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Cost-competitiveness of organic photovoltaics for electricity self-consumption at residential buildings: A comparative study of Denmark and Greece under real market conditions

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HIGHLIGHTS

- Regulations, solar irradiation and load profile affect PV self-sufficiency strongly.
- A model for calculating electricity bill savings from residential PV is proposed.
- OPV may offer significant residential electricity bill savings depending on location.
- Stakeholders should pursue scaling up the manufacturing capacity of OPV technologies.

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ABSTRACT

To address sustainability challenges, photovoltaics (PV) are regarded as a promising renewable energy technology. Decreasing PV module costs and increasing residential electricity prices have made self-consumption of PV-generated electricity financially more attractive than exporting to the grid. Organic photovoltaics (OPV) are an emerging thin-film PV technology that shows promise of greatly improving the environmental and economic performances of PV technologies. Previous studies have estimated the current and future costs of OPV technologies, but the attractiveness of investing in OPV systems has not been evaluated under real market conditions, especially under PV self-consumption schemes. In this study, we investigate the self-consumption of electricity generation from conventional and organic PV systems installed at residential houses in two different countries, Denmark and Greece, under current PV regulatory frameworks. We then focus on modelling and assessing the cost-competitiveness of organic PV technologies based on cost estimations for existing pilot-scale (kW-range), and projected scale-up (100MW) and industrial-scale (100 GW) manufacturing capacity levels. Our generic results applying to all PV technologies show that PV systems installed at residential houses in Greece perform economically better than those in Denmark do in terms of self-sufficiency and gross electricity bill savings (i.e. excluding PV costs). Using the two country cases, which present very different settings, we characterise and discuss the influence of three key parameters of the economic performance of PV systems, namely the PV regulatory scheme, the solar irradiation level and the temporal match between the electricity consumption and solar irradiation profiles. Focusing on organic PV systems developed in an industrial-scale cost setting (1.53 €/Wp), we find that they deliver significant electricity bill savings for residential houses in Greece (38%) under current conditions, while they may not be sufficiently attractive for residential houses in Denmark (6.5%) due to mainly the different PV regulatory schemes. Based on these findings, we therefore recommend investors interested in renewable energy technologies to pursue scaling up the manufacturing capacity of OPV technologies, as well as assess a large number of countries to identify and prioritise financially attractive settings for PV self-consumption.

1. Introduction

Solar photovoltaics (PV) are seen globally as one of the most promising technologies in the race again climate change [1]. In the European context, PV systems are expected to play a key role in improving the energy performance of the building sector (Directive 2012/

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27/EU) despite the operation management challenges associated with large-scale penetration of renewable energy sources at residential [2] and industrial level [3], the integration of energy storage and electric vehicles [4], and load management by active end users [5].

In recent years, continuously declining PV module costs, in combination with rising residential electricity prices and fading feed-in tariffs, have made self-consumption of PV-generated electricity financially more attractive than exporting to the grid [6–8]. Nevertheless, PV-generated electricity costs are still not low enough to compete on the electricity market, but depend on state support through self-consumption and net-metering schemes [7]. If PV are to compete on the market against established electricity generation technologies, like fossils or wind power, further cost reductions are thus needed. Following these trends, a growing number of recent studies in the literature has been assessing the self-consumption of PV-generated electricity and its economics, as in PV only systems or in combination with battery storage (see review by Luthander [9]) [10–15].

Organic photovoltaics (OPV) are an emerging thin-film PV technology that shows promise of greatly improving the environmental and economic performance of PV technologies [16]. OPV utilize abundant, non-toxic organic molecules or polymer materials to absorb light and convert it to electricity [17], and are typically built in multiple layers that are deposited on plastic foil by low-energy and high-throughput printing and coating techniques (see reviews by Krebs [18] and by Wang et al. [19]). Applications of OPV technologies have been demonstrated by previous studies, for example a pilot-scale OPV solar park installed in Denmark [20,21] and a portable solar charger, HeLi-on [22]. In terms of environmental impact assessment, OPV technologies have shown the potential to lower life-cycle environmental impacts compared to conventional silicon-based PV technologies, ranging from 32% to 98% depending on the environmental impact category (e.g. climate change, acidification, toxic effects on human and environment, etc.) [23].

