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The Contribution of Decentralized Photovoltaic Systems to Energy Poverty Alleviation in La Pila, SLP, Mexico

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Technology
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"MODELO DE SOSTENIBILIDAD PARA LA GOBERNANZA DE COMUNIDADES VULNERABLES:
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ABSTRACT

The nexus between deprivation of access to modern energy, poverty and the environment has been in evidence in international sustainability projects and studies. The use of micro-scale renewable energy technology has been promoted not only for its environmental benefits but also for the potential co-benefits of its applications. This research analyses how decentralized photovoltaic solar energy systems (DCPV) contribute to the energy poverty alleviation of La Pila Delegation, a vulnerable peri-urban community located in San Luis Potosi, Mexico. Adopting a multidisciplinary method based on secondary data, this study executed an energy poverty diagnosis, a policy analysis and built six different scenarios of the application of DCPV under distributed generation schemes. An impact assessment for social, environmental and financial aspects was applied in each scenario. Its results indicate that the application of grid-connected DCPV contributes to the local energy poverty alleviation by providing security and more affordability to the electric energy chain that is responsible for delivering part of the community's fundamental energy services. Further, it was discovered it positively impacts aspects of the energy vulnerability, precarity, injustices and fragilities of the socio-energy system that collaborates with the existence of energy poverty in the location. Environmentally, it supports climate change mitigation due to the avoidance of greenhouse gases emissions and water consumption in energy generation, also having the co-benefit of distributing financial savings to different governmental institutions and local households. Recognizing its limitations, this research concluded that this type of application represents a step further towards positioning technology in service of people's fundamental needs in coherence with the planetary boundaries.

Keywords

Energy Poverty, Solar Photovoltaic Energy Systems, Distributed Generation, Vulnerable Communities, Co-Benefits

RESUMEN

El nexo entre la privación del acceso a energía moderna, la pobreza y el medio ambiente ha estado internacionalmente en evidencia en proyectos y estudios en el área de la sostenibilidad. El uso de tecnologías de energía renovable a pequeña escala se ha promovido no solo por sus beneficios ambientales sino también por los posibles beneficios colaterales de sus aplicaciones. Esta investigación analiza cómo los sistemas descentralizados de energía solar fotovoltaica (DCPV) contribuyen al alivio de la pobreza energética de la Delegación La Pila, una comunidad periurbana vulnerable ubicada en San Luis Potosí, México. Adoptando un método multidisciplinario basado en datos secundarios, este estudio ejecutó un diagnóstico de pobreza energética, realizando un análisis de políticas y construyendo seis escenarios diferentes de aplicación de DCPV bajo esquemas de generación distribuida. Adicionalmente, en cada escenario se aplicó una evaluación de impacto para aspectos sociales, ambientales y financieros. Los resultados indican que la aplicación de DCPV conectado a la red contribuye al alivio de la pobreza energética local, al brindar seguridad y más asequibilidad a la cadena de energía eléctrica que es responsable de entregar parte de los servicios energéticos fundamentales a la comunidad. Además, se descubrió que impacta positivamente aspectos de la vulnerabilidad energética, precariedad, injusticias y fragilidades del sistema socio-energético que aportan a la existencia de pobreza energética en la localidad. Ambientalmente, apoya la mitigación del cambio climático al evitar las emisiones de gases de efecto invernadero y el consumo de agua en la generación de energía, teniendo además el beneficio de generar ahorros financieros para diferentes instituciones gubernamentales y hogares locales. Reconociendo sus limitaciones, esta investigación concluyó que este tipo de aplicación representa un paso más hacia el posicionamiento de la tecnología al servicio de las necesidades fundamentales de las personas en coherencia con los límites planetarios.

Palabras-clave

Pobreza Energética, Sistemas de Energía Solar Fotovoltaica, Generación Distribuida, Comunidades Vulnerables, Beneficios Colaterales

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Chapter 1. Introduction

> "Imagine the world at night as seen from space. I am sure many of you have seen this picture, but every time I see it, I am reminded of one of the most important issues of our day: energy poverty. […] Energy is critical for human progress - for health, education, job generation and economic competitiveness, for reducing poverty and building hope and opportunity. Ensuring that energy is sustainable is also essential — for minimizing the risks of dangerous climate change".

With this speech, the former United Nations secretary-general Ban Ki-moon (United Nations, 2011) illustrates a nexus that is in evidence in the international arena policy making: the link between deprivation of access to modern energy, poverty and the environment (García, 2014; United Nations, 2019).

The impossibility of accessing and using modern types of energy inside the home has material and social consequences for letting people deprived of attending to their most basic needs (González-Eguino, 2015). This phenomenon, known as energy poverty, is responsible for leaving people in the dark at night, feeling cold at home or coughing inside the kitchen because of the smoke coming from the firewood used to cook. It is commonly manifested in poor areas and linked to poverty states (Niu et al., 2013; Villalobos et al., 2019).

Even though people have always lived its consequences (World Energy Council, 2006), energy poverty started being discussed by science in the 1980s (García, 2014) and recognized in policy agendas in the 1990s (Bouzarovski, 2011). Formally defined as a particular manifestation of the material and social deprivation brought by energy unaffordability and its lack of use inside homes (Bouzarovski, 2011), it affects 11 million people in Mexico and 39% of the inhabitants of San Luis Potosi state (García-Ochoa & Graizbord, 2016). It is clear that energy consumption is necessary and will increase in order to improve people`s quality of life and reduce poverty (Niu et al., 2013).

A related issue is the current predominant ways of generating electricity, that in some places are highly linked to greenhouse gas emissions (GHG), mainly carbon dioxide (García, 2014). In the state of San Luis Potosi, 70% of the GHG come from central thermoelectric plants responsible to feed the grid with electricity (Ávalos Lozano et al., 2015). This type of gas is determinant of the environmental crisis lived nowadays for pushing the planetary conditions that allow the human species to live on Earth beyond its safe limits, accelerating a global climate change (Rockström et al., 2009).

Because of the concern on climate change, there is a global call for an energy transition to cleaner ways of producing electricity (United Nations, 2019). Many nations invest in fomenting technology capable of using renewable energy sources to untie energy production of GHG emissions, such as photovoltaic technology.

Through modular solar panels, cables and an inverter, it transforms the sunlight into electric energy (Smets et al., 2016; Yishu, 2019). Nonetheless, the energy transition is not limited by the new technology. It also concerns breaking paradigms of central generation and distribution, producing opportunities to democratize and disrupt traditional governance and property of power plants (Verbong & Geels, 2007).

Decentralized photovoltaic energy systems (DCPV) represent a whole new world compared to traditional centralized fossil fuel plants (Riutort Isern, 2016). They are modular, flexible, have a worldwide available geographic distribution and promote the energy transition inside and outside homes (Riutort Isern, 2016). Environmentally, they represent an almost CO_2 free pollution possibility (Denholm et al., 2014). Socially, they transform persons in active and empowered players in the energy transition and can put energy, which is usually seen as a pure economic good, in service of human development (Riutort Isern, 2016). The application of small-scale renewable energy systems in vulnerable communities has grown worldwide due to the social and environmental benefits it can bring to the application area and its inhabitants (Höhne & United Nations Environment Programme (UNEP), 2017; Nordhaus et al., 2016; Ulsrud et al., 2011; Yishu, 2019).

This master thesis is part of a project led by the Autonomous University of San Luis Potosi, researching new possibilities for the governance of vulnerable communities. It has as a pilot the peri-urban neighborhood of La Pila, in the state of San Luis Potosi, Mexico. Even though people have access to the energy grid in the community, it has been observed that they still present aspects of energy poverty (Cisneros Vidales, 2018). This research aims to investigate deeper the existing degrees of energy poverty and to propose a possible leverage point with the application of DCPV. For that, its main objective is *to analyze how decentralized photovoltaic solar energy systems contribute to the energy poverty alleviation of La Pila Delegation, for further policy making.*

Its specific objectives are:

1) To assess energy poverty in La Pila;
   - To build an Energy Poverty scale for the community;
   - To assess the financial situation of Households in La Pila concerning energy expenditures.
2) To assess the contribution of DCPV to the sustainability of La Pila in social and environmental terms;
3) To analyze the Mexican Energy Policy for DCPV technology application, focusing on vulnerable areas;
4) To give recommendations and suggest supporting policy.

