Ecological and Economic Assessment of Photovoltaic Technologies

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Overview

It is established and proven by now, that a transition towards renewable energies is needed to mitigate climate change [1]. In Germany, the share of renewable energies shall increase to 80 % of gross electricity consumption by 2050. Photovoltaics (PV) will undoubtedly play an important role in the transformation to future low-carbon energy systems [2]. Various PV systems are available, with multi- and polycrystalline silicon technologies being the most common. Next to these, a variety of thin film technologies are accessible: the amorphous silicon (α-Si), copper indium selenide (CIS) and cadmium telluride (CdTe) being the most important ones. [3] All these PV technologies differ in efficiency, price, material combination, production processes etc. [4–6]. To evaluate these differences, studies have been conducted by assessing the resulting environmental impacts [5; 3; 7] and economic costs with different methods [4; 6]. A common approach to assessing environmental impacts is Life Cycle Assessment (LCA), which evaluates a variety of different impact indicators such as climate change, resource depletion, water consumption, etc. Trade-offs between these indicators make it difficult to provide decision-makers with clear answers to support the policy-making process. To overcome this difficulty and thus simplify the decision-making process, this paper suggests a distance to target based weighting approach for the environmental impacts that has been adapted to the German political context. Its application in combination with an economic analysis permits to identify the most adequate PV technology.

Methods

We conduct an integrated environmental-economic assessment of CdTe, CIS, α-Si, ribbon silicon, mono and poly crystalline silicon PV systems. To quantify the potential environmental impacts, we apply Life Cycle Assessment, which assesses all life cycle stages from resource extraction, production, use and disposal. All inputs including material and energy must be taken into account [8]. A variety of different environmental impacts are assessed (climate, change, mineral and metals, energy demand, etc.). To make a statement about, which PV technology is the most suitable an updated distance to target approach based on the ecological scarcity method from Frischknecht and Büsser Knöpfel (2013) [9], Ahbe (2014) [10] and Muhl et al. (2019) [11] is applied. The applied methodology is able to aggregate all impact assessment results by a weighting scheme based on political targets of Germany and measuring the environmental burden in ecopoints. Additionally, an economic analysis is integrated. Trade-offs between environmental and economic indicators is analysed, using a normalization with respect to best and worst outcomes for the different technologies and a Euclidean metric.

Results

Preliminary results indicate a target conflict between costs and environmental impacts. Our analysis reveals that the α-Si system might be a good compromise showing both relatively low total impacts and costs. Costs per megawatt hour are lowest for the German electricity mix, while having the greatest environmental impacts, reaching almost $3.5 \cdot 10^4$ ecopoints/MWh electricity. Lowest environmental impacts per are found for CIS technology with $1{,}5 \cdot 10^4$ ecopoints/MWh. Most impacts occur in the impact category heavy metals into air resulting from the need of an increased copper production in Asia, which is needed for inverter, PV cells as well as electronics. According to our analysis, α-Si shows the best combination of environmental and economic performance. It is followed by CdTe and CIS.

Conclusions

Different PV technologies are evaluated both under environmentally and economically criteria to find a recommendable PV system. The results show advantages for α-Si, CdTe and CIS PV modules as those types have relatively small environmental impacts as well as specific costs. The preliminary results are indicating that the focus on poly and mono crystalline, although having benefits compared to the German electricity mix, is environmentally not beneficial as being low performer in comparison to other PV technologies. Consequently, politicians should support a shift to better performing PV technologies. Probably the incentive mechanism must be adopted and linked with the technologies' environmental and economic performance. Making incentives technology dependent could also bridge target conflicts as the environmentally technologies are almost the most expensive ones. An updated distance to target methodology for Germany was applied based on normative targets. Thus, using that methodology shows the impact of policy on technology application. Consequently, politicians can by its application give signals into the market as well as focusing on different impacts/costs.

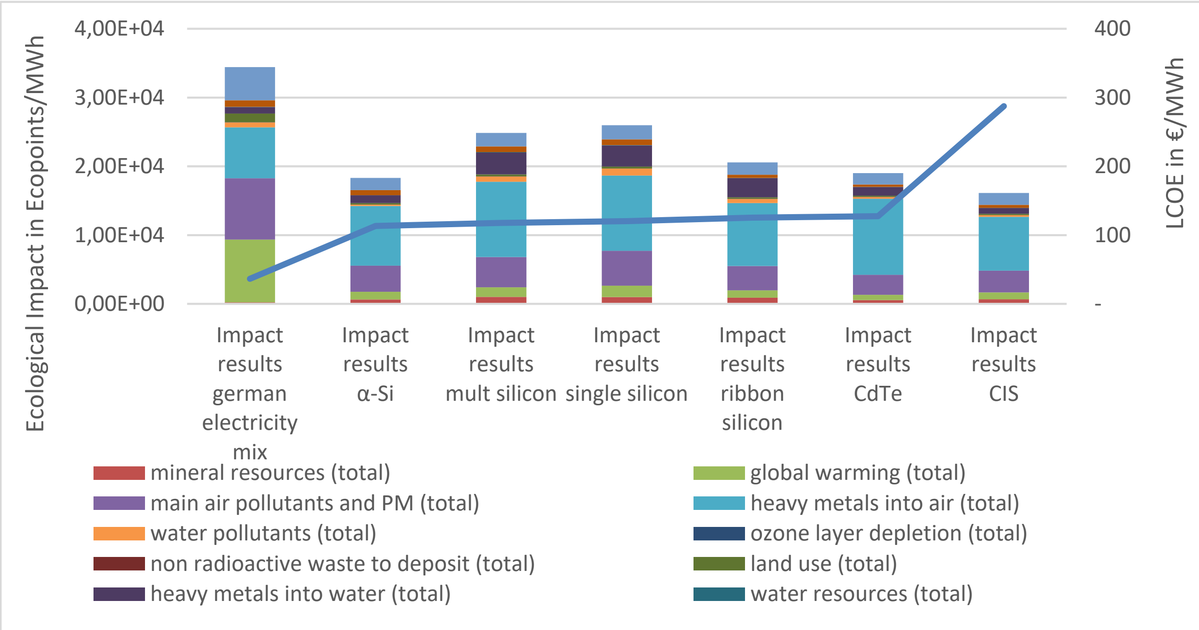

Figure 1 Ecological and economic comparison of the analysed photovoltaic systems

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