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Published in:
Energy for Sustainable Development

DOI:
10.1016/j.esd.2020.03.003

2020

Document Version:
Peer reviewed version (aka post-print)

Link to publication

Citation for published version (APA):
Gil Perez, A. J., & Hansen, T. (2020). Technology characteristics and catching-up policies: solar energy technologies in Mexico. *Energy for Sustainable Development*, *56*, 51-66.
https://doi.org/10.1016/j.esd.2020.03.003

Total number of authors:
2

THIS IS THE POST-PRINT VERSION OF THE PAPER NOW PUBLISHED AS

Gil Perez, A.J. & Hansen, T. (2020): Technology characteristics and catching-up policies: solar energy technologies in Mexico. *Energy for Sustainable Development*, Vol. 56, 51-66

Technology characteristics and catching-up policies: solar energy technologies in Mexico

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Abstract

Developing countries are giving increasing attention to industry development in renewable energy industries. Previous research highlights the influence of technology characteristics on such catching-up policies, distinguishing between complex products produced in small batches, and mass-produced simple products. We suggest that catching-up policies should move beyond this binary distinction between technologies. To illustrate this, we carry out a longitudinal analysis of catching-up policies in Mexico for two technologies – solar water heating and solar photovoltaics – that are both characterised as standard, mass-produced products, but which differ in degree of technological complexity. Our analysis highlights that the greater technological complexity of solar photovoltaics implies a larger focus of policies on providing access to resources in the form of knowledge, finance and legitimacy from abroad. Conversely, policies focusing on solar water heating had a greater domestic focus.

Keywords

Technology characteristics; catching-up; renewable energy policy; solar water heating; solar photovoltaics; Mexico

Highlights

Technology characteristics influence catching-up in renewable energy industries

Mexican policies for solar water heating and solar photovoltaics are compared

Solar photovoltaics policies focus more on providing access to resources from abroad

Policy mixes should consider complexity of product architecture and scale of production process

Technology characteristics and catching-up policies: solar energy technologies in Mexico

1. Introduction

With the increasing urgency of tackling climate change, it is becoming ever more evident that the energy sector needs to transition towards renewable energy. Associated with this development has been an increasing interest in the possibilities for creating industry development around renewable energy technologies (Grillitsch & Hansen, 2019), also in the context of developing and emerging economies (U. E. Hansen, Fold, & Hansen, 2016; Lema, Hanlin, Hansen, & Nzila, 2018; Lewis & Wiser, 2007). Recently, contributions have recognised that the characteristics of renewable energy technologies matter significantly for the opportunities for catch-up, suggesting the need for prioritisation and differentiation in technology policies (Schmidt & Huenteler, 2016). More specifically, the degree of complexity of product architecture and the scale of production process have been identified as two central parameters for identifying different technology characteristics and, subsequently, policy recommendations (Binz, Gosens, Hansen, & Hansen, 2017; T. Hansen, Klitkou, Borup, Scordato, & Wessberg, 2017; Huenteler, Schmidt, Ossenbrink, & Hoffmann, 2016).

The literature has so far assumed an inverse relationship between these two core technology characteristics: the more complex the technologies, the lower the scale of the production process. Thus, industries are either characterised as producing technologically complex products in small batches, or technologically simple products through mass-production. In the current paper, we challenge the assumption that technological complexity and scale of production are necessarily inversely related. Specifically, we compare two technologies – solar water heating (SWH) and solar photovoltaics (SPV) – that are both characterised as standard, mass-produced products, but which differ in degree of technological complexity. In the paper, we focus on catching-up policies for these two technologies in the case of Mexico, by examining differences and similarities in the focus of the policies. In this, we analyse differences in the emphasis of policies according to mobilisation processes for core resources for industry development – knowledge creation, market access, mobilisation of finance, and legitimacy creation (Binz, Truffer, & Coenen, 2016) – as well as the geographical focus (domestic vs. abroad) in these resource mobilisation policies.

Solar energy industries in Mexico profit from an average of 5 kWh/day/m^2 in solar radiation (SENER & GIZ, 2012) – almost double compared to Germany (Mata and Ortega, 2015). The development of SWH and SPV technologies in Mexico started to grow considerably in the last decades and especially after an energy reform that allowed private companies to participate in the energy system. This fostered the development of renewable energy industries, including the SWH but especially the SPV (Hoyt, Olivas, & Grajales, 2006; Rodríguez Suárez et al., 2017). Despite continuing challenges related to legitimacy, political instability and access to finance, it is expected that the Mexican solar energy sector will keep growing due to the combination of plentiful natural resources, low labor prices and increasing level of technological competence (Spector, 2018).

The paper is structured as follows: section 2 presents the theoretical framework, while section 3 contains the methodology. Section 4 introduces the Mexican case and section 5 contains the empirical analysis. Finally, section 6 concludes.

2. Theoretical framework

2.1. Catching-up

The catching-up literature is essentially concerned with understanding how infant industries in developing and emerging economies may in relatively short time-periods reach the level of western countries. A core focus in this literature has been the role of state-led policies in achieving catching-up. Historically, developed countries used interventionist trade and industrial policies to promote infant industries, which is the contrary to policies that are being promoted today (liberalization) and to the common understanding of how development should be done (Chang, 2006). Therefore, literature describes that a combination of government policy, foreign competition, and intra-firm capability building efforts is essential for rapid capability development (Figueiredo, 2008; Tran, 1988). Further, the degree of dependence on foreign resources should vary according to the development phase of countries. It is said that during the infant stage of industries, foreign resources should be used as much as possible, then gradually reduced as the industry grows and the country becomes capable to produce their own resources (Tran, 1988).

Catching-up policies emphasise the role of transnational linkages and the processes through which knowledge flows from one country and are anchored in another (Binz et al., 2017, 2016). Anchoring describes the modalities and institutional arrangements that have to be done by a region or country to articulate a mobile context of knowledge, adapt and acquire it (Crevoisier & Jeannerat, 2009). It means not only bringing new knowledge but also adapting and modifying it to local conditions. Thus, catch-up entails a learning process that considers the modification and adaptation of the *"nature, structure, organization, and dynamics of innovation and production sectors"* (Malerba & Nelson, 2011, p. 1649) through a long-term learning process. Drawing on the literature on technological innovation systems, Binz et al. (2016) further specify the four resources central to industry development: 1) *knowledge creation* is related to the activities that develop new technological knowledge and related competencies (Binz et al., 2016); 2) *market access* refers to the creation of a protected space and mass markets for new technologies; 3) *mobilisation of finance* is related to the possibilities of industry stakeholders to access finance (Binz et al., 2017, 2016); and 4) *legitimacy creation* is concerned with the acceptance of the technology and its alignment with norms and institutional structures (Markard, Wirth, & Truffer, 2016).

2.2. Technology characteristics

In a recent contribution, Schmidt & Huenteler (2016) point out that the catching-up literature has to a large extent neglected the role of technology characteristics for understanding the capabilities required for achieving rapid industry development. This follows Huenteler et al. (2016) in distinguishing between two core technology characteristics: i) the complexity of product architecture and ii) the scale of production process.

On one hand, the complexity of product architecture is understood as *"the number of sub-systems and components and the complexity of their interactions in the system"* (Huenteler et al., 2016, p. 104). It entails the complexity of the technology by itself; a technology with a higher product architecture is commonly designed and produced for specific customers, needs and special characteristics. Thus, it is tailored to the context in which the technology is used. Binz et al. (2017) exemplify this by locating biomass power plants as a system with a high degree of product architecture.

On the other hand, the scale of production process considers the *"modularity of the system as well as the size and homogeneity of user demand"* (Huenteler et al., 2016, p. 104). It entails the homogeneity and adaptability of the technology to different environments and conditions. Technologies with high scale of production processes are products that can (almost) be used anywhere, anytime and by anybody. Their main characteristics are the mass-production process and high standardisation that does not consider the characteristics of the environment in which it will be used. Huenteler et al. (2016) locate SPV systems as a technology with a high degree of scale production process.

The analysis of technologies considering these characteristics commonly results in a trade-off between both characteristics. A technology that has a complex product architecture has a low degree of scale of production process, while the technology with a high degree of scale of production process has a low complexity of product architecture (Figure 1) (Binz et al., 2017; Huenteler et al., 2016).

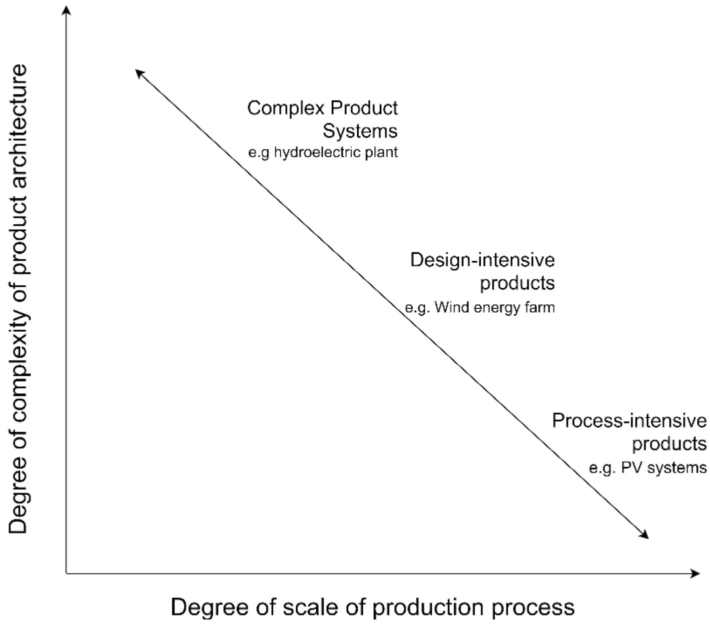

Figure 1: Framework to classify technology. Adapted from (Binz et al., 2017; Huenteler et al., 2016)

Contrary to previous conceptualisations of technology characteristics (Binz et al., 2017; T. Hansen et al., 2017; Huenteler et al., 2016), we do not assume a direct relation between the complexity of product architecture and the scale of production process. In other words, we might see variance in technological complexity for technologies with similar scale in the production process (and vice versa). In the subsequent analysis, we compare two technologies – Solar Water Heating (SWH) and Solar Photovoltaic (SPV) systems – that differ in technological complexity but are characterised by a similar scale of production process and market structure. Both systems are standard, mass-produced products that are merchandized and installed, for the domestic sector, in individual units (homes, offices, etc.) by similar kind of retail stores and similar type of technicians. Further, the installation process is largely similar: a specialized technician will install the technology at the user site. Despite of these similarities, the complexity of product architecture varies considerably, even if both technologies are less complex than e.g. wind energy systems. On one hand, SWH are simple systems composed by pipelines or vacuum tubes and thermal insulated tanks that do not require higher levels of technical capacities to be built. On the other hand, SPV systems are more complex due to the higher number of components and the complexity of them, such as solar cells. Its manufacturing process requires more technical capabilities and higher investment costs.