This research is justified in the academic environment by addressing two existing gaps. It is already known that PV technology plays a great role in rural and remote communities providing energy access, a necessary but short-term action to poverty and energy poverty ending (Nordhaus et al., 2016). Nevertheless, very little has been discussed about the new distributed generation policies' possibilities for alleviating poverty and energy poverty in urbanized scenarios such as the case study, where the population is already grid-connected but are still vulnerable from deprivation of energy services. On a broader view, there is an unexplored potential of using distributed renewable PV energy projects to mitigate energy poverty in urbanized communities. Moreover, energy poverty research in Mexico is almost inexistent (García Ochoa & Graizbord Ed, 2016). Filling both gaps, this research contributes scientifically with the debate and efforts to policy recommendations, contributing with the scientific compromise to address the Sustainable Development Goals of "no poverty", "affordable and clean energy" and "sustainable cities and communities" promoted by the United Nations as a requisite for sustainable development (UN, 2015).

Still, it brings scientific results and insights to the elaboration of a public policy currently being elaborated based on the experience of the project "Sustainability Model for the Governance of Vulnerable Communities". The project has installed eco-technologies in a partner public school in la Pila, the Francisco González Bocanegra school, which includes a DCPV system that is currently maintained by a group of parents. With its results, it provides inputs about ways the technology could be implemented to benefit also the community's households.

This thesis is divided into eight more chapters. Chapter 2 will provide a theoretical framework on the concepts and scientific background of the main themes, finishing with the perspective I have built to approach the research problem. Chapter 3 will present the methods and data sources used to assess the case study. La Pila delegation and the information on its energy scene is provided in Chapter 4, while Chapter 5 and 6 are dedicated to describing the data and results of the energy poverty assessment and its socio-energy most evident points, respectively.

Chapter 7, the most representative of this document, is divided into three subchapters with a logical order: its first part is used to describe, present and analyze current Mexican Policy related to objective 3; its second part presents scenarios of DCPV application and its co-benefits. Its third part presents the discussion that answers this research's main objective and leaves specific recommendations for the project. Finally, chapter 8 points to the conclusions, followed by the references used to execute the research.

Finally, due to the historical moment of the COVID-19 Pandemic under which this research was developed, data collection and participatory tools needed to be adapted in contrast to its initial proposal. All the explanation related to the theme can be encountered in Chapter 3.

Chapter 2. Theoretical Framework

2.1. Poverty

In the earlies and middle XXI century, poverty was commonly measured and defined by nutritional and income lines and thresholds (Sen, 1983). Considered by many as a very simplistic approach, discussions and contributions regarding the theme come from different disciplines, such as in social, environmental, anthropological, economic, political sciences, crossing international arena political and academic discussions (Austin, 2007). Lessons learned from the scientific debate leave the clear message that conceptualizing poverty involves more than just fixing a line (Sen, 1983).

In the last century, remarkable contributions to poverty debate came from different approaches, namely the absolute and relative poverty debate (Sen, 1983; Townsend, 1987), economical methods based on income (World Bank, for instance) and lines derived from an approach that face poverty as a deprivation of psychological and sociological needs (Max-Neef, 1992). This section will focus on the last one since it underpins the chosen energy poverty approach.

The concept of poverty in the physiological and sociological deprivations approach adds a vast range of dimensions beyond the income measures. They are based on observations that even when poor communities have enough access to resources, they might not benefit from them because of structural impediments (Lok-Dessalline, 1999). Such restrictions are characterized by lack of access to credits, health, education due to governance issues and power structures. Based on that, poverty is "not merely in the impoverished state in which the person actually lives, but also in the lack of real opportunity—due to social constraints as well as personal circumstances—to lead valuable and valued lives" (UNDP, 1997, p.16).

In practice, the measure of poverty occurs in terms of the deprivation of requirements for meeting human needs, which are majorly material (Lok-Dessalline, 1999). One of the advantages of this approach is that it represents services and economic goods in human welfare. Projects derived from this conceptual background agree that poverty alleviation programs should focus on human-scale development, participation, empowerment, and the use of bottom-up strategies related to the satisfaction of basic human needs (Lok-Dessalline, 1999; Max-Neef, 1992).

Fundamental Human Needs is one approach inside this debate, categorizing human basic needs thinking in the Latinamerican reality (Max-Neef, 1992). The postulates behind the fundamental human needs are that they are finite, few, and classifiable as they are equal in any place and time of the planet's history. The postulates behind the fundamental human needs are that they are finite, few, and classifiable as they are equal in any place and time of the planet's history. These needs are linked to inherent conditions of the human species, being its characteristics are the same in every given cultural, historical and social context (Max-Neef, 1992).

The representative matrix of Max-Neef's work is shown in Table 1. It is composed of two axes, representing needs that are axiological and existential. The author does not discard that, with time, a new need can be included, especially referring to a spiritual value (Max-Neef, 1992). An important consideration is that all the basic needs are interrelated and interactive, and apart from the need for subsistence, there is no hierarchy among them (Max-Neef, 1992).

Together with the fundamental needs, the author represents and explains the satisfiers' concept, which can be understood in how each society and person satisfies a chosen need. Satisfiers are not limited to one single need, meaning one satisfier can attend to various needs (Max-Neef, 1992). Although they are extremely related, it is essential to mention that satisfiers are not necessarily economic goods, which are considered the materialization of a satisfier (Max-Neef, 1992). Also, economic goods that are applied as satisfiers are permanent but dynamic – they change with the cultural background (Sen, 1983) and the available technology on the social context (Max-Neef, 1992).

Following the cited social sciences approach, nowadays the most accepted idea is that there is no one absolute state of poverty, but many poverty situations inside the poverty phenomenon (Max-Neef, 1992). It highlights the multidimensional nature of poverty and how its different areas are interrelated between each other. That means that only tackling one aspect of poverty may also improve others, but not solving others may keep the person in a poverty trap (Banerjee & Duflo, 2011).

Nowadays, this multidimensional approach is highly accepted internationally, and its occurrence is explained by an interrelated and linked deprivations and aspects of families life (Banerjee & Duflo, 2011; Díaz Acosta et al., 2006; Oxford Poverty and Human Development Initiative, 2018).

On the policy-making lenses, many national and international institutions adopt indexes to measure poverty that consider multidimensional indicators. Figure 1 shows the dimensions considered on the methodology used by the Mexican Council of Evaluation on Social Development National Policy Poverty Evaluation (CONEVAL) to evaluate national poverty levels (Díaz Acosta et al., 2006). Figure 2 indicates the Global Multidimensional Poverty Index (Alkire et al., 2019), currently adopted by the United Nations Development Program and suggested to its members.

Table 1. Matrix of needs and satisfiers (Max-Neef et al., 1989, p. 33)

Existential categories / Axiological categories	Being	Having	Doing	Interacting
Subsistence	1/ Physical health, mental health, equilibrium, sense of humour, adaptability	2/ Food, shelter, work	3/ Feed,procreate, rest,work	4/ Living, environment, social setting
Protection	5/ Care, adaptability, autonomy, equilibrium, solidarity	6/ Insurance systems, savings, social security, health systems, rights, family, work	7/ Cooperate, prevent, plan, take care of, cure, help	8/ Living space, social environment, dwelling
Affection	9/ Self-esteem, solidarity, respect, tolerance, generosity, receptiviness, passion, determination, sensuality, sense of humour	10/ Friendhips, family, partnerships, relationships with nature	11/ Make love, caress, express emotions, share, take care of, cultivate, appreciate	12/ Privacy, intimacy, home, spaces of togetherness
Understanding	13/ Critical conscience, receptiviness, curiosity, astonishment, discipline, intuition, rationality	14/ Literature, teachers, method, educational policies, communication policies	15/ Investigate, study, experiment, educate, analyse, meditate	16/ Settings of formative interaction, schools, universities, academies, groups, communities, family
Participation	17/ Adaptability, receptiviness, solidarity, willingess, determination, dedication, respect,passion,sense of humour	18/ Rights, responsibilities, duties, privileges, work	19/ Become affiliated, cooperate, propose, share, dissent, obey, interact, agree on, express opinions	20/ Settings of participative interaction, parties, associations, churches, communities, neigbourhoods, family
Idleness	21/ Curiosity, receptiveness, imagination, reckleness, sense of humour	22/ Games, spectacies, clubs, parties, peace of mind	23/ Day-dream, brood, dream, recall old times, give way to fatnasies, remember, relax, have fun, play	24/ Privacy, intimacy, spaces of closeness, free time, surroundings, landscapes.
Creation	25/ Passion, determination, intuition, imagination, bodness, rationality, autonomy, inventiveness, curiosity	26/ Abilities, skills, method, work.	27/ Work, invent, uild, design, compose, interpret	28/ Productive and feedback settings, workshops, cultural groups, audiences, spaces for expression, temporal freedom
Identity	29/ Sense of belonging, consistency, differeniation, self-esteem, assertiveness	30/ Symbols, language, religion, habits, customs, reference, groups, sexuality, values, norms, historical memory, work.	31/ Commit oneself, integrate oneself, confront, decide on, get to know oneself, recognize oneself, actualize oneself, grow	32/ Social rythyms, everyay settings, setting which one belongs to, maturation stages
Freedom	33/ Autonomy, self-esteem, determination, passion, assertiveness, rebeliousness, tolerance.	34/ Equal rights	35/ Dissent, choose, be different from, run risks, develop awareness, commit oneself, disobey	36/ Temporal/spatial plasticity

