

## **Chapter 8**

### **CONTRIBUTION**

PV end-of-life recycling technologies and regulatory regimes for PV end-of-life management are relatively new. Long lead times have previously predated the adoption of ecologically and economically sound e-waste technology and regulatory strategies. Given this experience, the time for many countries to begin developing similar methods for PV panel waste is now. Voluntary producer and public-private partnership programs have failed to generate the anticipated objectives, paving the door for more standard regulatory frameworks with defined roles and duties.

End-of-life policies need to be a part of a larger framework of intersecting enablers that assist the vision of sustainable PV life cycle policies. The enabling framework, tailored to unique country conditions and relative PV sector development, should emphasize a system-level approach. It should develop institutional, technological, and human capabilities, as well as a local or regional PV recycling sector and a financial framework to support end-of-life management. Institutional development is critical to promoting PV end-of-life practices that are sustainable. The ability of public and private sector organizations to make educated and effective decisions on management and treatment options will have a significant impact on the long-term management of end-of-life PV panels.

So far, only the EU has established end-of-life regulations, which classify PV panels as a sort of e-waste. Other nations, on the other hand, are researching institutional capacity to execute end-of-life policies (e.g., China, Japan). A monitoring and reporting system encompassing PV waste streams must be incorporated into national and regional laws to facilitate decision-making and enable better planning. This, in return, can offer the statistical data required to improve waste stream forecast, better understand the causes of panel failure, and revise regulatory frameworks.

A system-level approach to PV end-of-life management can improve the integration of many stakeholders, such as PV suppliers and customers, as well as the waste sector. Over the last few years, significant efforts have been made to create technology and legislation to enable PV implementation. To tackle the problem of handling larger amounts of PV waste sustainably, assistance will also need to include end-of-life technology and regulations. Such assistance can enable greater integration throughout the various PV life cycle stages, as well as other policies aimed at a holistic product life

cycle approach (e.g., 3R idea, circular economy approach). End-of-life management can have an impact on a wide range of stakeholders, including manufacturers and owners as well as families and bigger customers. Growing PV panel waste is reshaping the sector's ownership arrangements. A system-level approach to policy development for PV end-of-life can combine PV providers' aspirations and obligations with those of PV users, new entrants (such as trash firms), and other stakeholders.

To develop and execute socio-technological systems, R&D, education, and training are all required to support PV end-of-life management. Support for R&D in PV end-of-life operations can improve technology performance and increase the value of recycled materials. Further technological advancements may enable the development of high-value recycling techniques for rare, precious, and possibly toxic materials that exceed regulatory standards and give extra environmental and socioeconomic advantages not now available. Industrial cluster development in the energy and trash sectors, as well as cross-cutting R&D programs, can help to improve the quality of recycling technologies and processes.

To maximize societal benefits, minimize negative effects, and prevent unexpected consequences, technical R&D must be combined with projected techno-economic and environmental evaluations. This needs systematic access to human talent from many disciplines such as engineering, science, environmental management, finance, business, and commerce. Furthermore, vocational training programs will be required. They may, for example, teach PV installers about possible repair and reuse options for PV panels that are failing prematurely.

Strengthening domestic skills and encouraging the growth of local PV recycling enterprises can assist to maximize the value generation of PV end-of-life. New markets will arise as a result of rising PV waste streams. They will generate new trade flows while also giving local prospects for the energy and waste industries in various stages of decommissioning (e.g., repair or recycling of PV panels). The capacity to localize is determined by the features and competitiveness of local ancillary industries, particularly the waste industry. It is dependent on the amount, quality, and consistency of predicted local waste streams, as well as projected demand for secondary panels and secondary raw material extraction. Measures that increase demand for locally recycled goods and services will help the budding PV waste and recycling industry even more

(e.g., purchase tax rebates for secondary raw material recovered through PV recycling processes).

To overcome finance constraints and assure the support of all stakeholders, stimulating investment and novel financing methods for PV end-of-life management are required. Previous experience has yielded technological and practical information on funding end-of-life PV panel management, which may help organizations manage increasingly enormous waste streams. Forcing domestic consumers to recycle WEEE is unfeasible in developed economies such as Germany. Voluntary alternatives eventually fail due to the financial risks of free riders abusing the system and a lack of enforcement during the product's extended lifetime. Extended producer-responsibility schemes, such as pay-as-you-go paired with last-man-standing insurance, and joint and-several liability systems in which producers become liable for PV panel collection and recycling, have thus shown to be the most successful in reality. The expenses of effective treatment and recycling might be included in the product sales price, for example, by charging a small fee per kilowatt-hour generated.

Countries have a rare opportunity to achieve sustainable end-of-life management goals while strengthening their legislative and regulatory frameworks to alter their energy systems. Establishing PV end-of-life management plans may add value and provide long-term socioeconomic advantages such as material recovery through recycling, as well as the creation of new businesses and jobs. In the future, holistic, adaptive frameworks collecting and assessing the numerous consequences of PV end-of-life management (e.g., the EU WEEE Directive) can tilt the scales in favor of sustainable life cycle practices and policies globally.

To make choices, governments and PV stakeholders require a more comprehensive understanding of future PV waste management streams and compositions. The report's goal is to lay the groundwork for governments to move faster up the learning curve in legislation and technology for PV end-of-life management. It paves the path for additional research in this area.