Considering the differences in technology complexity and the similar degree of scale of production process of SWH and SPV technologies, the framework to classify the technologies will vary as showed in figure 2. It is observed that SWH has the same degree of scale of production process while SPV has a higher degree of technological complexity.

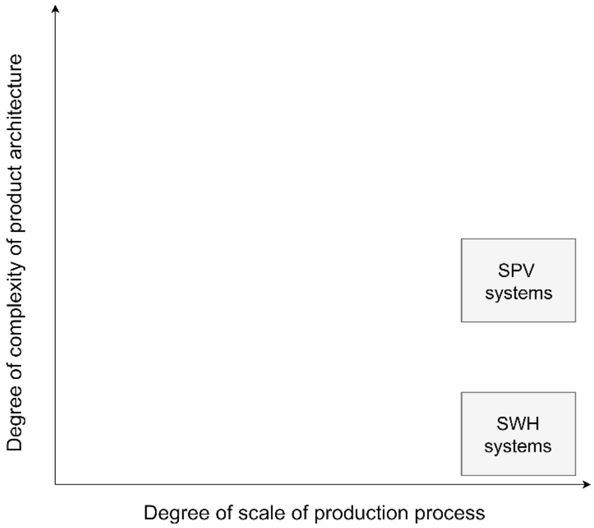

Figure 2: Classification of technologies.

Drawing on insights from the literature on policy mixes (Flanagan, Uyarra, & Laranja, 2011; Reichardt & Rogge, 2016), we argue for the need for analysing the wider portfolio of policies influencing resource formation around the two technologies, rather than focusing on individual policy instruments. This follows Binz et al. (2017) who present a stylized overview of policy mixes for industries with different technology characteristics, according to the previously described core resources to industry development processes (Table 1).

Resource	Process-intensive products	Complex product systems
Knowledge creation	- Government funded basic science and R&D programs - Supporting the quick translation of new technologies to the manufacturing process - Support for entrepreneurial experimentation in private start-ups - Support imports of capital equipment, turn-key plants, and/or knockdown kits	- Government funded pilot plant programs - Support for skills development in project contracting, and related management training programs. - Support for feasibility studies and infrastructure need assessments - Support for Foreign Direct Investments, openness of product markets to foreign competition
Market access	*Promotion of domestic markets:* - Policies aimed at creating domestic mass markets to facilitate economies of scale in production *Promotion of export market:* - Establishment of export processing zones with state-of-the-art trade infrastructure. - Interventions to decrease factor costs (raw materials, capital costs, labor costs, energy costs)	*Promotion of domestic market:* - Public procurement with explicit technology innovation requirements - State co-financing of innovative pilot plants and demonstration projects *Promotion of export market:* - Participation in international pilot plant projects and technology consortia (e.g., international space programs or pilot projects I nuclear fusion or carbon capture and storage technologies)
Mobilisation of finance	- Providing low-cost loans for plant expansion, equipment purchases - Creating a supportive private equity and venture capital system	- Direct plant co-financing to promote project-specific learning - Incentivize incumbents to provide long-term investment capital
Legitimacy creation	- Adopting international quality certification and standard systems - Mobilizing policy/public support based on success stories in export markets.	- Facilitating independent third-party assessment of pilot plant projects - Mobilizing policy/public support based on pilot performance, media coverage.

Table 1: Resource mobilization catching-up policies. Adapted from table 2 in Binz et al. (2017)

As the policy mixes outlined in Table 1 are based on the assumption of a direct relation between the complexity of product architecture and the scale of production process, they do not fully fit our technologies in focus. Consequently, below we elaborate on the expected characteristics of catching-up policy mixes for the two technologies in the current analysis: SWH (mass market, low technological complexity) and SPV (mass market, higher technological complexity). Here we also pay specific attention to expectations regarding the geography of the resource mobilisation: domestic or from abroad.

Knowledge creation refers to activities that create new technological knowledge and related competencies (Binz et al., 2017). The usual activities for mass-produced products are basic R&D support programs and support for implementation of new technologies in manufacturing (Binz et al., 2016). This resource is obtained in similar forms for both types of technologies. Nevertheless, due to the higher complexity of SPV systems, more efforts must be done to secure knowledge transfer and development. These efforts include the creation of clusters between suppliers of manufacturers, support production of licensed foreign equipment technology, and creation of joint ventures. Consequently, in the case of catching up processes it is expected that resources for SPV systems are to a greater extent relying on international linkages, while resources for SWH are more frequently developed domestically.

Market access points to the importance of creating a protected space for new technologies and to create domestic mass markets to facilitate economies of scale in production (Binz et al., 2017, 2016). The usual activities to obtain this resource is through supportive tax regimes, regulations, and subsidies (Binz et al., 2016). The domestic market for both technologies is similar, since both technologies are distributed through similar retail stores that follow the same frameworks to deliver and install both technologies. Export markets differ considerable, since SPV are global goods that are usually produced in a limited number of countries and installed in a much larger number of countries. Hence, international export markets play an important role in the development of SPV industry.

Mobilisation of *financial resources* for industry actors may be achieved through the provision of loans for expansion and equipment purchases and the creation of venture capital systems (Binz et al., 2017, 2016). For the technologies in case, finance is mobilized through these approaches. However, the only difference is that SPV systems may require higher amounts of finance due to their higher technological complexity. For both technologies, mobilisation of finance can be domestic or from abroad, but the larger capital requirements for SPV results in a greater need for attracting funds from non-domestic sources.

Legitimacy creation denotes the degree of alignment of the technology with existing institutional structures in society (Markard et al., 2016). Legitimacy can either follow from integrating a new technology in existing institutional structures or adapting the current environment to the new technology (Binz et al., 2016). Both technologies need legitimacy-building efforts, e.g. through adoption of international standards and certifications, and the promotion of success stories that may mobilize policy support. Table 2 summarises the expected policy mixes for the two industries.

Resource	*Mass market, low technological complexity (SWH)*	*Mass market, higher technological complexity (SPV)*
Knowledge creation	- Government funded basic science and R&D programs - Supporting the quick translation of new technologies to the manufacturing process - Support for entrepreneurial experimentation in private start-ups - Support imports of capital equipment, turn-key plants, and/or knockdown kits	- Government funded applied research and field trial programs - Supporting the quick translation of new technologies to the manufacturing process - Support for entrepreneurial experimentation in private start-ups - Cluster programs to ensure knowledge transfer between integrated equipment manufacturers and specialized component suppliers - Support licensed production of foreign equipment technology. - Creation of joint ventures
Market access	- Promotion of domestic mass markets to facilitate economies of scale in production. - Establishment of export processing zones with state-of-the art trade infrastructure - Interventions to decrease factor costs (e.g. raw materials and capital costs)	- Promotion of domestic mass markets to facilitate economies of scale in production. - Establishment of export processing zones with state-of-the-art trade infrastructure. - Interventions to decrease factor costs (e.g. raw materials and capital costs) - Supporting the international diffusion of domestic products through export credit assistance, tied aid, etc.
Mobilisation of finance	- Providing low-cost loans for plant expansion, equipment purchases - Creating a supportive private equity and venture capital system	- Providing low-cost loans for plant expansion, equipment purchases - Creating a supportive private equity and venture capital system - Supplying patient capital, long-term investment in niche technologies
Legitimacy creation	- Adopting quality certification and standard systems - Mobilizing policy/public support based on success stories	- Adopting quality certification and standard systems - Mobilizing policy/public support based on success stories

Table 2: Resource mobilization catching-up policies – SWH and SPV

3. Methodology

The design of this research is based on a policy analysis that seeks to identify how policy promotes the mobilization of knowledge, market access, mobilisation of finance, and legitimacy creation in relation to the two technologies. The most common methodology to compare policies is through an analysis of a historical case-based study (Geva-May, Hoffman, & Muhleisen, 2018, p. 28), which *"draw[s] conclusions by comparing different countries, localities and policy regimes, often over a period of time. They do not attempt to delimit any set of texts or sources for analysis, but rather freely mix scholarship, journalism, government reports and other sources"*.

The methodology is based on a desktop analysis of 27 policies promoting the development of the SWH and SPV sectors in Mexico. The solar energy sector in Mexico has been active since the 1950s, however, efforts to foster the industry started to appear in the late 1970s. Thus, the policy analysis focuses on the period from the late 1970s until 2018.

