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Product-service systems in solar PV deployment programs: What can we learn from the California Solar Initiative?

Jean Rodrigo Schmidt-Costa, Mauricio Uriona-Maldonado*, Osmar Possamai

Federal University of Santa Catarina, Graduate Program in Industrial Engineering, Campus UFSC, Trindade, Florianopolis, SC, 88040-900, Brazil

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ABSTRACT

The product-service system (PSS) model is a potential alternative for increasing the adoption of PV systems. The California Solar Initiative (CSI) incentive program aiming to expand the Solar PV installed base in California, included the PSS option. Little is known, however, about the contribution of the PSS model on the CSI program and if the CSI program acted as a catalyzer of long-term positive/secondary effects. In this sense, the aim of this paper is to twofold, first, to assess the contribution of the PSS model on the CSI program and second, to investigate if the CSI program generated long-term network externalities. A system dynamics model was built in order to visualize i) the influence of the PSS model on the CSI and ii) the long-term effects, i.e. network externalities of the CSI program. The results suggest, the PSS model led to a significant increase in the installed base of the program and in turn, the program led to positive network externalities.

1. Introduction

Solar PV, with its increasing 24 billion KWh of small-scale electricity generation has been standing out as one of the best alternatives for clean energy generation (EIA, 2017). However, there are still important barriers for its diffusion and deployment, mainly driven by the high upfront costs of PV systems (Karakaya and Sriwannawit, 2015; Negro et al., 2012).

The product-service system (PSS)[1] business model is a potential solution to overcome the high cost barrier, allowing consumers to benefit from PV systems without needing to purchase them (Tukker, 2015). There are two main PSS types. The first, also known as leasing, represents a Use Oriented PSS (Tukker, 2004), whereby the consumer pays a monthly fee, giving him/her individual access to all energy produced by the system. In the Power Purchase Agreement (PPA) option, considered a Result Oriented PSS (Tukker, 2004), the consumer pays a predetermined fee per kWh generated by the system. Third-party owned (TPO) (Drury et al., 2012; Overholm, 2015), and Energy Service Company (ESCo) (Hannon and Bolton, 2015) are also terms used to describe PSS models in the energy sector.

PSS applied to the PV market might bring up some advantages: i) economic advantages, by means of reducing energy consumption from utilities; ii) environmental advantages, through the production of clean energy without harming the environment and through reuse, enabling transferring contracts between users, or reinstallation of the PV system in another user at the end of the contract, reducing the use of natural resources for the manufacturing of new PV systems; and iii) social advantages, through the diffusion of the technology to users whom do not have the economic conditions to acquire a PV system.

One of the most successful cases of PSS applied to the solar PV market known to date, was the California Solar Initiative (CSI). The CSI was a ten-year program launched in 2006, aimed at expanding the solar PV market in California by targeting the installation of 1750 MW of solar capacity, with a budget of USD 2.098 billion, including the traditional purchase option and the PSS option (Evans et al., 2016). Even though the program had been amply studied in the literature (Corfee et al., 2014; Drury et al., 2012; Liu et al., 2014), the actual contribution of the PSS model to the CSI program remain unclear, therefore, our first research question is precisely this, i.e. what contribution the PSS model had on the CSI program? On the other hand, beyond the huge number of PV systems installed and barriers transposed to its diffusion, we question whether the CSI program acted also as a generator of long-

* Corresponding author.
E-mail addresses: jean.costa@posgrad.ufsc.br (J.R. Schmidt-Costa), m.uriona@ufsc.br (M. Uriona-Maldonado), osmar.possamai@ufsc.br (O. Possamai).

[1] PSS (Product-Service System) concept may be explored in Tukker (2015). We define it as a social innovation (see (Hubert, 2010)) where the ownership paradigm of material goods, usually related to esteem issues such as the development of self-identity and belonging to a group, gives place to the satisfaction of the consumer's real need, through access to the main function of the product or the result of this function.

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term positive/secondary effects. Hence, our second research question is: did the CSI program act as a catalyzer of network externalities[2] in the California PV market?

With these two research questions in mind, the aim of this article is twofold, first, to assess the contribution of the PSS model on the CSI program and second, to investigate if the CSI program generated long-term network externalities, in order to inform policy makers about the importance of large-scale programs such as the CSI along with PSS model for fostering renewable energy technology diffusion. The implications of this study are especially relevant for developing countries, which lacks PSS cases - except for China (Zhang, 2016) and Thailand (Tongsopit et al., 2016) – and large-scale incentive programs such as the CSI.

We use a system dynamics model, e.g. Sterman (2000), which allows a deeper understanding – through computer simulation – of the PSS influence on each market of the CSI program. It also allows running simulations on the future behavior of the CSI-like programs, in order to track for the existence of network externalities. The structure of our model is based on the formulation proposed by Bass (1969). The use of the Bass model is particularly useful for the case of CSI, in which the data comprises the installed base of PV system adopters for the whole duration of the program (10 years), allowing good parameter estimation and model fitting.

