Technological Forecasting & Social Change 99 (2015) 106–131

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

Modeling the diffusion of residential photovoltaic systems in Italy: An agent-based simulation

J. Palmer [a,*], G. Sorda [b], R. Madlener [b]

[a] Institute of Heat and Mass Transfer (WSA), RWTH Aachen University, Augustinerbach 6, 52056 Aachen, Germany
[b] Institute for Future Energy Consumer Needs and Behavior (FCN), School of Business and Economics/ E.ON Energy Research Center, RWTH Aachen University, Mathieustrasse 10, 52074 Aachen, Germany

ARTICLE INFO

Article history:
Received 30 September 2013
Received in revised form 1 February 2015
Accepted 16 June 2015
Available online xxxx

Keywords:
PV
Technological diffusion
Agent-based modeling
Italy

ABSTRACT

We propose an agent-based model to simulate how changes to the Italian support scheme will affect the diffusion of PV systems among single- or two-family homes. The adoption decision is assumed to be influenced by (1) the payback period of the investment, (2) its environmental benefit, (3) the household's income, and (4) communication with other agents. The estimation of the payback period considers investment costs, local irradiation levels, governmental support, earnings from using self-produced electricity vs. buying electricity from the grid, administrative fees, and maintenance costs. The environmental benefit is estimated by a proxy for the CO_2 emissions saved. The household income accounts for the specific economic conditions across different regions and the agent's age group, level of education, and household type. Finally, the influence of communication is measured by the number of links with other households that have already adopted a PV system. In each simulation step, the program dynamically updates the social system and the communication network, while the PV system's investment costs are revised according to a one-factor experience curve. The model's structure is applied for a case study based on the evolution of residential PV systems in Italy over the 2012–2026 period. The model's initial state is calibrated on the basis of the actual diffusion of residential PV in Italy over the 2006–2011 period. Our results show that, following Italy's new feed-in tariff scheme, domestic PV installations are already beyond an initial stage of rapid growth and, though likely to spread further, they will do so at a significantly slower rate of diffusion.

© 2015 Elsevier Inc. All rights reserved.

1. Introduction

Following the introduction of a governmental incentive program, the Italian photovoltaics (PV) market has experienced a remarkable growth. Electricity generated by PV systems increased from 35 GWh in 2006 to 10,796 GWh in 2011, an astounding increment (GSE, 2012a; see also Fig. 1 and Table 1). Italy has thus become one of the world's leading PV markets, accounting for about 18% of the global installed PV capacity in 2011 (EPIA, 2012).

Nevertheless, the diffusion of PV across Italy has followed a rather peculiar pattern. The number of installed PV systems is much higher in the north, although the irradiation level is lower there compared to other regions of the country. In addition, most of the installed systems in the north belong to private households and are thus characterized by a small rated power. However, while small-scale PV systems up to 20 kW are overwhelming in number (88% of the total, as of 2011), they account for only 15.5% of Italy's installed PV power (GSE, 2012c; see also Fig. 1). Furthermore, the share of small PV systems with respect to installed capacity has fallen steadily (from 66% in 2006 to 15.5% in 2011) due to the more recent

* Corresponding author. Tel.: +49 241 80 97471; fax: +49 241 80 92143.
E-mail addresses: palmer@wsa.rwth-aachen.de (J. Palmer), gsorda@eonerc.rwth-aachen.de (G. Sorda), rmadlener@eonerc.rwth-aachen.de (R. Madlener).

http://dx.doi.org/10.1016/j.techfore.2015.06.011
0040-1625/© 2015 Elsevier Inc. All rights reserved.

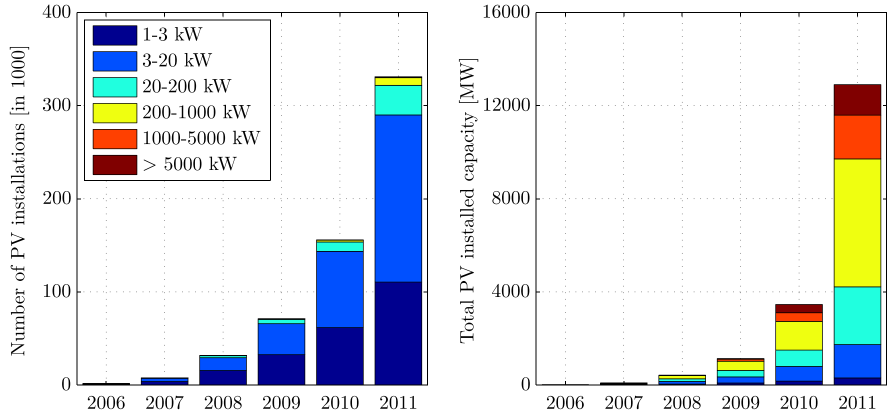

Fig. 1. Evolution of Italy's PV market, 2006–2011.
Source: GSE (2012a, 2012b, 2012c).