The first step of the analysis entailed compiling a policy library and establishing an initial overview of the development over time in policy focus. As the development of the policy library involves the identification of different sources of information that describes the implementation of policies, the main source of information are official policy documents from the Mexican government. However, other sources of information such as reports from research and innovation projects, NGO's, consultancies and international agencies are also considered. The main characteristic to consider a source for the research is its relevance for promotion of the mentioned resources (knowledge creation, market access, mobilisation of finance, legitimacy creation). If the source described the promotion or promote by itself the development of one of these resources for the SWH or SPV industry, it was considered as a pertinent source and included in the library. The methodology to find the sources was based on a purposive sampling technique that considers the knowledge and experience of the researcher as the main criteria to judge which element is sampled; the main objective of this sampling technique is to define a representative sample that covers the necessity of the research (Battaglia, 2011). The research library included 27 policy sources (see appendix 1). Policies were finally classified according to their type (see Table 3).

Policy type	*Description*
Law	Law enacted to promote SWH or SPV. Promotion of national and/or international measures are considered.
Regulation	Development of standards or technical regulations for the SWH and SPV sector.
International initiative	Initiative (e.g. programs, projects or plans) developed by the Mexican government in cooperation with an international entity to promote the sectors.
National initiative	Initiative (e.g. programs, projects or plans) developed by the Mexican government to promote the sectors.
Actors (NGO's, research centers, other organizations)	Establishment of new actors through policy frameworks with specific objectives to promote the development of the sectors.

Table 3: Policy typology description

The second step of the methodology consisted of reading, coding and analysing the policies in detail (see e.g. Nardelli and Broumels, 2017). The coding process was completed using the software NVivo 11, and subsequently exported into a spreadsheet file for further analysis. Codes can be developed bottom-up from reading the empirical material, or be determined a priori – so-called provisional coding – based on (Saldaña, 2009, pp. 120–121) *"literature reviews related to the study, the study's conceptual framework and research questions, previous research findings, pilot study fieldwork, the researcher's previous knowledge and experiences (experiential data), and researcher-formulated hypotheses or hunches."* For the current paper, codes were initially derived based on established categories (technology type, origin of resources, and resource mobilisation processes promoted by the policies), as we were particularly interested in structuring and analysing data according to the four resources central to industry development (Binz et al., 2016). In order to ensure a clear and joint understanding of the content of the codes, brief descriptions were developed for each of them.

It is particularly important to critically evaluate and eventually modify codes along the way when using provisional coding. As stated by Saldaña (2009, p. 122): *"If you become too enamored with your original Provisional Codes and become unwilling to modify them, you run the risk of trying to fit qualitative data into a set of codes and categories that may not apply."* This underlines the importance of discussions of the coding process along the way between the authors. Based on these discussions, code descriptions were modified during the research process. Table 4 provides the final descriptions of the codes for the four types of resources and the number of coded text pieces.

Code	*Code description*	*Number of coded text pieces*
Knowledge creation	The text refers to development of knowledge of importance for the technology. Knowledge can be of different types, including scientific knowledge, market knowledge, and knowledge about production, natural resources or logistics	76
Market access	The text refers to aspects related to market development. Examples of such aspects are market size, pricing systems, primary demand vs derived demand, articulation of demand (including customer preferences), and other drivers of market formation such as standards and procurement practices	71
Mobilisation of finance	The text refers to mobilisation of financial capital, including aspects such as direct investments, aid and equity capital	69
Legitimacy creation	The text refers to acceptability of the technology, for instance in relation to performance assessments, actual or perceived problems with the technology, or the text refers to social acceptance and alignment of the technology with formal (e.g. laws and regulations) and informal (e.g. norms and values) institutions	96

Table 4: Code descriptions and number of coded text pieces for resource mobilisation processes

The analysis was divided into three time periods. The first phase covers the period from the end of the 1970s to 2000, which is considered as the solar energy emergence period. This period is characterized by low involvement of the state, and the development of the sector was mostly promoted by private industry. The second period covers 2000-2013, where the Mexican state increased its involvement in solar energy promotion by developing regulation, laws and establishing nationally and internationally focused policy initiatives. The third period covers 2013-2018, which are the first years after the 2013-energy reform that changed the rules of the game by providing a new legal framework and establishing efforts to promote resource obtention through both national and international linkages. Illustrative quotes (in most cases translated from Spanish) are included throughout the analysis.

4. Case description

Mexico is one of the countries with highest solar radiation in the world (Mata and Ortega, 2015). However, these resources were poorly exploited until the last decades. For 2016, the share of renewable energy production in the country was 8.4%, with the share of solar energy constituting a small but rapidly growing share. The equivalent energy generation of SWH was in 2016 10.18 PJ, while for SPV it was 0.59 PJ (SENER, 2017). The distributed generation sector (SPV in domestic homes) has also shown an important growth rate, reaching 110% growth rate per year (Yaneva, Plamena, & Tsvetomira, 2018).

The first SWH builders in Mexico appeared around 1942 (Rincón Mejía & Aranda Pereyra, 2006) and were specialized in heating water for pools. However, the technology has gained significant importance in applications in commercial properties, small industries and especially the housing sector since the late 1970s. Since then, multiple policy instruments have been applied to promote the development of the industry and the use of the technology. The principal market has been the residential sector. Today, every variety available in the market (e.g. flat collector, evacuated tube) is being built by several Mexican companies. As the Mexican SWH industry is made up of a large number of smaller producers, gathering detailed information about the growth of production capacity is difficult. However, in a market dominated by Chinese firms, Mexican *Modulo Solar* is one of the non-Chinese producers (and the only from the Americas) that make it into the list of largest manufactures (Epp, 2020). Further, assessments of the industry indicate that it grows continuously (Rincón Mejía & Aranda Pereyra, 2006; Rodríguez Suárez et al., 2017). The production capacity of SWHs reached 26,300 MW in 2016. Most of the producing companies are Mexican and based on Mexican technology (Rodríguez Suárez et al., 2017). Internationally, the Mexican market has showed high growth rates in recent years. For the industrial sector, since 2012, 11 new solar concentrating systems were installed, with a total area around 4,700 m^2, and 40% of all concentrating systems worldwide are installed in Mexico (Weiss & Spörk-Dür, 2018).

The case of SPV is special, because electricity production was, until 2013, controlled by the Mexican government. Consequently, electricity is mostly produced from fossil fuels in Mexico (Grande-Acosta & Islas-Samperio, 2017). Nevertheless, the 2013 energy reform radically changed the hydrocarbon and electricity sectors, liberalizing the electricity market and opening it for private investors (Bellini, 2018b; DeFilippe, 2018; Spector, 2018). Subsequently, several measures have been implemented to promote renewables and especially SPV, which combined with the decreasing costs of SPV technology, has caused a rapid recent development. Thus, clear signs of catching-up in the Mexican context are evident from multiple recent establishments of SPV production plants, such as *Flextronics* who has established the largest plant in Latin America in Ciudad-Juarez, which now produces 1.3 million panels yearly for Sun-Edison Inc. (NAPS, 2016). With only two important SPV producers of Mexican origin, foreign firms constitute most of the industry that base their production on technology primarily developed abroad. A large part of the production is exported, primarily to the United States. Thus, the SPV industry has grown steadily since 2007, with the accumulated production capacity reaching 2074 MW in 2019 (Table 5 and Figure 3). In an international perspective, this growth is impressive. As updated comparative data on SPV manufacturing capacity per country is unavailable, most studies (e.g. Binz & Anadon, 2018) rely on data from the Earth Policy Institute (EPI, 2013). According to this data, Mexico would have ranked fourth in the World in 2012 after China, Taiwan and Japan and ahead of Malaysia and Germany with the current production capacity.

Location	Company	Date	MW/year
San Andrés Tuxtla, Veracruz	ERDM Solar	2007	30
Guanajuato	Solartec	2009	100
Pestejé, EDOMEX	IUSASOL	2013	500
Oaxaca	Solarvatio	2013	12
Ciudad Juárez	SunEdison + Flextronics	2015	450
Guanajuato	Solartec	2016	250
Ensenada	Sunpower	2016	400
Mérida, Yucatán	Solarsol	2017	20
Aguascalientes	Saya Energy	2018	100
San Andrés Tuxtla, Veracruz	ERDM Solar	2018	200
Querétaro	Solarever	2019	0.7
Puebla	SAECSA	2019	11.4

Table 5: SPV Production capacity. Created by the author with information gathered from (Bellini, 2018b, 2018a; "FÁBRICAS DE PANELES SOLARES EN MÉXICO - DirectorioDeFabricas.com," 2019; "Grupo IUSA invierte $200 millones en fábrica de módulos en México – pv magazine Latin America," 2014; "Inauguran primera fábrica de paneles fotovoltáicos en México," 2015; "NotiMx : Solarever, empresa mexicana trae innovación tecnológica para fortalecer la industria fotovoltaica del país," 2019; "SunEdison instala planta ensambladora de módulos solares en Chihuahua - El Diario de Coahuila," 2015; Sánchez, 2014)

