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Comparative Life Cycle Assessment of End-Of-Life Silicon Solar Modules

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By the end of 2016, the cumulative solar photovoltaic (PV) installed capacity worldwide was around 78 gigawatts, which is more than double than the capacity installed in 2014 and 32 times more than in the year 2000 [1]. Because of this growth in the photovoltaic market, the cumulative global waste from PV modules reached 250,000 tonnes by the end of 2016, and predictions show that by 2050 that quantity will increase to 5.5 6 million tonnes per year [2]. Today most of the end-of-life (EoL) modules go to the landfill, mainly because the recycling processes are not yet economically feasible and EoL regulations in most countries have not been established yet (with the notable exception of WEEE in the EU). However, during the last 15 years or so, methods for recycling solar modules have been developed worldwide and some of them are well developed. These processes propose to reduce the environmental impact of PV waste and to recover some of the valuable materials from PV modules. However, current recycling methods are mostly based on downcycling processes, recovering only a portion of the materials and value, so there is ample room for progress and research in this area. One of the better known recycling methods and commercially available in Europe [3] was originally created by PV CYCLE in 2007. The process of recycling crystalline silicon (c-Si) modules begins with the separation of the aluminium frame and junction box, followed by a mechanical process used for the extraction of the remaining materials of the module (similar to processes used for the recycling of glass or electronic waste). Because the need to recycle this type of waste is imminent, the search for better recycling methods and the possibility of generating profitable outcomes, have also supported the development of other recycling processes by PV researchers and manufacturing companies (e.g. First Solar, Pilkington, Sharp Solar, and Siemens Solar).

The development of adequate EoL management of PV modules is essential to understand and solve the imminent waste problem and identify the potential environmental impacts of each technology. Life cycle assessment (LCA) is a methodology that quantifies the environmental impacts of a process or a product. In this study we undertake an LCA of different EoL scenarios for c-Si solar modules, including thermal and chemical recycling routes. We consider global warming potential (GWP) and abiotic depletion potential (ADP) as the impact categories and a functional unit of one c-Si PV module. The GWP is calculated because this environmental impact is the most common for LCAs on PV technologies since solar energy is considered a green source of energy. The ADP impact refers to the reduction of availability of abiotic (non-living) resources taken from the earth, and the possibility of recovering non-renewable materials from solar cells and modules makes this impact important to this study.

The results show that recovery of materials from solar modules results in lower GWP and ADP when compared with other EoL scenarios considering our assumptions. These impacts can be even lower

with the adoption of more complex recycling processes that can recycle not just glass, aluminium and silicon, but also lead and silver. The combination of recycling processes can achieve good recycling rates and recover almost all materials from solar modules.

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