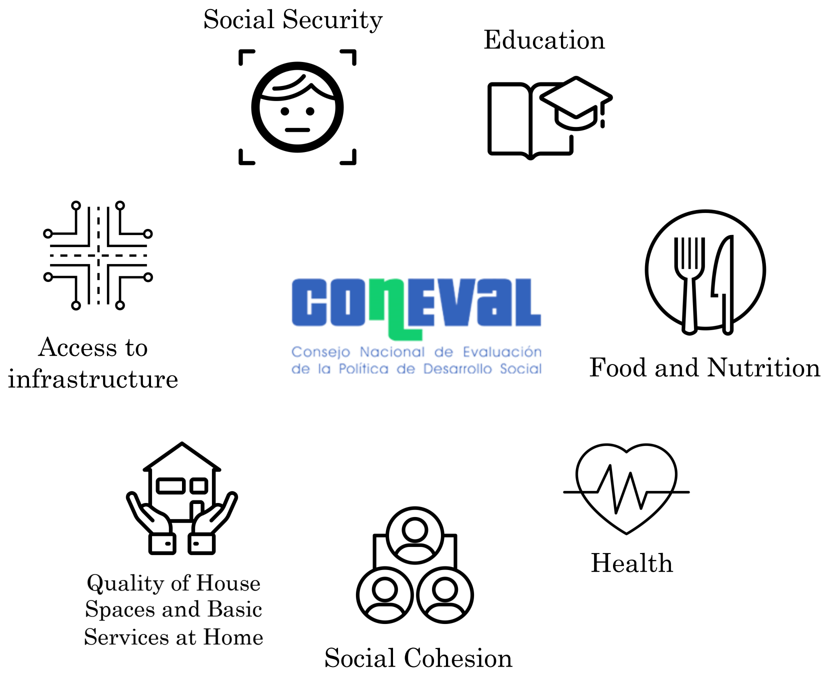


Figure 1. Dimensions of Mexico's official poverty index. Based on Díaz Acosta et al. (2006).

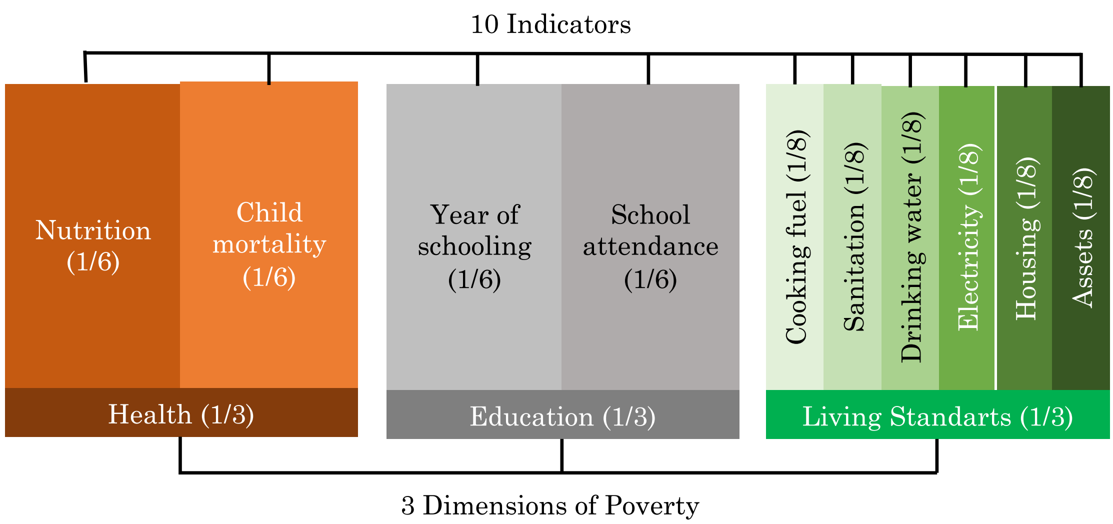


Figure 2. Global Multidimensional Poverty Index. (Oxford Poverty and Human Development Initiative, 2018)

2.2. Energy Poverty

Following section 2.1 conclusions, a specific type of poverty linked to the energy dimension of households is here presented. Energy poverty has many definitions, indicators and strategies of alleviation, that vary according to the cultural, socioeconomic and environmental background where it is analyzed. This section proposes to understand its origins, main authors and its connections with human development debate and environmental issues.

2.2.1. Brief history

The concept of energy poverty (EP) has its roots in the decade of 1980, in the United Kingdom (Garcia, 2014). Brenda Boardman's (1991) doctoral thesis is considered the main reference and starting point for the debate for synthesizing the discussion of energy and poverty relation with the concept of fuel poverty (Bouzarovski & Petrova, 2015, Garcia, 2014).

The initial definition of fuel poverty is "the inability to afford adequate warmth because of the inefficiency of the home" (Boardman, 1991, p.219). The definition carries a strong cultural and geographical British background. In the United Kingdom an increasing number of deaths occur in winter due to the lack of thermal comfort (heating inside the house) (Guertler & Smith, 2018) and equipment`s technology inefficiency, that makes bills unaffordable and limits people from energy consumption (Boardman, 1991). The threshold initially proposed by Boardman to a person being considered a fuel poor is the expenditure of 10% of house income in energy.

As the concept started to be adopted by other countries in Europe, some scientists pointed some limitations in applying Boardman's methodology on measuring fuel poverty, such as data availability and measuring temperature inside of a house (Garcia, 2014). Also, her point of view based only on the income aspect of the fuel poverty concept started to be questioned by social scientists based on statements of the poverty discussion. Based on Peter Townsend's relative deprivation concepts, the idea that income parameters and the needs of energy change within different and dynamic social contexts were also incorporated in the fuel poverty discussion (Healy, 2004). A new approach is, then, proposed through the "consensual focus", with a methodology for its measurement with objective and subjective indicators, which would complement the material indicators with social deprivations people have which are related to energy needs.

In the history line, the term "energy poverty" started being used with the adoption of the concept by different countries and continents (Bouzarovski & Petrova, 2015). Both concepts are commonly adopted as synonym by some authors, especially in the UK, where it was born (Garcia, 2014). Nonetheless, energy poverty can be considered the expansion of the initial idea brought by Boardman (1991) that incorporates theoretical contributions brought by other areas of science (Bouzarovski & Petrova, 2015), such as social and health science. Nowadays, the initial income idea is considered one among other factors that contribute to EP (Bouzarovski & Thomson, 2018).

2.2.2. Poverty x energy consumption relation

Energy poverty studies the relation between energy and poverty at different levels. Different methodologies and definitions can be found in the literature. Still, all have in common the perspective that EP happens when a family or individual doesn't have access to minimal adequate energetic conditions and suffer from a degree of deprivation because of it (Rodrigues & Gonçalves, 2018).

In a compilation of researches and studies contributions, Niu *et al.* (2013) illustrate in a straightforward and didactic way the reasons that make both electricity access and consumption be considered crucial in human development. First, it immediately improves health because it enables the refrigeration of food, vaccines and drugs; second, light allows people to study and read for longer periods, which increase literacy rates, and enables access to television, computer and internet. It is known modern society is extremely dependable on network information and communication technologies, which require electricity. The third reason is the number of household services it makes possible: heating, storing and cooling food, sanitation, entertainment, etc, which significantly improves the quality of life. The fourth, considered by many authors the main issue of energy poverty especially in rural communities (Bouzarovski & Petrova, 2015; González-Eguino, 2015; Rodrigues & Gonçalves, 2018) is the elimination of the indoor pollution caused by traditionally used sources of energy, such as biomass, wood and coal, that are associated with severe health problems (Niu *et al.*, 2013) and will be further discussed in this chapter.