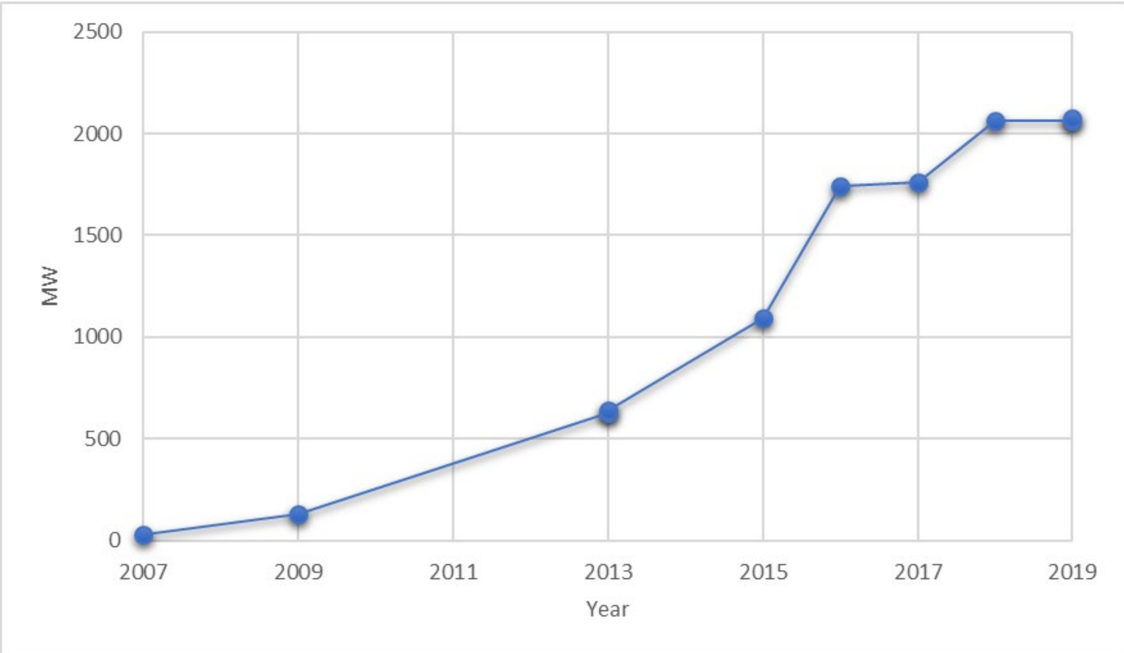

Figure 3: SPV production capacity growth. Created by the author with information gathered from (Bellini, 2018b, 2018a; "FÁBRICAS DE PANELES SOLARES EN MÉXICO - DirectorioDeFabricas.com," 2019; "Grupo IUSA invierte $200 millones en fábrica de módulos en México – pv magazine Latin America," 2014; "Inauguran primera fábrica de paneles fotovoltáicos en México," 2015; "NotiMx : Solarever, empresa mexicana trae innovación tecnológica para fortalecer la industria fotovoltaica del país," 2019; "SunEdison instala planta ensambladora de módulos solares en Chihuahua - El Diario de Coahuila," 2015; Sánchez, 2014)

5. Analysis

This section presents the policy biography and analysis. We focus on identifying core policies, the resources promoted through these, and the origin of these resources. The analysis is structured according to the three time periods described in section 3: late 1970s-2000; 2000-2013; and 2013-

2018. Figure 4 illustrates the policy development process over the entire period. The details of the activities and resources promoted by each policy are described in appendix 1.

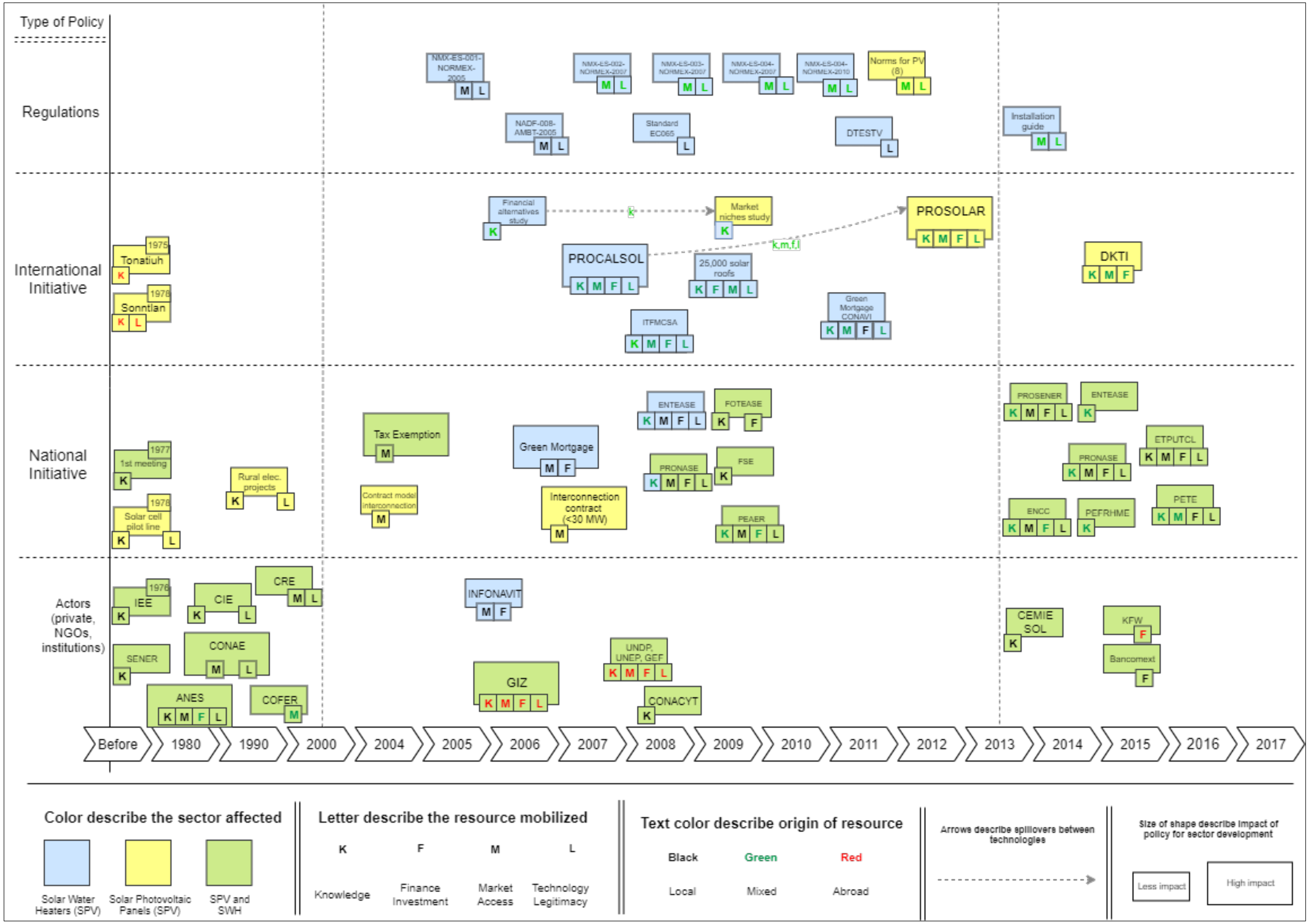

Figure 4: Policy analysis timeline

5.1. Solar energy emergence – late 1970s to 2000

The main policies that promoted SWH and SPV during the 1980s were related to the creation and establishment of actors, such as research centres, national meetings for information exchange and the national association for solar energy (ANES). These actors led to the emergence of the first SWH builders (Modulo solar, n.d.; Sunway, n.d.; Tecnosol, n.d.). These builders were directly linked to the solar energy research centres or were new ventures from well-established Mexican companies. This consolidated solar energy as an emerging niche. Nevertheless, few state policies were introduced to promote the development of the sector, with most of them focusing on technology transfer from France and Germany, which were unsuccessful due to the unawareness of local conditions by the promoters, for example *"The Sonntlan project […] included a small power plant to make a community self-sufficient. What they did not consider was that the community was only inhabited during the fishing season. Besides, the fishing product was a luxury – lobster – which is not there all year round and many people went there with their own boats"* (Rincón Mejía & Aranda Pereyra, 2006, p. 78). This highlights the importance of catching-up policies to link and adopt extra-regional knowledge to the local context.

During the 1990s, the involvement of the state in solar energy promotion increased with the creation of institutions to promote energy efficiency and renewable energy, to regulate energy markets and to diffuse information about successful projects (Páramo-Fernández, 1997). In line with this, a variety of successful electrification projects for the rural sector appeared. *"The cumulative photovoltaic capacity installed in Mexico by the end of 2006 was 19.7 MWp. Rural application is still the major application for photovoltaic systems serving as a solution for off-grid electrification or to avoid the high tariffs for pumping water for irrigation"* (Amtmann, 2009, p. 18). These actions located the state as a major stakeholder for the promotion of SWH and SPV. However, in general, policies during this period were generic, covering both SWH and SPV.

Knowledge creation

Knowledge creation was the most active resource formation process during the first period, with several actors, national and international initiatives engaged in its mobilization. At the beginning, knowledge on SPV technology from international sources could not be adopted due to incompatibility with local circumstances. The Tonatiuh project illustrates how imported knowledge and components were unrelated to the Mexican context. As part of the project, *"nine solar pumps were also installed in different locations in the north of the country, with a power of about one horsepower, manufactured in France, under French standards. These ignorant people (promoters of the project) did not know that the screws, the nuts, the valves, the gaskets, the diameters and qualities of the tubes, the fuses, electrical connectors and a long etcetera, made in France, correspond to technical norms different from the Mexican norms, therefore, no screw, nut, gasket, valve, and another long etcetera of components made in Mexico, could serve as spare part for these French installations"* (Rincón Mejía & Aranda Pereyra, 2006, p. 43) (Tonatiuh and Sonntlan unsuccessful projects, see Figure 4). In order to make the adoption of external knowledge possible, it was first necessary to develop a solid base of local knowledge that made absorption of knowledge from the outside possible. For this, three institutions were created that promoted knowledge development (CONAE, CIE and CRE, see Appendix 1). Thus, the largest mobilization of local knowledge is at the beginning of the period (see Figure 4), where a number of newly established actors played a key role in actions such as promotion of R&D activities for both sectors, and knowledge exchange during national meetings.

