Life Cycle Assessment of Crystalline Silicon Photovoltaic Module Delamination with Hot Knife Technology

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Task Managers:
Garvin Heath, National Renewable Energy Laboratory, Golden, CO, USA
Jose Bilbao, University of New South Wales, Sydney, Australia

Authors:
Rolf Frischknecht, Keiichi Komoto, Taisuke Doi

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Executive Summary

The objective of this study is to complete a life cycle assessment (LCA) of a novel technology that separates the crystalline silicon (c-Si) photovoltaic (PV) module front glass from the backsheet using hot knife technology. This is known to be the most challenging step in module recycling, where the choice of delamination approach can determine the process selection for the next steps of the recycling process, the economic value of the recovered materials, and environmental performance.

The life cycle inventory (LCI) reported here is based on primary data from the technology manufacturer. Different LCIs are established following the cut-off approach and the end-of-life (EOL) approach. The environmental impacts of the hot knife delamination process are analysed based on six indicators, and the main contributors to delamination efforts are identified. For the EOL approach, the potential environmental benefits from the recovered materials are compared to the environmental impacts caused by the delamination process.

The functional unit of this analysis is the delamination of 1 kg of used framed c-Si PV modules at the place of installation.

A questionnaire was sent to the manufacturer of the hot knife technology. The manufacturer was asked to provide information on their energy and material consumption and the amount and quality of the recovered materials. The disclosed information was used to establish an LCI of the hot knife delamination of c-Si PV panels. The LCL represents the technology as used in a pilot plant; the data are representative of year 2018.

To complete the life cycle of c-Si PV, the production and installation of the PV system are represented by the International Energy Agency Photovoltaic Power Systems Program Task 12 LCI update 2020 database using the weighted average of multicrystalline and monocrystalline Si PV modules based on the share of the global installed capacity of each technology in 2018. For other processes, such as background processes for which no specific data were collected, the Federal Department of the Environment, Transport, Energy, and Communications (UVEK) LCI database DQRv2:2022 is used.

The hot knife delamination process of c-Si PV modules is automated in a PV module disassembly line that consists of a junction box (J-box) separator, a frame separator, and a glass separator (hot knife technology), and it involves the following three steps:

- Removal of the J-box, after which cables are removed from the separated J-box

- Removal of the aluminium frame

- Separation of the glass from the laminate backsheet.

The hot knife delamination technology is only one part of a high-value recycling process. After hot knife processing, the copper cables and the laminate (cell and ethylene vinyl acetate [EVA] backsheet) are sold to an external recycling facility (refinery) where the EVA plastic is burned and the copper and silver are recovered. Processing at the external recycling facility and the recovery of copper and silver are not considered within the system boundary of the LCA presented here, nor are potentially avoided emissions accounted for. Burdens of the three disassembly and delamination steps are shared between the treatment service (EOL processing of the PV module) and the materials and components that are recovered by following economic allocation principles (revenues).

We find that the hot knife treatment of decommissioned c-Si PV modules causes a very small share of the life cycle environmental impacts of a 3-kWp PV system mounted on a slanted roof in Europe, according to the analysed environmental indicators. The highest contribution of delamination is observed for the climate change impacts, mainly caused by transport logistics (module collection and delivery to the hot knife treatment site) and electricity consumption. Our findings are consistent with other literature; detailed comparisons of the environmental impacts of this delamination process to other approaches can be the subject of future research.

Further development of the process could increase the amount and diversity of the recovered materials—in particular, metals. Large-scale deployment of the process could also lead to lower energy and consumables use per panel treated based on process innovations.

We recommend compiling primary data on copper cable and laminate treatment and the recycling of copper and silver to make the data basis of the LCIs more complete and robust.