The previous examples demonstrate that it is not energy *per se* that brings more quality of life to people, but the social and material services energy can provide, or in other words, the energy services (Bouzarovski & Petrova, 2015; Fell, 2017; González-Eguino, 2015). The perspective of EP through deprivation of energy services is accepted by European and Mexican scholars (Bouzarovski and Petrova, 2015, García Ochoa & Graizbord Ed, 2016) and have as definition "the inability to attain a socially and materially necessitated level of domestic energy services" (Bouzarovski and Petrova, 2015). Theory also considers a more holistic view to observe dimensions that influences on energy services delivery and, therefore, are also part of EP manifestations, such the possibility of energy consumption (access to the grid or an own generator), the affordability of the population when facing energy tariffs and the energy efficiency of existing equipment also influence on the deprivation of energy consumption, as shown in Figure 3.

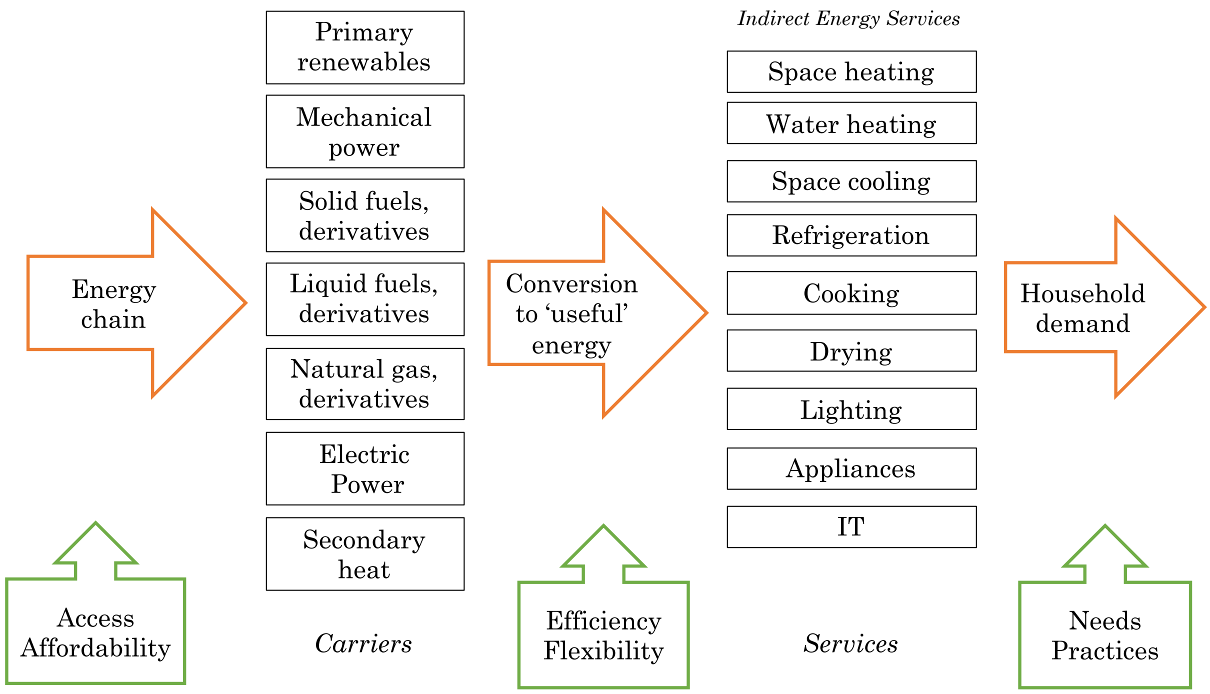


Figure 3. Framework dimensions influencing energy services delivery. (Bouzarovski & Petrova, 2015).

The empirical background to Energy Poverty debates and its translation to public policy are researches that analyze the impact of energy access and consumption on the Human Development Index (HDI). The HDI was the previously index adopted by the United Nations as the official measure for poverty, focused on the dimension of education, health and income (Niu *el al.*, 2013). Discoveries on this topic bring the conclusion that an increase in energy consumption improves human development in multiple levels. Also, there is a positive impact that energy consumption presents in other socioeconomic indexes like GINI, GDP and Theil Index (Niu *el al.*, 2013). These results show that "electricity consumption not only promotes human development, but also human development expands the social demand of electricity" (Niu *et al.*, 2013).

2.2.3. Indoor pollution and environmental degradation

EP has consequences in a person's life that goes beyond energy-related deprivations.

One of its main consequences is health effects caused by the indoor pollution of people who rely on biomass (dung, coal, wood and waste material) as an energy satisfier to cooking, heating and lighting. These fuels are burned inside of homes with insufficient ventilation, usually directly in cookers made of clay, brick or metal, generating smoke that contains carbon monoxide, suspended particles and aromatic compounds. A level of these components that is higher than the advisable levels characterizes the indoor pollution, which is the cause of 1.3 million of annual deaths (WHO, 2019). In fact, indoor pollution is one of the main reasons of health-related deaths in the world, being only after HIV/AIDS (OECD/IEA, 2010). Figure 4 shows the comparison with other diseases and its projection for 2030.

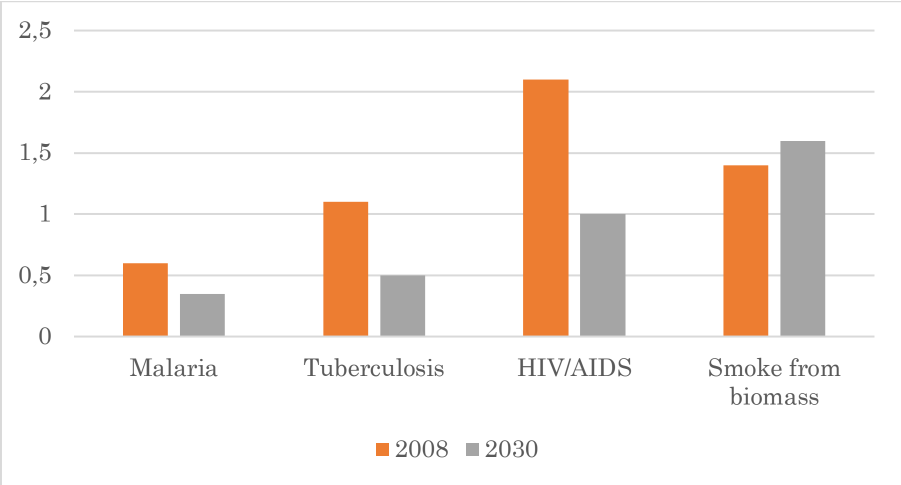


Figure 4. Number of deaths according to health cause (millions). (OECD/IEA, 2010)

People who are most exposed are the ones who spend more hours home (usually women, children, elderly), which are prone to lung cancer, cardiovascular and numerous respiratory diseases (OECD/IEA, 2010). It is particularly harmful to children under five for letting the respiratory system more vulnerable to pneumonia and chronic bronchitis (González-Eguino, 2015).

Also linked to the absence of modern energy access is the proven existing nexus of energy poverty and environmental degradation, explained by the fact that the biomass extraction (wood and charcoal) results in deforestation (Barnes et al., 2004; Bazilian et al., 2011). An example is Uganda, where energy poverty caused the loss of 67% of forests between 1962 and 1977 (Bazilian et al, 2011). Peri-urban areas are particularly exposed to this risk due to its interface with rural areas and the presence of vegetation (Barnes et al, 2004). Related with this land-use change are also desertification, land-degradation, which are linked with climate change processes and also present a threat to the availability of other resources, such as water (González-Eguino, 2015).

2.2.4. Geography and manifestations of Energy Poverty

EP debate is nowadays present in Global South and Global North through different manifestations in academic discussions and policies.

In Europe, 50 million people face a degree of EP and its importance is recognized by European Commission. It is required of every member-state to monitor its national situation and to include the topic into concrete policies and special attention and procedures regarding energy supply to vulnerable populations (European Commission, 2019). The cultural, social and political context of Europe makes EP be manifested in different faces between Eastern Europe and Western Europe (Bouzarovski, 2011). Western Europe, characterized by Welfare States and high technical preparedness and infrastructure, have extreme low statistics of grid disconnected localities, but still considerable numbers of deaths due to the deprivation of the thermal comfort energy service due to the non-payment of energy bills, especially in the UK (Guertler & Smith, 2018). EP in Western Europe is not characterized by a lack of grid infrastructure or technical issues, but by a social injustice scenario.