Market access

Efforts to establish access to markets were based on promoting quality standards and regulation of the energy market. On one hand, the NGO ANES and the National Commission for Energy Savings

(CONAE) were the main promoters of quality standards for both SWH and SPV. This combination of actors, involving private and public sector was crucial for the process. One of the main objectives of the ANES was *"to serve as a link between researchers, manufacturers, professionals and official and private agencies in the renewable energy sector, in order to seek the consensus of experts capable of giving their opinion on national energy management and administration policies"* (Rincón Mejía & Aranda Pereyra, 2006, p. 8). On the other hand, The Energy Regulation Commission (CRE) was created to regulate the energy market including regulation of solar energy, while the Council for the Promotion of Renewable Energies in Mexico (COFER) was created to strengthen the relation of the agents involved in renewable energy in Mexico. These measures had an impact on the domestic market due to the work of COFER, whose mission is *"to promote the renewable energy market in Mexico, under a scheme of free competition and promotion of national capacities"* (Rincón Mejía & Aranda Pereyra, 2006, p. 86). These include diffusion of renewable energies through promotion of R&D, regulation, and development of economic instruments. The promotion of domestic mass markets was done principally through the development of quality standards through policies that increase the benefits of using SPV and through improvement of regulation of the energy market.

Financial investment

Policies for mobilization of finance at the beginning of the solar energy industry were scarce. The main mobilization effort was done by the NGO ANES, which focused on mobilizing both domestic and foreign finance, the latter through multilateral agencies. However, finance mobilization was scarce, mostly from domestic sources, where private investors were central to finance the emerging industry related to production of solar equipment, especially SWH. Nevertheless, *"the Mexican government, at its different levels, has played an important role in promoting and financing some related projects, but almost all the systems installed responded to specific problems and did not explicitly arise from a concerted or planned government policy"* (Rincón Mejía & Aranda Pereyra, 2006, p. 8).

Technology legitimacy

The creation of legitimacy for solar energy during the first period was promoted by diverse actors but through similar mechanisms. In general, the divulgation of solar energy and the promotion of the benefits of it were advertised. To exemplify, one of the strategic objectives of COFER was *"the support of technology diffusion, education and capability development projects about renewable energy in the whole country"* (Rincón Mejía & Aranda Pereyra, 2006, p. 86). The role of the state during this period was only related to demonstration projects that were not very successful.

One of these was the Sonntlan project, which *"considered the complete construction of the infrastructure (for a community of fishermen) by the Mexican government, including import of solar and control systems from Germany. Germany participated with a generous support package from its government […] through its Ministry of Research and Technology […] The plant operated at its nominal capacity of 10 cubic meters per day of desalinated water around 1979. The experiment yielded important experiences, some of which were published. [However,] after the brief days of demonstration and experimental analysis, the Germans withdrew with their databases and left the regional government the thankless task of paying day and night for a team of watchmen to reduce the speed at which the facilities were cannibalized [stolen] by neighbours and visitors"* (Rincón Mejía & Aranda Pereyra, 2006, p. 77).

Policies for legitimacy creation were not of great importance during this period, as legitimacy rather developed because of increasing engagement by domestic actors in the industries. It should be noted that there were two additional projects that partly focused on creating SPV technology legitimacy (see Figure 4). One of them confirmed, through a solar cell pilot production line, the capacities of the country to produce SPV equipment, while the other demonstrated the performance of SPV in rural areas.

In summary, the period from the late 1970s to 2000 was characterized by the formation of actors to promote SWH and SPV and can be considered as the industry formation phase where the basic conditions for the promotion of solar energy industries were established. As the SWH industry was more developed due to the maturity of the technology, most policy efforts sought to stimulate development of SPV through supporting knowledge creation and technology legitimacy. Owing to the higher complexity of the SPV technology, international linkages were needed to mobilise these resources, however, a lack of domestic capabilities prevented successful uptake.

5.2. Acceleration of solar energy – 2000 to 2013

During the second phase, the state took an important role in the promotion of solar energy. The most important outcomes of this period were the development of new laws, regulations, studies and specific initiatives to promote the mobilization of resources, which resulted in accelerating solar industry development. Among the key policies were a tax reform, which fully exempted cost of machinery and equipment for renewable energy (Congreso de la Unión, 2013), specific laws to promote sustainable use of energy and the energy transition, and a specific regulation for SPV that promoted distributed generation (Gobierno de la República Mexicana, 2009; SENER, 2001).

Different studies to understand solar energy were made, one of the most important was the study *Financial alternatives for the promotion of the use of SWH in the domestic Mexican sector* (Hoyt et al., 2006), done by the CONUEE in collaboration with the German Agency for Cooperation (GIZ). The aim of the study was to *"identify and analyse financial alternatives for the promotion of the use of Solar Water Heaters (SWHs) in the Mexican domestic sector"* (Hoyt et al., 2006, p. 1). This initiated a long history of cooperation between Mexico and Germany for solar energy development, including the PROCALSOL initiative, which promoted SWH for the housing sector through strengthening the market, the national industry (producers, system designers, distributors, and installers) and technological development through establishing national research centres (CONAE, ANES, & GTZ, 2007).

During this period, successful experiences from the SWH sector were translated and replicated for SPV. The study *Market niches for the use of photovoltaic panels in connection to the electrical grid in Mexico* (Amtmann, 2009) exemplifies this as it was the first study to understand the financial possibilities of SPV, following the same mechanism as the project PROSOLAR. PROSOLAR intended *"to promote photovoltaic solar technology in the short and medium term; to guarantee the growth of the market with an adequate level of quality in the products and associated services and to develop a local market that favours the development of the national industry"* (SENER & GIZ, 2012, p. 12). This was supported in four ways: 1) Development of regulations, 2) financial support, 3) capability development, and 4) diffusion of information (SENER & GIZ, 2012).

Knowledge creation

Building on the domestically developed knowledge from the first period, knowledge was mobilized during the second phase through international linkages. The initiatives promoted by international initiatives like the GIZ and the UN entities in collaboration with Mexican institutes, resulted in successful projects, events and linkages that provided access to knowledge from foreign sources.

"The linkage with other groups and institutions, both national and foreign, helped to increase and strengthen the IIE's [the Mexican Electrical Research Institute] human capital in specific areas of renewable energy, a mechanism that is still in place and of great value today" (Huacuz Villamar, 2016, p. 201). A key initiative was the Financial Alternatives study (Figure 4) made by the GIZ and the CONAE

with the aim to understand and promote Mexican SWH market. This resulted in the PROCALSOL initiative for the SWH sector, considered as one of the most important initiatives for knowledge development in relation to SWH. The results and lessons learned were *"a valuable reference for replication in other countries of the Latin American region, in the implementation and sustainability of mechanisms to promote and strengthen solar water heating schemes and replicable for the distributed generation of renewable energies"* (Mata & Ortega, 2015, p. 68). In Mexico, PROCALSOL led to several other projects, the most important being PROSOLAR, which transferred knowledge from SWH to SPV (see Figure 4).

Thus, the mobilization of knowledge during this period was characterised by a mix of domestically focused knowledge development, and knowledge transfer through international linkages that promoted further-development of the two industries, however, knowledge development in SWH was to a much larger extent relying on domestic sources. In SPV, the higher technological complexity implied that improved R&D capacity and training for professionals and technicians required the integration of knowledge from abroad. As phrased by the National Strategy for Energy Transition and Sustainable Energy Use (ENTEASE) *"its [SPV's] successful implementation requires closer and more intensive collaboration with international actors who are in a position to share knowledge, technology and information"* (Secretaría de Energía, 2014, p. 44).

Market access

Market promotion during this period was focused on the domestic market and was characterized by improving regulation and increasing reliability of solar equipment. Several norms and standards were developed in collaboration between domestic and international actors (see Figure 4), which improved the quality of solar energy equipment. This included an initiative by the Mexico City government to promote a domestic mass market by obliging developers to install infrastructure to heat at least 30% of water usage per building with solar energy. Another strategy for market development was through policies enabling wider diffusion of solar energy technologies (see Figure 4, PROCALSOL, PROSOLAR, Green Mortgage, ITFMCSA and 25,000 solar roofs) through the implementation of schemes to support equipment acquisition and increase capabilities throughout the solar energy supply chain. Lessons learned showed that practices used in the SWH sector could be *"replicated for distributed generation schemes of solar thermal energy and other renewable energy sources in the country"* (Mata & Ortega, 2015, p. 68). In particular, as SWH and SPV share market characteristics, policies promoting market formation were transferred from SWH to SPV, especially to build capabilities for the final part of the supply chain, particularly for the sale and installation of equipment. As an additional illustration of similarities in market characteristics, SPV took over SWH retail stores and market structures, which facilitate sales to end-consumers.

Financial investment

Policies to mobilise finance investment gained importance during the second period with the development of financial schemes for end-users. These financial schemes mobilised both domestic funds and funds from abroad. National resources were mobilised by the government through the tax exemption for solar energy equipment and through Institute of the National Housing Fund for Workers (Infonavit). Subsequently, Infonavit established an agreement with international agencies (GIZ and UN) and developed the Green Mortgage program, *"with the aim of improving the quality of life of Mexican workers, by reducing household spending on utility bills whilst at the same time contributing to the efficient use of natural resources and the reduction of Green-House Gas Emissions"* (BSHF, 2016, p. 9). In addition, the Green Mortgage program was coordinated with technology and market development activities to facilitate the obtention of SWH equipment. The program was highly successful, and the Buildings and Social Housing Foundation *"recognised the significant achievements of the Green*

Mortgage Programme in the provision of sustainable and affordable housing options for low-income households, whilst at the same time achieving significant scale, with almost two million Green Mortgages provided" (BSHF, 2016, p. 7). Further, it provided 1.8 million green mortgages from 2007 to 2014, resulting in *"accumulated saving from electricity and gas of 71,227 million kWh"* (BSHF, 2016, p. 14) and was awarded with the 2012 World Habitat Award. Due to the success, PROCALSOL became part of the Green Mortgage Program.