installation of large PV farms (mostly located in Central and Southern Italy), a trend that strongly contributed to the PV boom in Italy (GSE, 2012c). As a result, the number, size and electricity generation of PV systems in Italy are rather unevenly spread across the country.

It is thus relevant to investigate whether the residential PV market will grow further, or whether the Italian PV market will be dominated in the future by large PV farms. The objective of this article is to simulate the future diffusion of small residential PV systems under different conditions. Due to the multitude of factors influencing a household's investment decision in favor of an innovative energy technology such as PV, we designed and implemented an agent-based simulation model (ABM). ABMs provide a suitable framework to explicitly model the adoption decision process of the members (agents) of a heterogeneous social system based on their individual preferences, behavioral rules, and interactions/communications within a social network.

To the best of our knowledge, in the recent literature only Zhao et al., (2011) implement an ABM to simulate the diffusion of PV systems. We use their framework as a reference and further extend their model. In particular, following Schwarz and Ernst (2009), we include adaptive socio-economic categories to represent heterogeneous household groups with distinctive attitudes toward adoptions and innovations. The socio-economic groups considered here are based on the Sinus-Milieus® categorization developed by the Sinus-Institut (2011).[1] More specifically, the Sinus-Milieus® paradigm is most relevant for the distribution of the households' income and the determination of group-specific social communication networks. Importantly, in each simulation step, the social system and the communication network are updated dynamically in order to account for demographic changes and new adopters among the population of agents.

Furthermore, we explicitly model the geographical distribution of the agents in order to account for the regional differences that have strongly influenced the PV diffusion in Italy. The investment in a PV system is assumed to depend mainly on (1) the payback period, (2) the environmental benefit of the investment, (3) the household's income, and (4) the influence of communication with other agents. For the estimation of the payback period, the model considers investment costs, local irradiation levels, feed-in tariffs, earnings from using self-generated electricity vs. buying electricity from the grid, as well as various administrative fees and maintenance costs. The environmental benefit of the PV system is estimated via a proxy for the amount of CO_2 saved. The level of the household income is associated with the specific economic conditions of the region where the agent is located, as well as the agent's socio-economic group (age group, level of education, and household type). Finally, the influence of communication is measured by the number of links with other households that have already adopted a PV system. It is assumed that each adopter communicates predominantly, but not uniquely, with other households that belong to the same socio-economic group. Furthermore, the likelihood that different groups interact with each other varies across the categories of agents considered.

The remainder of the paper is structured as follows. Section 2 provides a brief introduction to the current Italian PV support policy. Section 3 gives an overview of the relevant literature concerning the adoption of new technologies, its modeling via agent-based simulation frameworks, and the inclusion of a social system in the modeling architecture. Section 4 presents in detail the structure of the ABM. Section 5 describes the model's calibration, while Section 6 discusses the policy scenarios and the simulation results. Finally, Section 7 delivers the conclusions of the article and highlights strengths and weaknesses of our analysis.

2. The Italian support scheme for PV systems

The current legal framework for the support of PV systems in Italy is called "Conto Energia" (CE). The first CE has been issued in August 2005. Since then, the incentive scheme has been renewed five times with a series of adjustments and changes. An important characteristic of the CE is that support is

[1] The Sinus-Milieus® are a registered trademark product. Whereas the questionnaires used to generate the socio-economic categories are disclosed, the details of the multivariate analyses adopted to assign the questionnaires to the Sinus-Milieus® are not published. This poses a drawback concerning the transparency of the method adopted and the validation of the results. We discuss this aspect in more detail in the Conclusion (Section 7).

Download English Version:

https://daneshyari.com/en/article/7256462

Download Persian Version:

https://daneshyari.com/article/7256462

Daneshyari.com