Eastern European countries face a different reality associated with the post-communism scene, where raises in energy tariffs due to the end of state-regulated prices and existing general disparities among the society led to a more evident multidimensional poverty existence (Bouzarovski & Thomson, 2018). Energy tariffs affordability represented by energy disconnections or incapacity to pay the energy bill are commonly adopted indicators, but also infrastructure inside and outside households, such as the material existence of goods related to energy services satisfiers (Bouzarovski & Thomson, 2018). Among other scopes, the recent European debate on EP is originating an initiative to propose energy as a human right linking the dependence of basic human needs satisfaction to energy services, pointing out the maturity of the concept penetration (Hesselman et al., 2019).

The Global South represents a distinct political, environmental, economic and social context. Hot climate conditions, more enormous populational growth, poverty, socially absent states, lack of financial resources and availability of environmental resources shape the manifestation of Energy Poverty (García, 2014). In Global South, EP is mainly characterized by the lack of access to the grid or modern energies, having the major share among the global 840 million people without access to electricity (United Nations, 2019). Grids also face technical issues of reliability and good infrastructure. The challenge is mainly to connect the vulnerable population to the grid and to create a grid infrastructure with reliable characteristics to attend populational and industrial growth.

Latin America deals with the consequences of energy poverty since a long time (Gomes, 2018). Still, the fist document mentioning it is dated 2006 (World Energy Council, 2006), while the first academic publication was in 2009 (García, 2014). Like other rural global south areas, strategies to bring modern energies, considered the first step for the possibility of having energy services inside homes, are being recently addressed by most of the countries. In the urban scene, a particular manifestation of EP in Latin America is that its growth rate is associated with the migration of poor people to big metropolitan areas, in the form of non-affordability or non-access existence in urban poor settlements, like the favelas, in Brazil (Gomes, 2018; Moon, 2018; World Energy Council, 2006). Many times, these settlements are informal or not mapped by local government, showing that EP production in Latin American cities can be highly related to the non-access to networked infra-structure services (Bouzarovski & Thomson, 2018).

In Academia and Policies, EP mentions are rare and also very recent (García, 2014). Recently being mainly promoted by international organizations' interests, such as the Sustainable Development Goal number 7 - "to ensure affordable, reliable, sustainable and modern energy for all (United Nations, 2016), represented in Table 2. Authors working on the theme report a difficulty in implementing European Studies and methodologies on EP in Latin America because of the context differences, fact that leads to the creation of adapted methods (García, 2014; Villalobos et al., 2019). Until the extension of this thesis' knowledge, the first diagnosis on national EP situations in the Latin America region has started in the last 5 years (García-Ochoa & Graizbord, 2016; Gomes, 2018; Villalobos et al., 2019).

Table 2.Sustainable Development Goal 7 - Targets and Indicators. (United Nations, 2016)

Targets		Indicators	
7.1	By 2030, ensure universal access to affordable, reliable and modern energy services	7.1.1	Proportion of population with access to electricity
		7.1.2	Proportion of population with primary reliance on clean fuels and technology
7.2	By 2030, increase substantially the share of renewable energy in the global energy mix	7.2.1	Renewable energy share in the total final energy consumption
7.3	By 2030, double the global rate of improvement in energy efficiency	7.3.1	Energy intensity measured in terms of primary energy and GDP
7.A	By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology	7.A.1	International financial flows to developing countries in support of clean energy research and development and renewable energy production, including in hybrid systems
7.B	By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States, and land-locked developing countries, in accordance with their respective programmes of support	7.B.1	Investments in energy efficiency as a percentage of GDP and the amount of foreign direct investment in financial transfer for infrastructure and technology to sustainable development services

2.2.5. Correlated concepts

In this concluding part of the section, I present four other key concepts that are related to the energy poverty debate and will be further used in this thesis debate: energy injustice, energy vulnerability, energy security and energy precarity. Their perspective and definition are summarized in Table 3, together with other important concepts already defined in this section.

Table 3. Summary of Key Concepts.

Concept	Definition	Reference
Energy Justice	"evaluates (a) where injustices emerge, (b) which affected sections of society are ignored, (c) which processes exist for their remediation in order to (i) reveal, and (ii) reduce such injustices"	Jenkins et al., 2016
Energy Security	"how reliable is the energy supply and production, also assessing emergent insecurities that may threat them"	Jenkins et al., 2016
Energy Services	"functions performed using energy which are means to obtain or facilitate desired end services or states"	Fell, 2017
Energy Poverty	"the inability to attain a socially and materially necessitated level of domestic energy services"	Bouzarovski & Petrova, 2015
Energy Vulnerability	"the propensity of a household to become unable of meeting its energy needs"	Bouzarovski & Petrova, 2015
Energy Precarity	"calls attention to the performative experience of multiple vulnerabilities in the home, while illuminating the political and institutional embeddedness of fuel poverty manifested via the presence or absence of strategies of mundane resistance and everyday struggles that often take place beyond the boundaries of the home "	Petrova, 2018

The first presented concept, energy justice, is an idea that questions the justice roots regarding energy topics using the perspective of the social sciences. It "evaluates (a) where injustices emerge, (b) which affected sections of society are ignored, (c) which processes exist for their remediation in order to (i) reveal, and (ii) reduce such injustices". EP debate is highly related with the distributional justice debate (Jenkins et al, 2016, Walker & Day, 2012), by questioning who is targeted and benefited by pro-environmental modern energy technologies and infrastructure, who has access to it, and, moreover, the degrees of freedom people have to make their own decisions regarding energy consumption (Jenkins et al, 2016). By this approach, energy poverty is an energy injustice due to a failure of resource allocation in the system (Jenkins et al, 2016, García Ochoa & Graizbord Ed, 2016).

Energy vulnerability is also an adapted concept from social sciences to energy discussion, meaning "the propensity of a household to become unable of meeting its energy needs" (Bouzarovski & Petrova, 2015). The factors and driving forces considered in its core are largely related to EP, since energy vulnerability is a state that leads to EP (Table 4).

Table 4. Energy vulnerability factors and their constituent elements (Bouzarovski & Petrova, 2015)

Factor	Driving force	Sphere of action
Access	Poor availability of energy carriers appropriate to meet household needs.	External/internal
Affordability	High ratio between cost of fuels and household incomes, including role of tax system or assistance schemes.	External/internal
Flexibility	Inability to move to a form of energy service provision that is appropriate to household needs.	Internal/external
Energy efficiency	Disproportionately high loss of useful energy during energy conversions in the home	Internal
Needs	Mismatch between household energy requirements and available energy services, for social, cultural, economic or health reasons.	Internal/external
Practices	Lack of knowledge about support programmes or ways of using energy efficiently in the home.	Internal/external

The third concept, energy security, tells "how reliable is the energy supply and production, also assessing emergent insecurities that may threat them" (Fell, 2017).

Finally, the concept of Energy Precarity, presented by the scientist Saska Petrova (2018) makes a call to go beyond boundaries of home, complementing the EP and vulnerability discussion with the expansion of the perspective in a dual way: firstly, on how political and institutional circumstances can whether model the EP reality or give an opportunity for particular socio-demographic populations to act on the issue, and secondly, how population act, adapt and resists to EP and energy vulnerability with solutions beyond the household level (Petrova, 2018).

2.3. Decentralized Photovoltaic Energy Systems (DCPV)

2.3.1. Photovoltaic Technology

The photovoltaic technology (PV) allows the conversion of sunlight into electricity (Sampaio & González, 2017; Yishu, 2019). Its functioning is based on the photovoltaic effect, which is "the generation of a potential difference at the junction of two different materials in response to electromagnetic radiation" (Smets et al., 2016, p.980). In other words, when the sun or other source of electromagnetic radiation hits a surface composed of two pre-selected different materials, a difference is generated in its potency and electrons are released. These electrons are then conducted and transformed into electric energy.

Even though PV technology can be found nowadays in different available products (such as thin-film solar cells and concentrator PV), the most affordable dominant technology is based mainly in silicon cells (Sampaio & González, 2017). Since the invention of the first crystalline silicon solar cell in 1954 by Gerald Pearson, Calvin Fuller and Daryl Chapin, it has become an interesting option for the production of electricity in large scale (Smets et al., 2016). Its use has grown exponentially all around the world and has been promoted through support schemes in many countries to foment a transition to a renewable energy era (Sampaio & González, 2017).

2.3.2. PV System and its components

A PV system can be composed of just a PV module and the load that requires the electric energy, consisting of small and simple appliances, or of big power plants with several MW generation that feed the electricity grid (Yishu, 2019). The systems are moduled and adapted to meet particular requirements, and can also be expandend when more power is demanded (Riutort Isern, 2016). Three main types of PV systems are stand-alone or off-grid, grid-connected and hybrid systems (Smets et al., 2016).