Furthermore, PROCALSOL granted close to 37,000 green mortgages, and the ITFMCSA and "25,000 solar roofs" initiatives jointly invested an additional €4 million in SWH. Finance mobilization for the solar energy equipment production sector also took place during this period through several domestic policies, including FOTEASE, PEAER, the National Strategy for Climate Change (ENCC) and laws such as the General law for Climate Change (LCC).

Technology legitimacy

The mobilization of technology legitimacy was promoted by improving the regulatory framework, which led to increasing consumer trust in solar energy solutions. Since 2005 (see Figure 4), several regulations were introduced. In the case of SWH, regulations were formulated and established by domestic actors, however, for SPV, regulations were developed in collaboration with international agencies by copying or adapting international norms to the Mexican context: due to the higher technological complexity of SPV, it was instrumental to build on previously established regulations from other contexts to provide legitimacy for SPV. To this end, *"agreements were established with advanced institutions in the field […] These agreements allowed the Mexican Electrical Research Institute (IIE) researchers to participate in large-scale international projects, and helped to consolidate the cadre of young national specialists, who acquired in-depth knowledge of the technologies, as well as the methods and strategies followed in those countries for their development and introduction to the market"* (Huacuz Villamar, 2016, p. 23). Subsequently, this contributed to the establishment of technical norms, quality assurance systems of equipment and certification schemes for installers informed by insights from countries with more developed SPV industries and markets. In addition to regulations, pilot and demonstration projects were also established, along with campaigns to raise awareness about the benefits of solar energy.

In summary, the period from 2000 to 2013 was characterized by accelerating solar industry development, driven by an increasingly active Mexican government and international actors such as the GIZ and the UN. Market development and legitimacy were primarily mobilised domestically, while international linkages were of greater importance for access to finance and, in particular, knowledge. During this period, SWH consolidated itself as a functional and proven technology, while the promotion and diffusion of SPV started to accelerate, however this technology was still facing multiple barriers for its development, such as financial, technological, legal, and lack of capabilities and information (SENER & GIZ, 2012, p. 24). Further, due to the higher technological complexity of SPV, resource mobilization for this technology were to a greater extent relying on non-domestic relations, in particular for knowledge creation and technology legitimacy. Conversely, due to similarities in market characteristics, policies stimulating market development were very similar for SWH and SPV.

5.3. Consolidation of solar energy – 2013 to 2018

The third period is characterized by the development of institutional arrangements to increase the use of solar energy, specifically for SPV as SWH was already widely diffused. In 2013, a wide-ranging energy reform took place, which among other things legalised energy production by private entities. This fostered development of distributed SPV generation among households and in private industries:

“Mexico reached 247.6 MW of [SPV] DG [distributed generation] capacity at the end of 2016, up by 110% year-on-year” (Yaneva et al., 2018, p. 18).

The reform introduced a series of policies and regulations for the sector. The national program for the sustainable use of energy (PRONASE) was introduced to promote energy efficiency and renewable energy, and the strategic program for human resource formation in relation to energy (PEFRHME) promoted education and formation of skills to support the sector’s development (SENER, SEP, & CONACYT, 2014). The Energy Transitions Law (LTE) was introduced to regulate the sustainable use of energy. These programs and laws were connected to the Transition Strategy to Promote the Use of Cleaner Technologies and Fuels and to the special program for the energy transition (ETPUTCL) that promoted renewable energy and disincentivised the use of fossil fuels.

Knowledge creation

Knowledge creation during the third period was less important for SWH, as a solid knowledge base had at this point been established. Nevertheless, for SPV continuous knowledge mobilisation in the form of research and development efforts, formation of highly qualified and specialized human capital, technology transfer and establishment of linkages between academia and industry was crucial to keep up with general developments in the technology abroad. Consequently, new challenges were identified in conjuncture with the implementation of the energy reform and other regulatory changes: *“The first challenges were to form a critical mass of researchers specialized in the subject and to create the necessary laboratory infrastructure. Thus, IIE researchers training at the postgraduate level abroad was promoted, and also repatriation, with CONACYT support, of Mexican students who had recently completed their postgraduate studies on the subject at universities in other countries”* (Huacuz Villamar, 2016, p. 41). All these activities were carried out with inputs from international partners.

Market access

Efforts to expand market access during this period were carried out for both technologies with a focus on the domestic market, but the impact was bigger on SPV as the energy reform was focused on electricity production. Thus, a vision for diffusion of SPV technology was a principal underlying aim behind a central objective, namely that *“the energy reform was to create a favourable regulatory framework to promote clean distributed generation”* (Secretaría de Energía, 2014, p. 10). Policies supported equipment purchasing by establishing linkages between key actors, supporting new business models and simplification of administrative procedures. Despite a focus on SPV market creation, it should be noted that the development of an installation manual for SWH, which specified the requirements for correct installation, contributed to further diffusion of SWH technology.

Financial investment

Policies supporting financial investments were considerably more developed for SPV than for SWH during this period. Investments were mobilised through the development of financial schemes for micro-grids, establishment of finance programs for big scale projects and improved guarantee mechanisms for big scale projects. While most resources were mobilised from domestic sources, a new collaboration with the GIZ was initiated, the DKTI solar program. With a focus on SPV, the aim of this collaboration was specifically to *“strengthen the institutional capacities of banks with respect to the financing of investment in renewable energy. Keeping a close relation with the National Bank for International Trade (Bancomext), which has a credit line from the German Development Bank (KfW) to finance large-scale solar projects […] In this way, the DKTI Solar program contributes to overcoming the barriers to greater use of climate-friendly energy technologies, thus contributing to the long-term sustainable development of the energy system”* (GIZ, 2014, p. 2). No new initiatives were established for SWH, but finance continued to be available through the previously established Green Mortgage programme.

Technology legitimacy

By this period, SWH had already a high degree of legitimacy, which was further enhanced through the development of an installation guide *"aimed at plumbers, water and gas pipe installers, engineers, architects and industrialists in the construction sector and sub-sectors who design, execute and supervise installations of solar water heating systems, with the aim to guide them in good practice in the installation of individual solar water heating systems for housing and to support them in increasing their skills"* (Torres Reyes, 2014, p. 15). Conversely, legitimacy for SPV was promoted in a much general spectrum, through the *"establishment of outreach and dissemination programs to raise awareness of users and actors in the electricity sector to increase acceptance of smart grid developments"* (SENER, 2016, p. 109) which were mainly powered by SPV.

In summary, the third period was characterised by the development of institutional arrangements for the new technologies, especially for SPV. Relatively few policies focused on strengthening legitimacy of the technologies, while a larger number of policies aimed at mobilisation of the three other types of resources. As in the second period, resource mobilisation from abroad was in particular focused on providing access to knowledge and finance. Again, the greater technological complexity of SPV necessitated a continuing need for policies focusing on obtaining knowledge from international sources.

6. Conclusion

The literature on catching-up of emerging and developing countries in renewable energy technology industries increasingly highlight how technology characteristics, in particular the degree of complexity of product architecture and the scale of production process, influence catching-up processes. While the literature has up till now formulated catching-up policy mixes based on the assumption that simple technologies are produced in high numbers, and complex technologies are produced in small numbers, the current paper challenges the suggestion that technological complexity and scale of production are directly inversely related. Rather, mass produced technologies may also be characterised by different degrees of technological complexity, with important implications for catching-up policy mixes.

Empirically, we study solar water heating and solar photovoltaics industry development in Mexico. Both industries are characterized by the dominance of Chinese producers, but indications of catching-up by Mexican manufactures with developed countries' firms are found for both SWH and SPV, despite a lack of internationally comparable data on production volumes. For SPV, a string of factory openings followed the liberalization of the energy market in 2013, which has led to a rapid growth in manufacturing capacity. The SWH industry has existed for considerably longer time in Mexico, but is also characterized by continuous growth, supported by a strongly developing domestic market.

Our longitudinal analysis of solar energy policies in Mexico highlights similarities and differences between two technologies, which are both characterised as mass-produced products, but differ in degree of technological complexity. While there were fewer differences in the policies during the solar industry emergence phase, differences became more pronounced during the phases of industry acceleration and consolidation. In particular, the policy approach to promote the more complex SPV industry was two-folded, first through promoting domestic mobilization of resources and, second, through international linkages to anchor more advanced resources required for industrial consolidation. Efforts focused on domestic resource mobilization for SPV were significantly influenced by lessons learned from previous policy instruments focused on supporting SWH development, including the PROCALSOL initiative. Further, as SPV is characterised by greater technological complexity, policies have continuously focused on sourcing knowledge from abroad to keep up with the global technological frontier. Conversely, the less complex SWH industry was predominantly promoted through local innovation processes.

The larger focus on mobilizing resources from abroad for the SPV industry was found for both knowledge creation, financial investments and technological legitimacy. Essentially, the more advanced requirements following from the higher technological complexity of SPV necessitate higher capital requirements, sourcing of knowledge unavailable in the Mexican context, and reliance on the legitimacy of international standards and regulations. Conversely, few differences were found between the two industries regarding policies promoting market access. Essentially, we argue that these findings illustrate the value of a perspective on technological characteristics, which allows for considering the complexity of product architecture and the scale of production process as independent from each other, rather than inversely correlated. This contributes to a better understanding of the influence of technology characteristics on policy mixes, particularly in developing countries, which will at the end of the day allow for creating catching-up policy mixes that better reflect the characteristics of individual technologies.

