Modeling the role of policy, innovation and market for the diffusion of photovoltaic industry in Colombia

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Abstract

In recent years, there has been a sharp increase in the number of studies into photovoltaic (PV) technology with a weak link between policy, innovation and market. These three concepts cannot be understood separately. Particularly, this paper shows alternatives for the implementation of the value chain in PV industry to understand the dynamics among policy, innovation and market, supported in a simulation model with the system dynamics methodology. Through simulation scenarios this study shows that energy policy and strategies based on innovation allow the electricity market in Colombia, generate a trend of competitiveness. This is illustrated by the case of some electricity industries dedicated to the generation and distribution in the Colombian electricity market. The results show a new point of view that contributes to the proposal of alternatives for the diffusion of PV energy.

Keywords
PV industry, Electricity market, Systems dynamics, Innovation, Energy policy

1. Introduction

At present, innovative disruption is considered a factor that allows developing markets, generating a competitiveness trend and minimizing the negative side effects associated with economic growth, such as global warming, security of energy supply and air pollution (Kishna et al., 2017; Markard et al., 2012; Walrave and Raven, 2016). In this sense, there are challenges that must be addressed through suitable policies given that their impact is directly related to mitigate the climate change and the depletion of natural resources. This is why it must be recognized that all production and consumption systems (e.g. PV industry) must change in order to face these challenges and generate sustainable contexts through technological innovation system management and policy design (Bergek et al., 2008).

The renewable energy has a great impact on the process of decarburization of the environment and is crucial for energy security and the creation of new jobs. In this sense, for society to incorporate within its environmental

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sustainability scheme and bringing the business development of PV industry, it must tend to produce innovation and changes in conventional energy systems to renewable energy. Inside the process of transition from conventional to renewable energies, there is evidence of the increase of innovation processes (Lo et al., 2013) and the creation of new needs to access basic electricity services. Proof of this is the evidence from regions such as Sub-Saharan Africa and South Asian countries where, due to their socio-political context, different stakeholders have promoted energy systems without connection to the grid as a remedy for energy poverty (Kebede and Mitsufuji, 2017). Among renewable energy technologies without connection to the grid, photovoltaic technology has been promoted as a potential means of rural electrification in developing countries (Henao et al., 2012; Herrera et al., 2018).

However, it is important to contemplate that all energy technologies have a long evolution due to the interaction between different stakeholders, including demand characteristics, availability of resources, essential capital expenditures, infrastructure of services and maturity of technology (Lo et al., 2013), being the most complex barrier to overcome the regulations that exist in each country in which you want to implement photovoltaic energy technologies (Moallemi et al., 2017a).

In the international context, it is observed that the accumulated capacity and the generation capacity of the photovoltaic energy has been increasing allowing a global accumulated capacity at an average annual rate of 49% (Jimenez et al., 2016). These rapid increases in cumulative photovoltaic capacity and generation capacity can be explained in three ways: first, by the intrinsic benefits of photovoltaic technology, which have motivated its adoption due to the simple generation process of energy and its respect for the environment; second, by reducing the production costs of photovoltaic systems; and, third, given that the policy seeks alternative energy generation technologies as a way to face different environmental problems, geopolitical instability and volatility of fossil fuel prices (Cardenas et al., 2017; Jimenez et al., 2016).

As for Colombia, a mixture of electricity dominated by the generation of hydroelectric energy has been reflected with approximately 70% of its total installed capacity, followed by fossil fuel plants, non-conventional renewable sources that represent approximately 29% and 1%, respectively (Morcillo et al., 2018). The real capacity of renewable energy resources (2% of total electricity generation) is produced by photovoltaic solar systems, small hydroelectric plants and an ecological park in La Guajira in northern Colombia (Devis-Morales et al., 2014). Thanks to its geospatial position, Colombia has the potential to generate energy from non-conventional resources, solar, wind, biomass, geothermal and solid solids (Quijano H et al., 2012; Vides-Prado et al., 2018).

From the above it is established that photovoltaic energy is an alternative to generate sustainable energy for the country, but there are barriers related with policy, innovation and market that do not allow the diffusion of the same. In this context, the modeling of the value chain of PV industry allows to understand the energy system as from the relationships identified between actors and design innovation policies alternatives.