Off-grid systems work independently from any other source with the support of batteries (Yishu, 2019, Smets et al., 2016). It is commonly applied in rural areas or in places the grid does not reach.

Grid-connected applications, on the other hand, are popular in built-environment and count with an inverter that transforms the DC power into electricity that can be used in loads or injected straight to the electricity grid (Smets et al., 2016). When the system is connected, the grid provides electricity at night times or when the PV generation is insufficient. Finally, hybrid systems are those who combine the PV technology with another source of electricity generation, such as wind power, gas or diesel (Smets et al., 2016).

PV modules are the heart of a PV system but do not work by itself. Table 5 and Figure 5 bring a general picture of its main components, its functions and how they are connected. The lifecycle of most PV based technologies is from 25 to 30 years (Yishu, 2019), while the inverter expected lifecycle is from 10 to 15 years.

Table 5. Components and Functions of a PV System. Based on Vezzoli et al., 2018

Component	Function
Photovoltaic Module	Convert solar energy into electricity
Charge Controllers	Control the current that arrives in the batteries and stop it when it is fully charged
Battery Bank	Store the surplus of the PV system
Inverter	Convert the DC to AC, so it is compatible to feed loads and the grid.
Breaker box	Distribute electrical current to the various circuits.
Electric metre	Measure the energy that is injected and consumed from the grid for billing purposes.
Wires/cables	Conduct the electrical current.

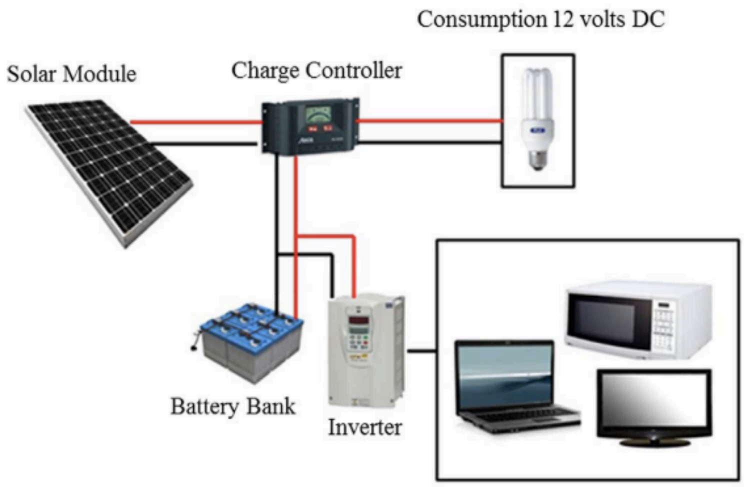


Figure 5. Traditional equipment that composes a PV solar energy (Sampaio & González, 2017)

When compared to other renewable energy technologies, it has less operational costs, less noise and ecosystem interferences (Sampaio & González, 2017).

Financially, PV systems are faced as attractive investment projects due to the return of investment they bring after some years, especially in its grid-connected applications (Smets et al., 2016). An initial investment is necessary to buy and install the equipment, but when the system starts its operation, they bring savings or profit because of its energy generation. The technology gets every day cheaper, presenting attractive payback times to investors (Smets et al., 2016).

2.3.3. Decentralized PV systems

A decentralized PV system can be defined as a small-scale generation unit composed of PV system(s) located near the point of use, where the users can be the producers (Vezzoli et al., 2018). When the second scenario happens, it is defined as distributed generation (Vezzoli et al., 2018). If the small scale PV systems are connected to each other, they become a PV Local Energy Network (Barbero & Pereno, 2013). Figure 6 exemplifies possible structures and combinations between these concepts.

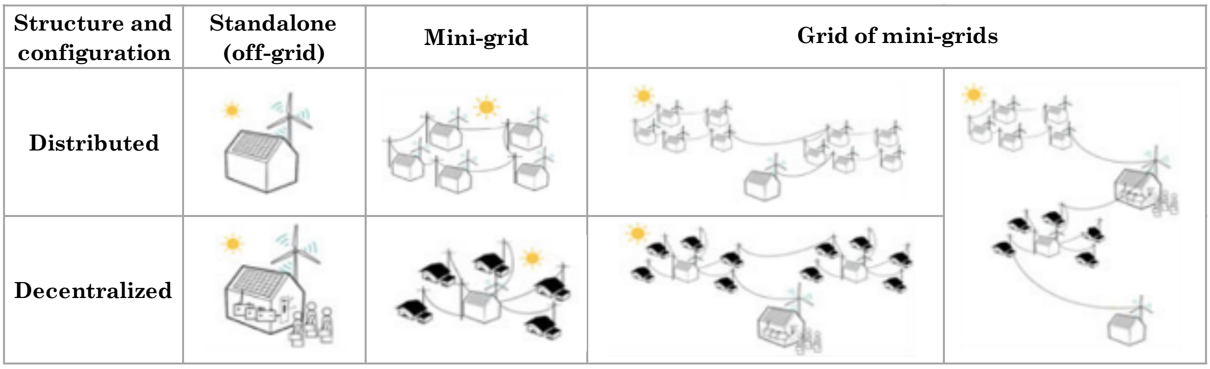


Figure 6. Examples of distributed and decentralized applications (Vezzoli et al., 2018).

DCPV has been gaining popularity in the last decades and is seen by many authors as the force behind the "solar revolution" in the coming years (Smets et al., 2016; Vezzoli et al., 2018), having its potential applications highly linked to the energy transition debate. According to projections of the International Energy Agency (IEA, 2019), DCPV applications will grow 250% in capacity until 2024. Some authors argue that the transition is not only in choices of the sources of energy but also in the way energy is produced, transmitted and distributed (Verbong & Geels, 2007). Decentralized and distributed generation represent a change in the paradigm of the energy industry, which is majorly concentrated in central power plants with a few leading players (Figure 7). PV systems, in the words of Vezzoli et al., are "installable and manageable by small-scale economic entities such as a single residential complex or single individuals. If adequately exploited then, such renewable resources would enable every human being to have more power and move towards a democratic regime of resource management" (Vezzoli et al., 2014, p. 4).

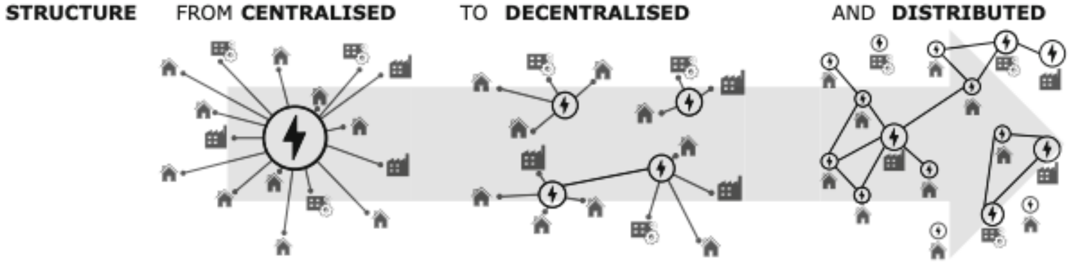


Figure 7. The Structure Transition inside the Energy Transition. Adapted from Vezzoli et al., 2018.

2.3.4. Social and Environmental impacts of DCPV

The main argument for favoring the use of PV energy is the few environmental impacts associated with its life cycle and process of energy generation when compared to traditional sources. Associated climate change, air pollution, global warming and acid rain are minimal or inexistent (Sampaio & González, 2017). Since it uses energy from outside the Earth to generate electricity (sunlight), it does not comprise an extraction process, refinery or transportation to the generation site (Sampaio & González, 2017), sparing Earth's resources. Moreover, the module production is based in silicon, the second more abundant resource on the planet (Sampaio & González, 2017).

Even though it is a clean source of energy during its 20-30 operation life, some environmental impacts exist in the PV technology supply chain and also in its components (manufacturing, transportation and discarding) (Deng et al., 2019). Issues of the correct discarding and recycling of the equipment are frequently highlighted and a proper solution is still under development. The reality is that, in the majority of the time, the modules end their lifecycle landfilled as electronic garbage, contributing to soil and air pollution (Deng et al., 2019).

Without taking for granted the environmental impacts associated with its discarding process, the PV technology is still considered an excellent option among the existing technologies. A scoped study in the lifecycle of PV panels indicates that, compared to traditional fossil energy used in Europe and the United States, they represent a reduction of 89-98% in GHG emissions, heavy metals, radioactive species and criteria pollutants, counting their entire lifecycle (Fthenakis et al., 2008). DCPV and distributed applications may have a slightly higher indirect pollution associated with transportation to the site of installation since a smaller quantity of modules is brought to more places (Fthenakis et al., 2008).