Consequently, we argue for greater technology-sensitivity in catching-up policies: the possibilities for successful catch-up are increased if policies are aligned with technology-specific resource requirements (see also Binz et al., 2017). This points to a need for governments in developing and emerging countries to engage in careful analyses of prospective technology fields, their expected requirements in terms of the different types of resources, and the perspectives for domestic resource creation in both the short and longer time horizon. Further, while we do not question the role of policy interventions focused on stimulating knowledge creation and knowledge spillovers (e.g. Hansen & Hansen, 2020) (the analysis highlights the importance of not narrowly focusing catching-up policies on capability development, but rather tailoring policies to the various types of resource mobilisation processes – knowledge creation, market access, mobilisation of finance and legitimacy creation – which are central to industry development.

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Appendix 1

Period	Typology	Policy name and description
1975	Law	*Electric Power Public Service Law (LSPEE)* - Market: Mexican central government, only entity allowed to produce and manage energy
1974 - 1975	International Initiative	*Tonatiuh project (French technology transfer project)* Installation of 14 solar pumping plants that also produce energy in remote and arid areas. Unsuccessful project. - Knowledge: Failed attempt to import extra-regional knowledge
1976	Creation of actor	*Creation of Non- conventional energy sources department at the Institute for electrical research (IIE)* - Knowledge: research and development for solar energies
From 1977	National Initiative	*First National meeting for Non-conventional energies* - Knowledge: Exchange and combination of knowledge between stakeholders. These meetings are being still held, yearly.
1978	International Initiative	*Sonntlan project (German technology transfer project)* Development of a coastal desert fisherman's community through solar energy. Unsuccessful project - Knowledge: Failed attempt to import extra-regional knowledge - Legitimacy: Low success implied that little technological legitimacy was created
1978 - 1980	National Initiative	*Pilot production line for solar cells in Polytechnic University in alliance with the CINVESTAV* - Knowledge: Acquisition of experience in solar cell production and research and development promotion - Legitimacy: Demonstration of the existence of technical capacities in the country for PV systems production
1980	Creation of actor	*National Association for Solar Energy (ANES) was founded.* - Knowledge: diffusion of knowledge through information exchange, unity and cooperation between members. - Market: Promotion of standards development for quality - Finance: Mobilization of national and international finance to improve production processes. - Legitimacy: Promotion of benefits of solar energy and demonstrative projects
1986	Creation of actor	*Creation of the Center for Energy Research (CIE)* Center for energy research with a specialized department for solar energy - Knowledge: Research, development and innovation in solar energy
1989	Creation of actor	*Creation of the National Commission for Energy Saving (CONAE)* A national entity created to promote renewable energies. - Market: Promotion of standards development - Legitimacy: Promoted renewable energies, its divulgation, promotion, and development.
1980 - 1990s	National Initiative	*Several projects for the rural electrification all over the country* The inclusion of PV and SWH energy as the backbone of these projects - Knowledge: better understanding of solar technologies, especially PV systems. - Legitimacy: Demonstrative projects of the benefits of solar energy.
1992	Law	*Electric Power Public Service Law (LSPEE)* Allowance to private entities to produce energy for self-consume. - Market: Promotion of PV systems acquisition by increasing benefits of its usage
1995	Creation of actor	*Creation of the CRE* Energy regulation commission

Period	Typology	Policy name and description
		- Market: Aims to regulate the energy market
1996	Creation of actor	*Creation of the COFER* Council for the promotion of renewable energies in Mexico - Market: Aims to promote and strength relations between agents of the national and international market of renewable energy.
2001	Regulation	*Model of contract for connection between a private power generator and the national energy grid* - Market: Promotion of PV systems acquisition by increasing benefits of its usage
2004	National Initiative	*Income tax law* Tax exemption for acquisition of renewable energies equipment - Market: Promotion of domestic market of PV systems
2005	Regulation	*NMX-ES-001-NORMEX-2005*. Development of a national standard for test methods for thermal performance and functionality characteristics of SWH. - Market: Boost market by increasing reliability on SWH equipment - Legitimacy: Increase legitimacy by developing quality standards
2006	International Initiative	*Financial alternatives for promoting the use of solar water heaters (SWH) in the Mexican domestic sector*. Study to identify a best financial mechanism for SWH, collaboration project by ANES, GIZ, and SENER - Knowledge: Better information about the alternatives for SWH's
2006	Regulation	*NADF-008-AMBT-2005*. 30% of solar warm water per new building and regulation of minimal quality standards for SWH - Market: Boost market by increasing reliability on SWH equipment and force its purchasing by end-users - Legitimacy: Increased legitimacy by developing quality standards
2007	National Initiative	*Model of contract that allows the low scale producer (below 30 MW) to connect to the National Electric System.* - Market: Promotion of PV systems acquisition by increasing benefits of its usage
2007	International Initiative	*PROCALSOL* *Program for the promotion of Solar Water Heaters, promoted by the GIZ, CONUEE and ANES.* - *Knowledge:* Support to increase formation and capacitation of well-capacitated technicians and installers of SWH and Promotion of seminars in exchange of offer and demands of technological development. - *Market:* Increase the offer of well-capacitated technicians for installation of SWH, Implementation of generalized interest rates and financial scheme to reduces the initial cost of acquiring SWH, and Implementation of mortgage for buying SWH in new houses (Green Mortgage). - Financial: Financial support to SMEs dedicated to build, sell and install SWH and to end-users through the Green Mortgage - Legitimacy: Promotion of norm development and regulatory instruments for systems and installations, Certification of design, installation, operation and maintenance companies, establish a quality seal for equipment, Realization of pilot and demonstrative projects in the public, social, commercial and industrial sector, campaign to raise awareness about the benefits of SWH for the population, and website with information about benefits of solar energy
2007	National Initiative	*Hipoteca Verde (Green Mortgage)* Loan program that grants an extra amount of money as part of the housing mortgage for SWH. - Market: Booster of the market through facilitating the access for SWH's - Finance: Financial support to end-users to get SWH's
2007	Regulation	*NMX-ES-002-NORMEX 2007.* Definitions and terminology.

Period	Typology	Policy name and description
		- Market: Boost market by increasing reliability on SWH equipment - Legitimacy: Increased legitimacy by developing quality standards
		NMX-ES-003-NORMEX 2007. Minimal requirements for the installation of solar thermal water heating systems. - Market: Boost market by increasing reliability on SWH equipment - Legitimacy: Increased legitimacy by developing quality standards
		NMX-ES-004-NORMEX 2007. Thermal evaluation for solar water heating systems. Test method. - Market: Boost market by increasing reliability on SWH equipment - Legitimacy: Increased legitimacy by developing quality standards
2008	International Initiative	*Transformation and strengthening of the Solar Water Heating market initiative (ITFMCSA)* - Knowledge: Capacity building of local SWH manufacturers, distributors, installers, and financing sector to offer products, delivery models (including financing), installation, after sale and financial services that are conducive to overall market transformation goals of the project, enhancing capacity of the supply chain to offer products and services promoting a sustainable SWH market - Market: Enabling legal and regulatory framework to promote a sustainable SWH market, increase demand for SWH systems based on the availability of attractive end-user financing mechanism, development of different direct or indirect financial and fiscal incentives to promote a sustainable SWH market, enhancing capacity of the supply chain to offer products promoting a sustainable SWH market - Finance: Improving the incentives such as commercial soft loans with government support, capacity building of the capacity of local SWH financing sector to offer products and financial delivery models - Legitimacy: Enhanced awareness and capacity of the targeted end-users, housing developers, and other key stakeholders to facilitate the integration of SWH into new housing developments and into other promising new market segments (information), recognition of SWH installers through the development of a standard (set of criteria) to demonstrate their know-how and to the best projects., development of an effective and affordable certification and quality control scheme applicable for all SWH systems manufactures and/or installed in Mexico, campaigns to raise awareness for end-users on the benefits, economic feasibility and other characteristics
2008	Regulation	*Technical Standard of Labor Competence for the installation of Solar Water Heating systems EC065* Standard for evaluation and certification of installers of SWH. - Legitimacy: Increased legitimacy by developing quality standards.

Period	Typology	Policy name and description
2008	Law	*Law for the Use of Renewable Energies and the Finance of the Energy Transition (LAERFTE)* - Knowledge: Support the promotion and use of scientific research and technology for renewable energy, propose the creation of funds and trusts with the aim to support promote the use of scientific and technological research in matters of renewable energy. - Market: Establishment of a normalization program for energy efficiency - Finance: propose the creation of funds and trusts with the aim to support technological research in matters of renewable energy. - Legitimacy: Establish a normalization program for energy efficiency, procure the necessary measures for access to reliable and appropriate information in relation to energy consumption of the equipment, devices, and vehicles
2008	International Initiative	*National Strategy for the Energy Transition and Sustainable Use of Energy (ENTEASE)* - Knowledge: Promote programs for the formation of high-level professionals in the national and international arena - Market: Development of norm and standards to secure quality and boost the market. - Finance*:* Establish support programs for the low-income sector to acquire energy efficient technologies. - Legitimacy: Design diffusion programs to accelerate the adoption if efficient technologies and best practices.
2008	Law	*Law for the Use of Renewable Energy (LASE)* - Knowledge: promotion of the scientific and technological research for the sustainable use of energy, include in the study programs of the basic, middle and middle-high education topics about the sustainable use of energy, promote the formation of specialists in the use of renewable energies, in the superior level. - Legitimacy: Establish a normalization program for the energy efficiency and allow access to people to reliable and effective information about energetic consume of equipment, devices, and vehicles, among others
2008	Creation of actor	*Commission for the Efficient Use of Energy (CONUEE)* The CONAE evolves towards CONUEE - Market: promotions of actions for energy efficiency and energy saving, which improves the market. - Legitimacy: diffuse information about renewable energies
2008, 2014 (new version of program)	National Initiative	*National Program for the Sustainable Use of Energy (PRONASE)* - Knowledge: Increase capacity building for design, implantation, and operation of projects related to energy efficiency and renewable energies, promote research and technological development for energy efficiency, promote and support the collaboration and knowledge exchange between national and international institutions for energy efficiency, promote the formation of human resources dedicated to technological, economic, environmental and social energy-related research, and promote the use of the sectoral funds for energy-related research. - Market: Strengthening of the regulation for energy consuming devices and systems produced in the country, Strengthen and increase the offer of consultancy and project development companies

