States and Israel.

The transition from fossil fuels to renewable energy is one of the most effective strategies for reducing greenhouse gas emissions. Solar energy use has seen the fastest growth among all renewable energy sources over the past decade and is expanding at a rate that exceeds all predictions. While the production process of solar systems involves greenhouse gas emissions, the energy payback period has shortened to around one year by 2024.

A photovoltaic (PV) module is designed to last over 30 years. However, research shows that some PV modules are decommissioned before reaching the end of their expected lifetime. The growing number of PV installations combined with early removal, present an increasing challenge of PV module waste that has to be addressed.

Israel has set a target to integrate renewable energy into its electricity grid, with a goal of 30% of its electricity to be produced from renewable sources by 2030. To meet this goal, a significant number of solar systems have been installed, along with other renewable technologies such as wind and biogas facilities. In 2023, solar power made up 90% of Israel's installed renewable capacity, largely due to the country's high solar irradiation, both in terms of intensity and hours of sunlight per year. To date, total solar capacity reached approximately 5.5GW. To meet its target by 2030, the installed capacity will need to more than triple.

Objectives

PV modules have been installed in Israel since 2009. Although there are regulations covering most aspectes of PV management - such as the installation process, grid connection and Fid-in Tariffs - there is still no regulation addressing end-of-life management of PV modules. Additionally, no estimates have been made for the volume of PV waste expected in the coming years. The objectives of this research are: 1) assess the annual and cumulative volumes of PV module waste in Israel through 2050, and 2) recommend policy measures that effectively address the issue of PV module waste.

Methodology

Assessing PV waste volume requires developing a power-to-mass ratio for converting the annual installed capacity (measured in megawatts) into mass (measured in tonnes). The ratio was calculated using data about module weight and nominal power installed each year in Israel by 2023. The data was provided by several renewable energy companies operating in Israel. PV

module's efficiency increase annually, resulting in a decreasing power-to-mass ratio. Therefore, the projected power-to-mass ratio by 2050 is calculated using an exponential decay function, to account for the ever increasing efficiency.

The time-to-failure of PV modules is assessed using the probability density function of the Weibull distribution, a common method for evaluating failure rates and estimating the lifetime of electronic devices. Using this method, this study estimates PV waste volumes according to three scenarios: the first scenario is based on technical degradation, the second follows the European Union's parameters for estimating PV module waste, and the third incorporates technical degradation, damage and typical technical failures, and economic incentives to replace the modules.

Waste estimates also consider the installed capacity required to meet the Government's 2030 renewable energy target, along with two 2050 scenarios developed by the Ministry of Energy. These scenarios assume different rates of renewable energy adopted and integrated into the electricity grid - 54% and 90%.

Results

This study's results indicate that the annual waste volumes would range between 1,375-12,482 tonnes by 2030, and between 50,098-110,882 tonnes by 2050. Cumulative waste volumes are expected to range between 5,087-63,272 tonnes by 2030, and between 378,426-1,185,049 tonnes by 2050. Additionally, the volume of recovered materials for 2050 is calculated according to material type, based on the maximum recovery rates achievable during the recycling process. PV waste data gathered from energy companies that install PV modules in Israel shows that actual cumulative waste volumes to date (2023) range between the estimations of the second (4,064 tonnes) and the third (11,421 tonnes) scenario.

The vast majority of PV installations in Israel use silicon-based modules, which are the primary focus of this study, though other prevalent PV technologies are also reviewed. Israel doesn't have a PV recycling infrastructure, therefore, decommissioned PV modules are either landfilled or sold for reuse abroad. When waste volumes are low, most decommissioned PV modules worldwide are recycled mechanically, recovering bulk material rather than extracting high-value materials. As waste volumes increase, other recycling options are viable. Given the low PV waste volumes in

Israel, a financing mechanism or well-structured policy is needed to incentivize the establishment and operation of recycling facilities.

Policy measures

This study provides a review of global strategies and policy measures for PV waste management, including financial and operational responsibilities, target setting, PV module waste classification, and other waste management actions according to the waste hierarchy. While the European Union (EU) implements an extended producer responsibility (EPR) framework, countries like Taiwan and Japan use consumer responsibility to finance End-of-Life management for PV modules. Countries also vary in their collection and recycling targets; the EU sets the collection targets based on the volume of products placed on the market, while Taiwan aims to collect all the decommissioned modules.

Although all EU Member States implement EPR schemes to finance and operate PV waste management, they apply different financial models. France applies a 'pay as you put' approach, where an upfront payment is set to ensure collection and recycling. Other Member States use a 'pay as you throw' approach - where the producers pay when the waste is generated. The latter is usually combined with 'last man standing' insurance strategy - when producers exit the market without fulfilling their waste management responsibilities, the remaining producers cover the costs. Germany, on the other hand, applies a mandatory insurance policy to secure waste management funds in case the producer ceases to exist.

Since Taiwan and Japan implement consumer responsibility, they both established a PV waste management fund, where consumers pay recycling fees. This fund is financed through a recycling levy collected via the Feed-In-Tariff according to the amount of energy generated (Japan) or as a fixed annual payment according to the installed capacity (Taiwan).