The literature also covers several other benefits that PV systems bring to the electric system and the institutions responsible for its management, such as contributions to the electricity grid capacity in terms of transmission, distribution and generation and the avoidance of costs related to these aspects (Denholm et al., 2014). By reducing electricity price in the long term, it affects the reliability and security of the grid (Denholm et al., 2014). Even though the scope of this thesis is not focused on quantifying this kind of impact, it is important to consider that DCPV systems have the potential of being beneficial in technical and economic aspects when the grid is ready to receive it.

In the social sphere, many benefits, especially related to the democratization of energy and the empowerment it brings to people regarding its electric energy choices, are cited in the literature and in case studies (Riutort Isern, 2016). In the traditional centralized market, rarely or never has the final user influence in the decisions made regarding sources and prices, or power of choice on which company he wants to buy from (Riutort Isern, 2016). DCPV brings to the user to the role of a producer of its own energy, or *prosumer*, changing the paradigm of property and choices, bringing access and affordability to people in different scales, such as households, villages or cities (Riutort Isern, 2016). Self-generation is a synonym of self-supply, meaning that politically it represents a social emancipation that allows the appropriation of electric energy in people's lives and, consequently, of the social and economic spaces where they develop their lives. The user that is part of a DCPV is, therefore, a player of the market and actively responsible for the energy transition. In these scenarios, decentralization also happens in the level of power, control and choices (Riutort Isern, 2016).

When applied by poor or vulnerable communities, they can also redirect energy generation and its benefits to serve people's well being and to focus on human development instead of contributing to the logic of accumulation that is prevalent in the energy markets (Riutort Isern, 2016). Moreover, it can contribute to a community's coping capacity in disaster recovery and generate local jobs (Denholm et al., 2014).

2.4. Policies Supporting Energy Poverty Alleviation

This section explores which set of policies and measures are commonly taken by governments when targeting EP alleviation for low-income and vulnerable populations. Firstly, an overview of European policies, which already contains EP on its political agenda, will be given following the classification proposed by Dobbins & Pie (2016). Then, some considerations on Latin American policies are stated.

The Researches and compilations made about European governments' policies shows that three types of measures are prevalent within the European Union (EU). The first common set in use is financial interventions. In this type of action, the government supports vulnerable and low-income people with money transfers, tackling the affordability face of EP. It is commonly made either by direct payment to help covering energy costs or via general social welfare deposits (Dobbins & Pie, 2016). An also used alternative is through social policies that force the market to internalize this aspect, requiring the application of social tariffs for gas and electricity companies to protected consumers (Bouzarovski, 2018; Dobbins & Pie, 2016).

Financial interventions are recommended when integrated with other policies and measures, since they are, by themselves, short-term actions (Omic & Halb, 2019). Even though they address immediate affordability issues, they do not attack the underlying structural matters of EP (Bouzarovski, 2018; Dobbins & Pie, 2016). Good case examples can be found in places such as the Netherlands and

Scandinavian countries, where social financial transfers exist as support measures but combined with major efforts on energy efficiency and social housing policies (Dobbins & Pie, 2016).

The second set of policies and measures are additional consumer protections for users depending on the retail market. They aim to ensure that vulnerable users are not disadvantaged by regulated markets operations and require a strong role for the national regulator (Dobbins & Pie, 2016). In practice, measures target the prevention of disconnection of vulnerable users, where the regulator establishes codes of conduct for companies and market players, besides defining which groups are considered vulnerable users (Dobbins & Pie, 2016).

Such measures are popular within the EU, where they are adopted by 80% of its State members (Dobbins & Pie, 2016). Moreover, it is also possible to find specific measures to ensure energy supply to indebted users, allowing them to switch to other suppliers and individually finding solutions to pay for the energy. This is the most heterogeneous category of policy and measures among EU States (Dobbins & Pie, 2016).

The third category towards EP alleviation is energy efficiency programs. Considered as a long-term priority policy (Bouzarovski, 2018; Dobbins & Pie, 2016), they can lower EP rates by educating users for energy consumption, improving the quality of homes, reducing the levels of energy consumption, and, finally, making energy bills more affordable (Omic & Halb, 2019). EU countries have a great number of policies and good cases with energy efficiency programs, that have been proven effective in EP alleviation. A common appliance is through social housing programs (Bouzarovski, 2018). Energy Efficiency policies focus on three types of policies: financial, information and legislative policies (Dobbins & Pie, 2016), which are better described in Table 6.

Table 6. Energy Efficiency Policies in EU (Omic & Halb, 2019).

Type of policy	Measures
Financial policies	Financial incentives, grants, vouchers, loan subsidies, and tax incentives to help construct and retrofit homes to meet higher energy efficiency standards.
Information policies	Energy efficiency labelling, information campaigns, advanced “smart” metering systems, and energy consumption training programs;
Legislative and regulatory policies	Building codes, minimum standards for heating systems, and thermal/insulation ordinances.

Relevant to the matter is the fact that energy efficiency programs can generate a rebound effect for lower-income households, characterized when they redirect generated savings to increase their energy consumption (Omic & Halb, 2019). This can be illustrated by buying new televisions or equipment for ensuring thermal comfort in other areas of the house. Nevertheless, the rebound effect is seen as a positive outcome when savings are used to improve the overall quality of homes and families (Omic & Halb, 2019).

The last category concerns information provision & raising awareness among low-income users. Policies and measures aim to inform users about their rights, energy tariffs and billing (Dobbins & Pie, 2016). This includes transparent billing, campaigns on advice provision and available and accessible information on price comparison. These measures tend to be higher in states where civil society's work towards EP is substancial (Dobbins & Pie, 2016), since they either pressure policy agenda and are vehicles of making information accessible to targeted groups.

As it is a specific interest of this thesis, a particular search was conducted concerning incentives and policies for PV installation targeting low-income and vulnerable households in EU. Generally, they are available among fomented technologies in energy efficiency programs. Among governmental actions contemplating PV technology are financial incentives for energy communities (Greece), extra financial AID to self-consumption PV systems (Cyprus) and zero-interest loans funding PV systems in Belgium (EU Energy Poverty Observatory, 2020).

When it comes to the Latin American region, EP debate is new and is still penetrating agendas (for more details, see 2.2.4). Differently from EU, countries do not count on an official definition and indicator (UNDP, 2018) and there is rarely mention to the term "Energy Poverty" in official documents.

In the region, the most common type of policies is focused on bringing modern energy grids to the population or electrification programs for rural areas, since countries of the region face considerable percentages of the population without access to gas and electricity grid (UNDP, 2018). In these cases, PV technology is contemplated as an option for isolated areas (Programa de Desarrollo del Sistema Eléctrico Nacional, 2018). Countries that are commonly cited as references in successful electrification programs are Brazil and Mexico. In Brazil, it possible to find subsidized tariffs for electricity targeting low-income groups (ANEEL, 2016).

2.5. Connecting theories and concepts - Final Considerations

Agreeing with the roots of the debate regarding energy and poverty, this thesis assumes that poverty is unacceptable in any society (Pereira et al., 2010). The underpin poverty approach here considered is Max Neef's theory, due to the proximity to Latin-American reality, its challenges and the possibility of deriving specific projects and actions to the poverty scenario amelioration.

Poverty debate and the mentioned official indicators leave the contribution and clearness of the complex and multidimensional characteristics of Poverty, to which a systemic view approach is needed for its comprehension. Energy is considered in the debate because of its influence in these dimensions. The presented indexes recognize the need for the use of energy inside home, using indicators such as access, type of fuel and the existence of a few some established economic goods inside homes as ways of measuring and analyzing its deprivation. I consider that this approach is an initial approximation to the relation existent between energy deprivation, but it is does not fully represent and explore how modern energy deprivation has consequences to human development. For being a topic that scopes into this theme, the energy poverty perspective depths the aspects and factors involved in this relation, opening opportunities to analyze holistically the causes and consequences of the deprivation of domestic energy services and how it is materialized inside homes.

Even though both topics have similarities, it is essential to clarify that an energy poor is not necessarily poor, neither is a poor necessarily energy poor (García Ochoa & Graizbord Ed, 2016; Villalobos et al., 2019). Energy poverty is both a cause and consequence of poverty (González-Eguino, 2015) and is one of the many deprivations that can be analyzed (one of the poverties, as said by Max-Neef) inside the multidimensional poverty approach (Villalobos et al., 2019). It is recognized that energy consumption won`t get people out of poverty state. Nevertheless, it is also understood that energy provides basic services that to attend people's have basic needs and leave social and material deprivation states present in poverty (García Ochoa & Graizbord Ed, 2016).

