Solar Energy Materials & Solar Cells 156 (2016) 122–127

Contents lists available at ScienceDirect

Solar Energy Materials & Solar Cells

journal homepage: www.elsevier.com/locate/solmat

Multi-criteria decision making for PV deployment on a multinational level

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ARTICLE INFO

Article history:
Received 8 August 2015
Received in revised form
23 February 2016
Accepted 24 February 2016
Available online 7 April 2016

Keywords:
Multi-criteria analysis (MCA)
ELECTRE III
Net Present Value (NPV)
Internal Rate of Return (IRR)
Payback time (PBT)
CO_2 contribution
Cost for Support (CFS)
Cumulative PV installed

ABSTRACT

Photovoltaic (PV) system decision making techniques have traditionally been based on a single economic criterion. However, to properly address global and regional targets for green energy economy, it is necessary to consider a myriad of criteria including environmental implications. A global range of existing or emerging financial support policies should be considered, presenting a complex mathematical problem across several stakeholders to decide where, what and when to invest. This paper presents a multi-criteria framework to evaluate the impact of different financial support policies on their attractiveness for domestic PV systems deployment on a multinational level. The paper also reviews historic cumulative PV installation under certain studied financial policies, and brings the framework output into this discussion related to evident effectiveness of these policies. The paper highlights the policies that have the potential to encourage rapid deployment of PV systems which in turn may facilitate sufficient investments to several stakeholders.

1. Introduction

The use of low carbon technologies, such as solar Photovoltaics (PV), is deemed critical to tackle emerging environmental and energy challenges. As a result, different economic support schemes and policies have been put in place to encourage users (e.g., household customers) to invest in PV and other novel technologies. These policies promote investment security and provide continuous support for all valid renewable energy technologies. However, potential investors are still cautions to invest in renewable energies sources even if the support in place is attractive as the perceived risk can be deemed significant. This can be attributed to uncertainties in political, economic, market stability, regulatory, technical and environmental fields [1].

Even though the different policies are meant to motivate acceleration of PV deployment, their attractiveness and effectiveness can vary substantially in different contexts. Thus, different countries have deployed and customised specific RESs support schemes. For example, countries such as the United Kingdom, Spain, France, Italy and Germany, have developed their support schemes based on the first Feed-in-Tariff (FiT) model developed in United States. Other countries, such as Denmark, favours net metering and subsidies.

This selection of specific financial support policies, depends on the resources, renewable energy deployment targets, electricity system and planning laws in each country [2]. Accordingly, support policies vary per country and, even within a given country, can change drastically over time [3–16].

Based on the above, the design and selection of support policy schemes is critical for each country. A review of support schemes has depicted direct and indirect support schemes [17]. A number of common elements which have to be carefully considered when designing financial support policies are:

- To provide financial support for all potential developers;
- to ensure that the tariff rates are high enough to pay off the expenses of the project and encourage development;

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http://dx.doi.org/10.1016/j.solmat.2016.02.015

- to provide tariffs for a long enough period of time, proposing long-term certainty such as 20 years;
- to allow access to the national grid; and
- To provide appropriate and easily administered application processes [2].

Overall, it is recognised that the effectiveness of PV support schemes can significantly improve when it motivates the installation of PV systems at the domestic level [18]. However, this requires engaging domestic users, which are heavily influenced by the relevant economic benefits. In this light, the aim of this paper is to (i) assess, compare and rank different PV policies currently implemented in different countries based on their potential to engender sufficient investment in PV systems to meet particular economic and environmental targets and (ii) analyze the growth of cumulative PV installed and how they have held up in the market over the years. For this purpose, and with the aim of properly addressing different key perspectives, the comparison is based on multi-criteria analysis (MCA).

The adaptation of MCA can ease the comparison of PV support policies by combining different standpoints under a standardized assessment procedure. Among the outranking methods available in the literature, the ELECTRE III method was selected as it can properly assess both the reasons that support and negate the idea that an alternative outranks another [19,20]. Other outranking methods, such as SMART and PROMETHEE can offer similar advantages when simultaneously dealing with qualitative and quantitative criteria. Nevertheless, the ELECTRE III model is preferred as (i) it can manage the uncertainty and ambiguity that is found in predictions and estimations, (ii) it has the same robustness as SMART methods [21], and (iii) it offers superior features of virtually having non-compensatory treatment of the problem and proportional thresholds for imprecise data [22].