As for collection targets, most EU Member States have set a collection target of 65% based on the average weight of products placed on the market over the previous three years (applies for all electric and electronic products, including PV modules). France, on top of this target, has a standard service where the producer responsibility organization (PRO) responds to every collection request of PV waste. Poland is the only EU Member State to set a collection target based on an annual waste projection, requiring producers to collect 85% of the estimated waste for that

year. Taiwan aims to collect all the generated waste, as PV owners register the modules both upon purchase and disposal.

PV module management in Israel

In 2012, inspired by the EU's Waste Electrical and Electronic Equipment Directive, Israel enacted the Environmental Treatment of Electric and Electronic Equipment and Batteries law (ETEEEB). This law places an extended producer responsibility on producers and importers of these products. Although the EU included PV modules under the directive's scope, Israel has not. Over the years, the Ministry of Environmental Protection has received several inquiries regarding the inclusion of PV modules under this law, but the legal status of PV modules has yet to be resolved.

Including PV modules under the current ETEEEB law introduces several difficulties, as the PV market and the electric and electronic products market differ in critical aspects. In mature and saturated markets, such as refrigerators or washing machines, the waste volumes are roughly similar to the volumes of products entering the market. PV modules market, on the other hand, is an emerging market, and the amount of installed modules greatly exceeds the waste volumes. Another difference is that PV modules generally have a much longer lifespan than most electronic devices.

The current recycling target for electric and electronic equipment is set at a minimum of 50% of all products placed on the market in the preceding year. Regulating PV modules under the current ETEEEB law would increase the amount of products placed on the market, but will contribute only a negligible amount of waste. This would lead to an immediate surge in the recycling rates of electronic waste, and would make it hard for PROs to meet the goal. For instance, if we would estimate PV waste volumes for 2025 according to the moderate scenario (second estimation scenario), PRO's would have to recycle 72% instead of 50% of total electronic waste to meet the collective recycling target.

The same situation would apply for the funds for PV module waste management under the current financing system. Since more PV modules are entering the market than those being decommissioned, and given that they have a longer lifespan than other electronic products, the current PV waste volumes are low. As a result, funds intended for PV waste treatment may be redirected to recycle waste of electric and electronic products. This may lead to insufficient funds

in the future for collection and treatment once the modules reach end-of-life. Therefore, it is essential to ensure dedicated financial resources for managing PV module waste. Additionally, under the current ETEEEB law, PROs operate as profit-oriented organizations with a five-year approval period. This means that any funds collected but not used for PV or other electronic waste treatment would become the property of the PRO, thereby failing to fulfill their intended purpose. Ultimately, regulating PV modules under the current ETEEEB law would not support the implementation of a suitable funding system.

Recommendations

Consequently, this research's primary recommendation is to amend the ETEEEB law to better address key aspects of PV waste management. The main challenge is to develop a sustainable funding mechanism to ensure sufficient financing for PV waste treatment over the next two to three decades. It is therefore proposed to establish a designated fund, managed by a third party to allocate resources according to the PV waste treatment requirements. Funds could be collected as an upfront payment at the time of purchase or through the Feed-in-Tariff over the initial years of use.

Furthermore, as the PV market is still an emerging, unsaturated market of products with a long lifetime, where the installed module volumes greatly exceed waste volumes, it is recommended to set collection targets based on an annual waste estimates rather than on volumes placed on the market. Regardless of the annual collection targets, it is advised to establish a service standard, ensuring that requests to collect decommissioned PV modules without replacement are fulfilled within a reasonable timeframe. As for recycling targets, they should be determined by the recovery rates achievable in the recycling process. An 85% of the collected volume is a reasonable recycling target that matches the European recovery target and can be achieved even through mechanical bulk recycling.

Additionally, since producers should be accountable for their impact on pollution under the polluter-pays-principle, and as the PRO framework provides a suitable operational infrastructure, it is recommended to implement extended producer responsibility for PV modules. This responsibility should be placed not only on producers, importers, distributors, and online sellers, but also on energy companies that import and install PV modules in Israel. As PV modules require

an expert or a certified installer, it is advised to mandate take-back schemes, where installers would collect the decommissioned modules and transport them to authorized treatment facilities.

Lastly, as data on actual decommissioned PV modules show, other than serial recalls, most decommissioning operations were due to repowering of utility scale installations. Consequently, applying measures like waste prevention or reuse may extend the use phase, reduce waste volumes and reduce the environmental impact associated with primary production. Recommended waste prevention strategies include promoting maintenance practices and favor importation of more durable PV modules. Recommended reuse mechanisms include setting standards for testing modules prior to reuse, and encouraging utility-scale operations to sell or donate functioning modules for reuse. Moreover, municipalities should consider installing PV modules, removed due to repowering or building redevelopment (renewals and rehabs), on roofs previously identified as unsuitable for permanent installations – for instance, buildings that are scheduled for renovation or upgrade in the coming years or residential buildings.

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