The research simulates the dynamics of innovation and electricity market as from future scenarios generated by different energy policies. This paper is organized into five sections including this introduction. An overview of the technological transitions of the PV industry is discusses in section 2. Section 3 describes simulation model as from the system dynamics methodology. This section considers the validation model and assumptions data in the case of study for SMEs in PV industry of Colombia. Section 4 discusses the obtained results of simulation. Finally, the conclusions are presented.

2. Conceptual frameworks of technological transitions

The transitions of clean technology in electricity sectors have been highly influenced on the industrial development of countries (Castaneda et al., 2017; Jimenez et al., 2016). Energy transitions have historically involved several kinds of changes (Furtado and Perrot, 2015; Kebede and Mitsufuji, 2017; Li et al., 2015; Moallemi et al., 2017b). The first associated to the energy flows between electricity generation and demand, which coordinate through energy markets. The second has been change in technologies used for extracting, transforming and utilizing energy. The third has been change in policies regulating the role of energy systems, for instance to modernize a country, increase its independence, or reduce poverty (Cherp et al., 2018). Thus, the technological transitions (TT) involve changes in practices, regulation and infrastructure, which affect economic and social systems (Li et al., 2015; Moallemi et al., 2017a).

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In this frame, the debate on socio-technical sustainability transitions is entering a new phase, as some green niche-innovations are beginning to diffuse in some countries of Latin-American (e.g. renewable electricity, electric cars) (Herrera et al., 2017b, 2017a). Thus, it is important to put analytical attention from the emergence of green niche-innovations to their diffusion. In this sense, there are four models of TT adoption that emphasize different mechanisms and factors (Geels and Johnson, 2018): a) Epidemic models, b) Rational choice models, c) Social-psychological frameworks and d) The increasing-returns-to-adoption (IRA) model. In this paper, the simulation model is proposed like framework to understand the dynamics between the decision-making (policies), market share and perceived innovation.

The technological transitions can include a wide range of incremental or disruptive changes in policy decision practices of the decision-makers (Cherp et al., 2018; Reichardt et al., 2017). Several studies show social-technical analysis combined with political analysis on energy transitions (Cherp et al., 2018; Li et al., 2015; Moallemi et al., 2017a). This implies a particular concern for the energy policy effects as well as for its institutional articulation with electricity market and perceived innovation. Thus, studies of technological transitions often emphasize the particular role of the renewable energy (e.g. wind and solar energy). In addition, greater attention has also been given to perceived innovations for sustainability in relation to their transformation potential (McDowall, 2018; Yu and Gibbs, 2018).

The technological transitions of the renewable energy could be understood around different modeling approaches. In this paper, the system dynamics modeling is proposed to represent the interaction between the decisions (policy) of PV industry and perceived innovations as well as its effects on customers (market share). Due to the complexity of generic concepts to study technological innovations, this paper provide a description of the model's dynamics, rather than providing a detailed explanation of all equations.

3. Simulation Model

This document analyzes the relationship that exists between the times of the PV supply chain, and its effect on the perceived innovation and the change in customer satisfaction. For this, a system dynamics model was realized to represent the PV supply chain and its relationship with the market and innovation, as presented in Figure 1. With the model there were eight simulations (experiments), in each one of them was made policies with the variation in the times of the supply chain (supply time, industry time and development time). The simulated time is based on Colombian companies, where the average installation time varies between three and four weeks (this depends on the size of the installation and the place where it will be carried out) (América Fotovoltáica, 2018).

