Forecasting Photovoltaic Decommissioning: Integrating Survival Analysis and System Dynamics for Long-Term PV Waste Projections

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Abstract

Rapid growth in photovoltaic (PV) installations across Europe is building a large future waste stream whose timing and volume remain poorly quantified. Decommissioning is driven by a complex mix of technical, economic, and environmental factors, yet empirical data on failures and deinstallations remain sparse. This uncertainty complicates the planning of recycling capacity and circular-economy strategies.

We develop a System Dynamics model of the French PV fleet that integrates survival-analysis lifetime distributions using conveyor-belt ageing chains and Weibull-based hazard functions. This structure avoids cohort blending and enables explicit modelling of early, constant, and wear-out failures. The model incorporates installation scenarios, evolving technologies, and material compositions and was tested through behavioural validation and calibration against collected waste data.

Simulations reveal wide but plausible ranges of future waste volumes. Annual PV waste is projected to reach 154,000–300,000 t by 2050 and 238,000–434,000 t by 2070, depending on lifetime assumptions and installation goals. Cumulative waste is expected to reach 1.95–3.85 Mt by 2050 and 6.0–11.4 Mt by 2070. Young modules dominate the waste streams, reflecting rapidly increasing installation rates and early failures.

Integrating survival analysis methods into System Dynamics widens the range of uncertainty that can be represented explicitly and enables more transparent modelling of PV decommissioning. The findings highlight the strong influence of lifetime variance on long-term forecasts and show that recyclers must prepare for heterogeneous waste streams, including different technologies. While uncertainty remains high, even conservative scenarios indicate substantial growth in PV waste, underscoring the need for improved monitoring and recycling infrastructure.

Keywords: photovoltaics, PV waste, circular economy, forecasting, survival analysis, system dynamics

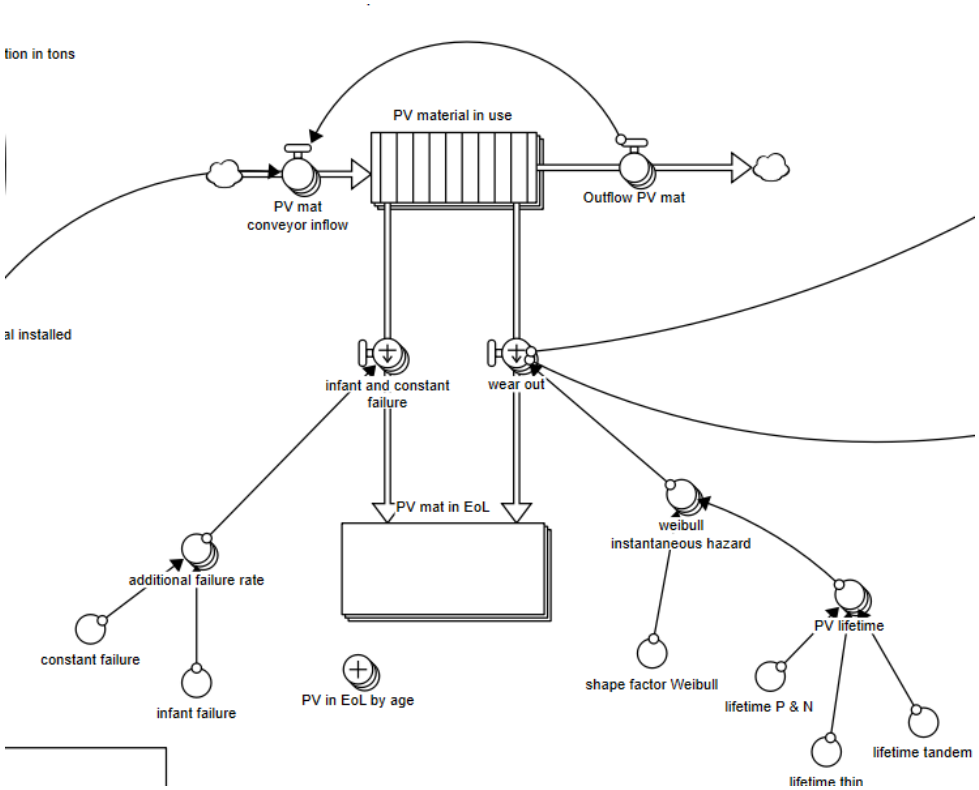

Figure 1 Refined EoL model: Includes separate constant and early failures, and a Weibull-based outflow considering separate lifetimes for different PV technologies.