Until now, OPV module costs have not been able to compete at market level due to shorter lifetimes and lower power conversion efficiencies. Early studies of OPV economics have focused on preliminary cost estimates [24–26] or have calculated cost targets and financial indicators [27–29] (see summaries of findings by Mulligan et al. [30] and Gambhir et al. [31]). More recent studies have projected commercial-scale production costs based on real data from pilot-scale production [30–33]. More specifically, Machui et al. [32] have estimated that, under an industrial processing scenario, costs of OPV modules could reach 0.05–0.6 €/Wp (depending on achieved efficiency, material choice and structure), thus outperforming conventional PV technologies. Also, Gambhir et al. [31] have showed that at a conservative estimate OPV can have closely comparable levelised cost of electricity (LCOE) values to established PV technologies, while estimates at the more optimistic end showed that OPV costs can be more than 50% lower than costs of established PV technologies [31]. Although previous studies have assessed OPV costs and compared them with costs of established PV technologies, the attractiveness of investing in OPV under real market conditions has not been researched until now. Hence, do OPV technologies offer an attractive investment for households, especially in a context where government support is decreasing and PV regulatory frameworks are gradually transitioning from feed-in-tariff to self-consumption schemes?

The goal of this study is to address this question, and evaluate the competitiveness of current and potential future costs of OPV systems installed on household roofs with a 20-year investment period under the current self-consumption frameworks using Denmark and Greece as case studies. The two countries present an interesting comparison as they offer different contextual settings (e.g. PV regulatory framework, solar energy availability, renewable energy policy, etc.) as explained later in the paper. Even though the scope of the study has a strong focus on OPV systems, the developed methodology and the detailed analysis of the regulatory and market frameworks for PV are generic and apply to all PV technologies.

2. Methods and materials

2.1. Overall methodology

Fig. 1 shows the methodology and the associated steps adopted to assess the cost-competitiveness of OPV self-consumption. These five steps are described in the following Sections and can be applied to any national setting. They include:

1) A comprehensive study of the Danish and Greek regulatory frameworks for residential PV installations served as a basis for identifying modelling and data requirements, e.g. PV regulations and possible installation capacity limits, technical specifications of electricity netting, electricity billing and remuneration schemes, etc. (Section 2.2);
2) The modelling of the PV system electricity flows was required to calculate electricity self-consumption, exports and imports between the PV system and the grid (Section 2.3);
3) The electricity bill savings from installing an OPV system were calculated based on current electricity bill tariffs/components and

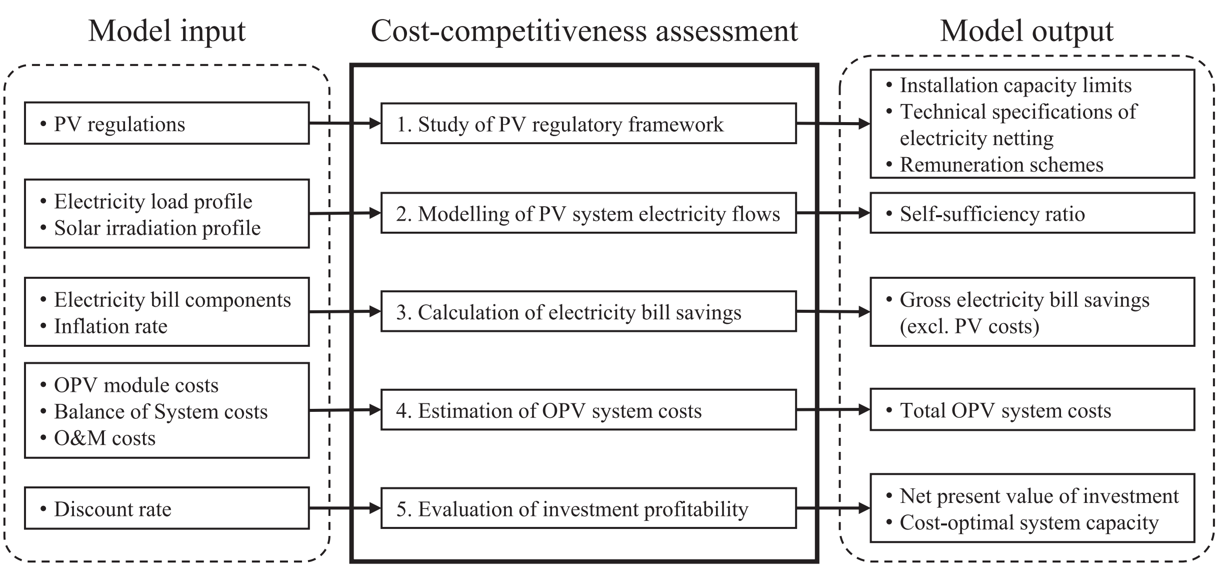

Fig. 1. Steps taken and key model input and output to assess the cost-competitiveness of OPV self-consumption in this study.