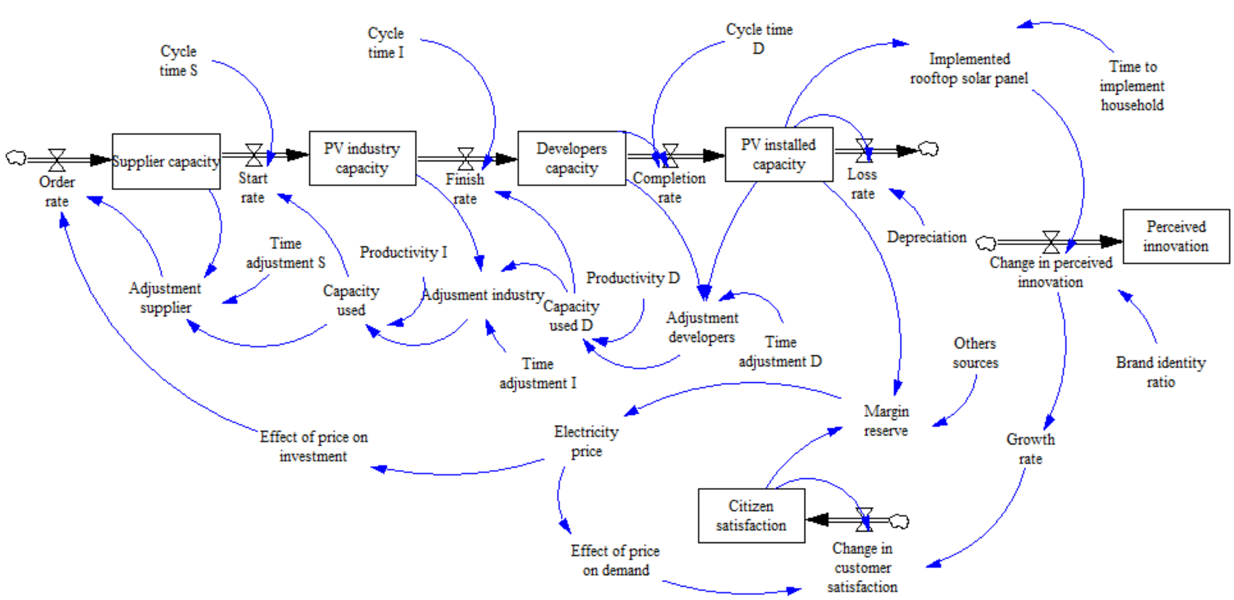

Fig. 1. Stock and flow diagram of the PV supply chain

The stock and flow diagram represents the supply chain (suppliers, industry and developers), also exhibits the change in customer satisfaction related with electricity marker. In addition, the simulation model shows the effect of implementation rooftop solar panel on perceived innovation.

4. Results of simulation

When performing the eight experiments, as from the simulation model obtained four different percentages for the average of the perceived innovation and for the average change in customer satisfaction. This means that the results of experiments number 1, 2, 3 and 6 are the same to 5, 4, 7 and 8, respectively. This occurs because when cycle time of developers and PV industry are equal, without import the changes in cycle time of suppliers, the results will be the same, as presented in Table 1.

Table 1 Average change in customer satisfaction of experiments

Experiment	**Time-delay (weeks)**			**Average Change in customer satisfaction (MW)**
	Supplier	**Industry**	**Developers**	
1	0,3	0,3	0,3	8,9
2	0,25	0,25	0,25	7,5
3	0,3	0,3	0,25	8,1
4	0,3	0,25	0,25	7,5
5	0,25	0,3	0,3	8,9
6	0,25	0,25	0,3	8,2
7	0,3	0,25	0,3	8,2
8	0,25	0,3	0,25	8,1

From the simulation carried out, it can be deduced that the policy to foster the growth of perceived innovation is the one used in experiment 1. The policy that least favors the growth of innovation is used in the experiment 2, as illustrated in Figure 2.