The ELECTRE family of outranking methods is used extensively in literature. Some examples include the application of ELECTRE methods for the assessment of engineered infrastructure investments [22–31], to extend existing planning tools to assess municipal solid waste management based on outranking approaches for MCDM and multi-attribute rating techniques [26], [32–38], personalised ranking of British Universities [39], investment stock selection [40], sustainable demolition waste management strategy [41], energy systems selection [42], thin-film PV technology processes [43], urban storm water drainage [35] and housing evaluation [44] as well as PV technology assessment [45].

This paper is structured as follows: first, in Section 2, the outline of the methodology is highlighted with the definition of alternatives, criteria explanation and the ranking approach of the ELECTRE III methodology. Afterwards, in Section 3, a case study is presented with the general assumptions and results. Later, in Section 4, the sensitivity analysis tested the robustness of the methodology. Finally in Sections 5 and 6, the findings are related to the cumulative PV installed capacity in a discussion section and the main conclusion is drawn respectively.

2. Methodology

2.1. Definition of alternatives

For the sake of simplicity, only the two most widespread types of financial support policies are considered in this study, namely feed-in-tariff (FiT) and net metering. However, it is worth highlighting that other policies could be addressed using the methodology presented in this work. The most basic feed-in model can be considered like a “pricing law” which allows producers of renewable energy to get paid a set rate for their produced electricity. This rate is usually dependent on the type of technology used and the size of the installation. Net metering is a variation of pricing laws which state that consumers can install small renewable energy systems and offset their energy consumption while selling their excess energy to the grid [2].

The seven alternative scenarios highlighted in Table 1 represent different PV support mechanisms adopted now or in the past by specific countries. These countries reported considerable progress in exploiting these technologies or have a different approach to renewable energy dissemination policies. Since this analysis concentrates on a 3 kWp system, which is relatively small, the tariffs were accordingly gathered mostly for building integrated or private sector systems [3–16]. The FITs can provide economic incentives for all PV generation (FIT rate), energy exports to the electricity grid (Export rate) and for avoided electricity consumptions (Import rate). Regarding the latter, it is assumed that the actual grid electricity-mix cost is 60% of the imported rate, the export rate is for electricity exported to the grid. These values represent the incoming and outgoing cash flows electricity rates for the alternative.

Some schemes also offer subsidies on the use of PV electricity within the building before any exports. This is termed by the Solar Fraction (SF), which is the fraction of the load met directly by the PV system as defined in [46]. In order to consider environmental implications within this study, the grid CO_2 levels were taken based on the electricity mix in particular countries as presented in [47].

2.2. Criteria explained

The potential of different financial support policies to facilitate domestic PV systems deployment on a multinational level is evaluated with four economic criteria, one environmental and one policy based criteria. It is worth highlighting that these criteria were chosen an illustrative example, while the proposed methodology is flexible enough to accommodate other criteria. In this particular case, a priority to the attractiveness of the policy for household users, which is measured in terms of three typical criteria. These are represented by the magnitude of the support for each customer (i.e., Net Present Value – NPV), how fast they will recover their money (payback) and how efficiently is their money spent (i.e., Internal Rate of Return – IRR). A carbon assessment is used as the environmental criterion and as a means to recognise the importance of environmental challenges. Finally, the last

Table 1
Alternative scenarios and assumptions.

	FIT €/kWh	Import €/kWh	Export €/kWh	Subsidy %	SF %	grid CO_2 kg/kWh	Example
A1	0.170	0.247	–	–	0	0.477	Germany
A2	0.160	0.149	0.050	–	0.5	0.441	United Kingdom
A3	–	0.262	0.180	–	0.5	0.315	Denmark private
A4	–	0.262	–	40	0.5	0.315	Denmark commercial
A5	0.342	0.128	–	–	0.5	0.061	France building integrated
A6	0.084	0.128	–	–	0.5	0.061	France ground mounted
A7	0.170	0.180	0.170	50	0.5	0.862	Malta (on roof)