The article is structured as follows: section 2 synthesizes the main facts about the CSI program; section 3 describes the model building and testing processes; section 4 presents the main results of our study; section 5 brings up the main lessons and limitations and finally, section 6 presents the main conclusions and future research opportunities.

2. The California solar initiative program

Aiming for PV technology expansion in the national market, US State and Federal agencies developed a series of public policies in three stages, according to the framework proposed by Doris (2012). First, legal and institutional barriers were removed, such as the technical and legal option of power generation systems, interconnection with the grid and the legislation authorizing the ownership of PV systems by third parties other than utilities.

The second stage comprised building up solid foundations for market creation, in order to reduce uncertainties for investors and establishing public awareness. The Renewable Portfolio Standard (RPS) mandate, which determined a percentage of the utilities portfolio from renewable energy sources, the net metering policy that allowed users to receive compensation for surplus energy produced and fed into the grid, and financing mechanisms and public benefit funds demonstrated to stakeholders the government's commitment to creating a long-term market (Doris, 2012).

The third stage aimed at expanding the market by using subsidies, rebates and tax incentives mechanisms to ease PV system acquisition equipment and policies such as feed-in tariffs, reduced payback time and intrinsic investments risks (Doris, 2012).

After successful actions in the first two levels of public policies that had resulted in 14,771 systems with 118 MW of solar PV installed capacity, (NREL, 2017), the California Government proposed a program to stimulate the adoption of solar PV systems in 2006. The program, known as the California Solar Initiative (CSI), aimed at transforming and expanding the solar energy market by means of reducing the PV system price. The program achieved the installation of 1750 MW of solar capacity by the end of 2016, with a total budget of USD 2098 million (Evans et al., 2016).

Although the CSI financial incentives program did reduce the cost of PV systems, for a large share of the population these were still high enough to cope with (Karakaya and Sriwannawit, 2015). In this sense, the PSS option proved to be key for the success of the CSI program (Corfee et al., 2014), allowing users to enjoy the benefits of the PV technology without having to buy the equipment nor pay for its maintenance over time. Instead, the PSS option allowed for lower monthly payments and leasing rates.

Fig. 1 illustrates the cumulative adoption of residential and non-residential solar PV adopters within the CSI program split among PSS adopters, owners, commercial and governmental/non-profit ones. Data were obtained from CaliforniaSolarStatistics (2017), which enables to observe different consumer patterns among the four types of PV systems. In the residential market, there is an initial dominance of the purchase option. The PSS model grows slightly over the first 20 quarters and afterwards, it begins to show an accelerated growth until reaching almost the same number of adopters who opted for the purchase option, at the end of the 40-quarter period.

In the non-residential market, the commercial sector showed the highest growth since the beginning of the program compared to the non-profit and governmental sector. Fig. 2 shows the main control metrics of the CSI program, financial resources and installed capacity.

3. Model development

We follow the steps proposed by Ford (2009), Sterman (2000) and Rahmandad and Sterman (2012) in order to develop the system dynamics model. The complete model involves significant detail for all of the four market types of the CSI program. Supplementary material associated with this paper provide the full list of equations and can be found in an online appendix or upon request. Moreover, Appendices A–C provide further details about the diffusion of innovation theory, the Bass Diffusion Model and the learning effect, respectively. This section indicates salient elements of these details.

We include specific structures to model: the installed capacity, resources employed; adopters' accumulated knowledge about the technology, price reductions through experience curves, and the influence of program financial incentives on consumer decision to choose between available forms of ownership.

Fig. 3 presents the structure of the simulation model, composed by five sectors or modules: (1) PSS residential market module; (2) Host owner residential market module; (3) Commercial market module; (4) Governmental and non-profit organizations market module; and (5) Measurement module. It is worth noting that modules 1 through 4 have a similar structure, based on the Bass Diffusion Model. In the following subsections we will detail the main components of the model.

3.1. Diffusion modules 1–4

There are six feedback loops that generate the dynamic behavior of the model on the four consumer decision modules, three reinforcement loops and three balancing loops, see Fig. 4.

The loop R1 links *Adopters* and *Adoption from internal influences* and is called "Word-of-Mouth" due to the interrelationships between members of the social system, forming a positive reinforcing loop. In other words, as the number of adopters grows, the likelihood of members of the social system (*Potential market*) to meet an adopter, increases at the rate *Adopters / Potential market,* exposing the innovation to a large number of potential customers. As the number of *adopters* increases, two balancing loops become dominant. Loop B1 demonstrates the market saturation effect on the *adoption from internal influences* as the *potential adopters* decrease. Loops R1 and B1 are highlighted in Fig. 4a.

B2 also produces a similar effect, which also reduce the *adoption from external influences* as the number of *potential adopters* decrease.[3] On

[2] We define network externalities, based on Schilling (2013), as the positive effect produced when the value of a good to a user increases with the number of other users of the same good, i.e. a positive consumption externality.

[3] It is worth noting that the decrease of potential adopters is due to the fact