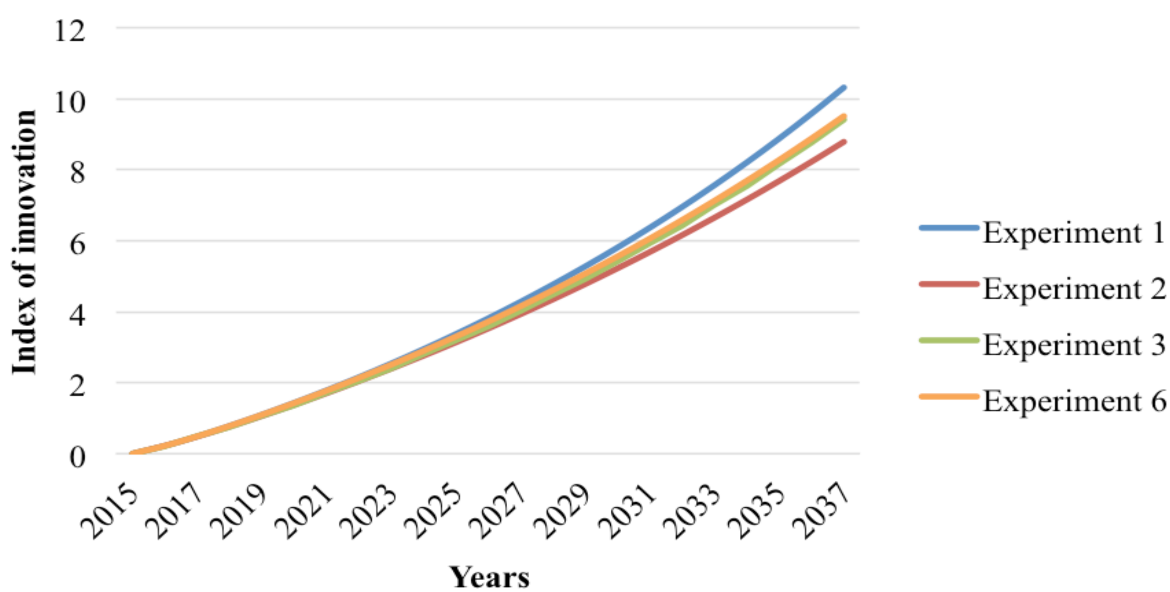

Fig. 2. Behavior of perceived innovation as from the experiments of simulation

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Based on the simulation performed, it can be deduced that the policy that promotes the change in customer satisfaction is that used in experiment 1, and the policy that least favors the growth of the change in customer satisfaction is the one used in the experiment 2, as presented in Figure 3.

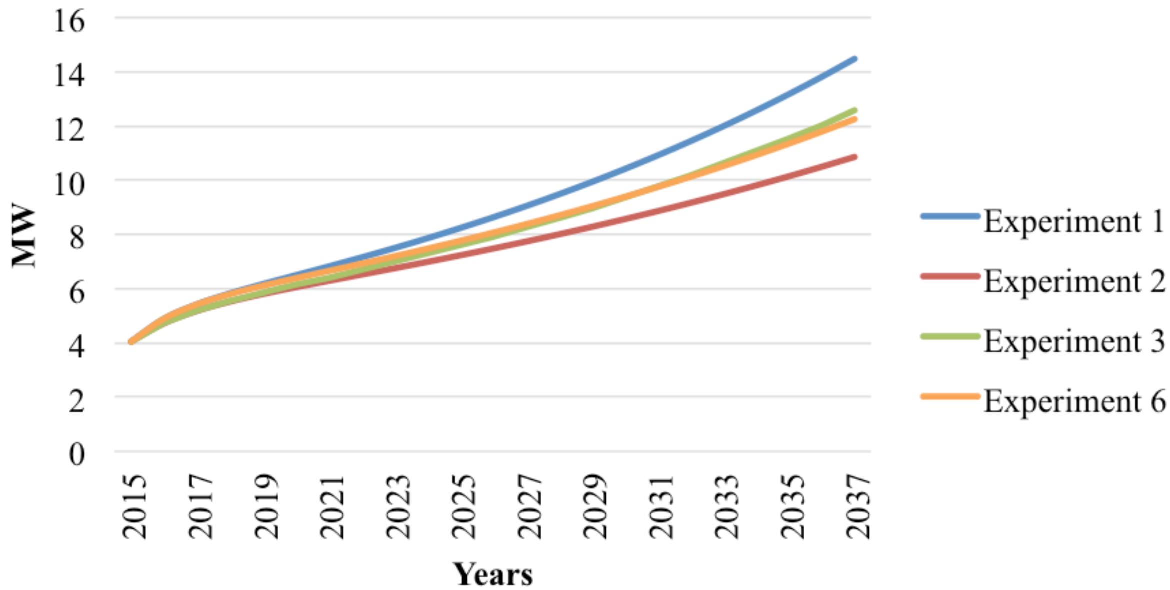

Fig. 3. Results of change in customer satisfaction

5. Conclusions

In order to illustrate the dynamics that emerge from electricity market and perceived innovation, this paper developed several experiments characterized by different industrial policy. The development of a formal model allows better understand the dynamics of development in the PV industry associated with market and innovation processes. This paper, therefore, expand the methodological toolbox of technological transitions studies proposed by others authors (Geels and Johnson, 2018; Walrave and Raven, 2016).

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