Period	Typology	Policy name and description
		- Finance: Promote the utilization of sectorial funds for the technological, environmental, economic and social investment in relation to the energy reform - Legitimacy: Disseminate information about the sustainable use of energy, design orientation campaigns related to the sustainable use of energy, establish collaboration agreements with public, private and social organizations to disseminate information about the sustainable use of energy, and promote the inclusion of topics related to the sustainable use of energy in the low, middle and middle-high education
2008	National Initiative	*CONACYT – SENER sectorial fund for Sustainable energy (FSE)* - Knowledge: Finance of research projects for sustainable energy and promote the formation of highly qualified specialists
2009 (Implemented again on 2016,2017)	National initiative	*Fund for the Energy Transition and Sustainable Use of Energy (FOTEASE)* - Knowledge: Finance of projects for sustainable energy - Finance: Mobilization of resources for renewable energy sector development.
2009	International initiative	*25,000 solar roofs for Mexico* - Knowledge: Establish capacitation programs to increase the knowledge related to installation and maintenance of SWH. - Market: Strengthen the Mexican production capacity and services, establish capacitation program to increase the knowledge related to installation and maintenance of SWH, development of a mortgage facility combining the already existing "Hipoteca Verde" with a grant of foreign funds. - Legitimacy: Raise awareness among clients and institutions about the benefits of the technology and finance options, diffusion strategy for the residential sector
2009	International initiative	*Market niches for grid-connected photovoltaic systems in Mexico* Document that studies the market niches for grid-connected photovoltaic systems in Mexico, done by SENER, CONUEE, and support from the German GIZ. - Knowledge: Better information about the alternatives for SWH's
2009	National Initiative	*Special Program for the Use of Renewable Energies (PEAER)* - Knowledge: promote capacity building in relation to solar energy in rural communities, promote research as a tool to achieve cheaper and more efficient systems, promote international cooperation for research and technological development for renewable energies and different types of agreements, and establish collaboration networks between national and international research centers. - Market: Establish optimum conditions for productivity and competitivity of the solar energy industry, ensure compliance with environmental normativity all over the value chain of solar energy. - Finance: Establishment of optimum conditions for productivity and competitivity of the solar energy industry, bringing investments and generating formal and quality jobs. - Legitimacy: A website with all the relevant documents of this law must be developed, creation of the National System for energy information that aims to register, organize, update and disseminate information related to the sustainable use of energy, publish of a catalog with devices and equipment and information about energy consumption.
2010	Regulation	*NMX-ES-004-NORMEX-2010-Energía Solar (2nd version)* National voluntary norm that establishes how to perform the thermal evaluation for solar systems water heating processes - Market: Boost market by increasing reliability on SWH equipment - Legitimacy: Increased legitimacy by developing quality standards

Period	Typology	Policy name and description
2011	International Initiative	*Green mortgage – CONAVI (SISESIVE – ECOCASA)* New regulations for Green mortgage, every mortgage must include SWH. Collaboration with the GIZ. - Knowledge: Development of a tool to evaluate housing efficiency and increase knowledge of end-users about energy savings - Market: Boost market by promoting acquisition of SWH and PV's - Finance: Promote end-user financial solutions for the acquisition of PV and SWH. - Legitimacy: Develop a tool to evaluate the house efficiency and promote the acquisition of efficient equipment.
2011	Regulation	*Set of eight norms for PV systems* - Market: Boost market by increasing reliability on PV equipment - Legitimacy: Increased legitimacy by developing quality standards
2012	International initiative	*Program to Promote Photovoltaic Systems (PROSOLAR)* - Knowledge: Identification of the already existing capacity building programs and its improvement. - Market: Promotion of regulatory instruments to facilitate the transfer of electricity generated by PV plants to the CFE, promotion of development of necessary norms to ensure the quality of PV systems and of its installation, promote a certification mechanism for PV system installers, promote infrastructure for certification in Mexican laboratories and consolidate the capacities of the test laboratories. - Finance: Analysis of the activities of the private bank for financing PV systems, structure a proposal for a guaranty fund with public resources, and form a workgroup for the development of a financial mechanism. - Legitimacy: Promotion of education, awareness-raising, sensitization and information diffusion programs to transit towards a low carbon economy and adaptation to Climate change, norms will be published to establish criteria, technical specifications, and procedures to guarantee measures against climate change and pilot projects will be made to increase legitimacy
2012	Law	*The General Law of Climate Change (LCC)* - Knowledge: promote education, research, development and technology transfer for the topics related to adaptation and mitigation to climate change, fiscal incentives for research, incorporation or utilization of mechanisms, equipment, and technologies with the aim to avoid or control emissions and to research to renewable energies and low carbon technologies. - Market: Norms promotion to establish criteria, technical specifications and procedures to guarantee measures against climate change. - Finance: Creation of the fund for the energy transition and the sustainable use of energy - Legitimacy: promotion of education, awareness-raising, sensitization and information diffusion programs to transit towards a low carbon economy and adaptation to Climate change, norms publication to establish criteria, technical specifications and procedures to guarantee measures against climate change
2013	National Initiative	*National Strategy for Climate Change (ENCC)* - Knowledge: promote bilateral cooperation, experience sharing and better practices in south-south cooperation, promote research, development, and adaptation of advanced technology for renewable and clean energy generation like oceanic, solar, hydrogen, bioenergy, etc. - Market: Design economic, fiscal, financial and market instruments to incentivize mitigation and adaptation actions, strengthen the regulatory

Period	Typology	Policy name and description
		framework, institutions and the use of economic instruments to use clean energy sources, development of tax policies and economic and financial instruments with a climatic approach - Finance: Develop economic, fiscal, financial and market mechanisms in national policy to promote mitigation and adaptation actions, identify and promote the access to international finance for mitigation and adaptation actions, strengthen the regulatory framework, institutions and the use of economic instruments to harness clean energy sources and more efficient technologies. - Legitimacy: promote the appropriate and adequate information about emissions associated with production, commodities, and services available in the market, strengthening of the regulatory, institutional and economic instruments for clean energy sources and efficient technologies
2013	Initiative	*Sectorial Energy Program (PROSENER)* - Knowledge: promote the development of information and communication technologies for the diffusion of potential renewable energy zones, strengthening of the public, social and private sectors capacities for transition and energy efficiency capacities. - Market: instrument market mechanisms and regulations for clean and renewable energies supported by public and private investments. - Legitimacy: increase the available information to promote renewable energies and energy efficiency, strengthening of the regulation to meet standards for energy efficiency.
2013	Creation of actor	*Creation of the Mexican Center for Innovation in Solar energy (CEMIE-SOL)* - Knowledge: Development and technological innovation for the solar energy sector
2014	National Initiative	*Installation Guide for SWH* - Market: provision of the minimal requirements for correct installation of SWH.
2014	National Initiative	*Strategic Program for Human Resource Building in Energy-related topics (PEFRHME)* - Knowledge: Promote the formation of specialized and high-level human capital, increase the offer of programs for the reconversion of technicians and professionals, increase offer of capacity building and certifications programs, create or consolidate capacity building centers and establish a formation and updating campaign.
2015	Law	*Energy Transition Law (LTE)* - Knowledge: Promotion of applied research and technological development, promote the development of new knowledge, materials, techniques, processes, services, and technologies, promote investment in technological development and innovation for clean energies. - Finance: Establish finance programs for solar PV micro electric grids, strengthen guarantee mechanisms for big scale renewable projects, develop financial schemes for the acquisition of renewable energy equipment, develop business models for deeper penetration of solar thermal technology, promote the development of electric-generation micro companies on a social basis in the rural and urban sector.
2015	National Initiative	*Transitions Strategy to Promote the Use of Technologies and Cleaner Technologies (ETPUTCL)* - Knowledge: promotion of formation of qualified human resources, that design, install, operate and maintain technological elements, promote research, development, demonstration of new low carbon technologies. - Market: develop finance schemes that facilitate the equipment acquisition for the use of solar energy, develop business models that facilitate the rapid penetration of the solar thermal technology.

Period	Typology	Policy name and description
		- Finance: Establish finance programs for solar micro electric grids, strengthen guarantee mechanisms for big scale renewable projects, develop business models for deeper penetration of solar thermal technology - Legitimacy: Increase the number certified solar-thermal providers
2015	International Initiative	*Solar Large-Scale Energy Program – Mexico (DKTI))* - Knowledge: Promotes research and innovation from international and national research institutes (private and public sectors), promotes technology transfer of innovating systems - Market: promotes the development of an integrated market strategy between key actors. - Finance: promotes the improvement of financial conditions for large scale solar energy applications
2017	National Initiative	*Special Program for the Energy Transition (PETE)* - Knowledge: Foster the technological and supply chain talent for renewable energies, increase the offer for the formation of professionals for clean energies, promote national and international linkages, networks and knowledge transfer to increase the national capacities in clean energies, support the research and development through the Mexican centers of research, promote linkages between academia and industry through collaboration projects. - Market: Simplify and transparentize the administrative procedures for the development of clean energies, promote the quality of information for planning and accountability, elaborate specific strategies for the development of value chains for each clean technology, promote financial schemes for the use of clean energy sources with the participation of the development and private bank. - Finance: promote the access to finance and capital by entrepreneurs, micro and medium businesses that generate energy with clean sources. - Legitimacy: promote the community participation and public consultation in the planning and development processes for clean energies