For this work, it is adopted the idea of the existing theoretical obsolescence of the definition of fuel poverty and it is considered the synthetized and consistent definition of energy poverty brought by Bouzarovski & Petrova (2015): "the inability to attain a socially and materially necessitated level of domestic energy services". In other words, energy poverty occurs when homes do not have economic goods that are considered basic to satisfy fundamental needs (Garcia, 2014), or do not have conditions that are requirements for the proper functioning of such home appliances, such as affordability or access to modern energy.

As stated by Max-Neef, the detection of levels of deprivation in modern energy use can be considered as a potential resource to mobilize, organize and bring innovative solutions (Max-Neef, 1992). On one side, there is an availability of technologies, namely here PV in its different applications, that are capable of providing access and affordability to modern energies. Motivated mainly by climate change mitigation, there is an urgent need for a transition to more clean energy sources and to create communities that are also providers of its own resources in a sustainable way. In this way, there is an intersection of possibilities and synergies where DCPV, energy poverty zones and environmental concerns can be drivers of innovative solutions that go beyond typical off-grid applications to provide energy access. Differing from typical rural electrifications projects with off-grid PV that aim to give energy access to disconnected people, this study involves possible DCPV grid-connected applications in a specific manifestation of energy poverty in Latin America. As exposed by the World Energy Council (2006), the region faces a growth of urban populational marginal areas, usually peri-urban communities that have the infrastructure of an energy grid but still present social and material deprivations due to a lack of delivery of domestic energy services.

Locally, energy poverty scenarios in grid-connected areas leave a potential room for the application of DCPV for tackling two emergent, linked and existent problems: a social matter characterized by energy poverty states and the existent environmental degradation in a local level and regional level, namely deforestation and air pollution. The discussion here goes, then, on how PV can contribute to energy poverty alleviation in a systemic view, concerning also issues of energy justice (Jenkins et al., 2016), energy security (Jenkins et al., 2016), energy vulnerability (Bouzarovski & Petrova, 2015), energy precarity (Petrova, 2018) and affordability (Bouzarovski, 2011) that directly or indirectly affect the EP scenario. The local and regional environmental conditions might be closely interrelated to this social scenario linked to energy deprivation.

Nevertheless, it is also stated by energy justice scholars the distributional issue among modern technologies, that many times are not capable of penetrating social realities that are excluded from the system (Jenkins et al., 2016). In this matter, directed public policy use a set of mechanisms to tackle EP and favor the democratization of these technologies to energy poor, as explored in Section 2.4. While in Latin America the approach to energy poverty alleviation is mainly through rural electrification and efficiency programs, the EU recognizes energy poverty as a regional issue and makes use of a different set of instruments for low-income and grid-connected populations. To the penetration of PV technology in EP areas in such realities, the government also needs to provide the necessary regulation and support scheme due to the initial high costs. Financial incentives have a unique role for low-income population.

Until the extension of this thesis' knowledge, no specific works concerning this perspective were found. Nevertheless, previous researches looking in the same direction of mitigating EP with DCPV in grid-connected communities in Latin America were found.

Moon (2018) studied the acceptance of PV in an urban emarginated area - favela - in Rio de Janeiro, Brazil, intending to make electric energy affordable. She concluded that people were opened to own a PV system and that Brazil had a positive momentum for its application (Moon, 2018).

Barquero (2016) analyzed the viability of creating a community integrated energy PV system in a grid-connected energy poor rural community of Chihuahua (Mexico) in two scenarios: individual applications or community level, based on local cooperative management. This study demonstrated that individual PV systems had a greater acceptance between the inhabitants, but a mini-grid would be more financially feasible and have more governmental credit available. In the rural context, the system structure could be integrated with food production and also bring benefits to crop production (Barquero, 2016).

Going beyond the individual EP level, Buendía Oliva (2019) found potential environmental education benefits and development of working competences in a grid-connected PV system maintained by parents in a public school in La Pila, Mexico (Buendía Oliva, 2019).

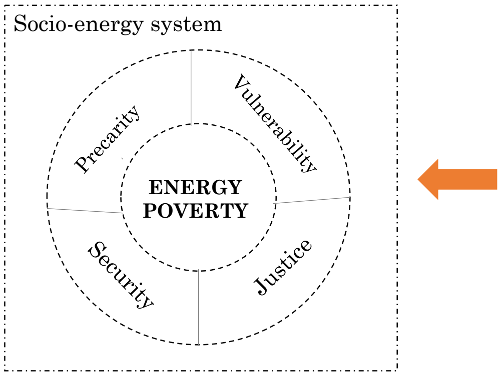
Finally, considering discoveries of the cited researches, summed up with the social benefits brought by the DCPV of the pioneer local cooperative "Som Energía" (Spain) (Riutort Isern, 2016), already mentioned in Section 2.3.4, compose the guidelines and contributions to the perspective of this work.

2.6. My own approach

Considering all the review on literature and the presented interrelation, what I present is an approach that permits having a holistic view of PV co-benefits in energy poverty zones. For that, three disciplines are interconnected: environmental, social sciences and political sciences.

From the social side, the energy poverty scenario is affected and also exists because of aspects coming from outside the household's walls. I consider essential understanding a locality's socio-energy system characteristics, especially if, as a grid-connected community, it is possible to rely on the existing energy supply provided (Villalobos et al., 2019). In this discussion, aspects that englobe energy precarity, energy justice, energy vulnerability and security and grid reliability profoundly influence how, when and if people can rely on the energy provided by the grid, highlighting deeper structural problems. Based on that, they are considered to diagnose energy poverty, explicitly considering the pressures they make on the energy poverty scene. For this particular focus, a scope is given on how energy poverty is also politically created and until what extension could DCPV effectively work. The findings will guide general recommendations on how DCPV scenarios can also tackle key points that generate energy vulnerability and policy gaps. Hence, this kind of view of the socio-energy system provides inputs for the correct choice of DCPV equipment and its design, especially concerning the need for the use of batteries and technical recommendations for system design.

The EP diagnosis considers the presence of material energy needs satisfiers inside homes (Bouzarovski & Petrova, 2015; García-Ochoa & Graizbord, 2016) to understand the degrees and ways that energy poverty is locally manifested. Because of the known potential of DCPV acting on the affordability of electricity (Moon, 2018), this specific aspect is also assessed. The conditions that households have to pay energy bills in case of grid-connected communities is an important data to check the security of its constant access (Bartl, 2010; Villalobos et al., 2019) In low-income communities that are fed by the private market companies, it is crucial to consider these aspects because they are impeditive to the first aspects that influence domestic energy services delivery: access and affordability (Bouzarovski & Petrova, 2015). The guiding questions of the socio-energy scene are represented in Figure 8.



- What role does electricity play in families' life?
- Are there families who are still grid-disconnected?
- How are the energy tariffs? Do households find it expensive?
- Is there a special tariff for low-income population?
- Can households afford the electricity bill?
- Is there a special protection against disconnections? How is the debt forgiveness culture?
- What are the energy and electricity burdens? Is it within the expected for the State reality?
- Where does the electricity come from?
- Is the electricity grid stable and reliable?
- Which external decisions are affecting the location's electricity supply?
- Do households own the necessary goods for attending their fundamental energy services?
- How many people are energy poor?
- What are the degrees of energy poverty?

Figure 8. Key questions to approach the socio-energy scene.

This approach also considers systemic views' contribution: a socio-energy system is inserted in a bigger system, a socio-technical scenario that also receives pressures and it is in constant change (Geels & Schot, 2007). This scenario can be favorable or not to impulse disruptions inside the system in focus (Meadows, 2009), being policy a powerful and leverage point instrument on this matter (Omic & Halb, 2019). For that, it is valid a comprehension of public policy and regulation looking at energy poverty and DCPVs, its main guidelines, goals and perspectives. Apart from providing information on where it is guiding the local system, it contains crucial practical inputs for existing funding and regulation to suggest scenarios. Without incentives, it will hardly reach the poor (Gündel et al., 2001).

From the environmental field comes the contribution of new clean technology such as PV, which is the technology being here assessed. It also provides the knowledge on planetary boundaries and the need to mitigate greenhouse gases, (IPCC, 2018; Rockström et al., 2009) and energy poverty, since it is also associated with land-use change and deforestation (Bazilian et al., 2011; González-Eguino, 2015). Quantifying the contribution to the environment, is, then, a particular and relevant point embraced by this approach.

Having identified the political position on the theme, the environmental and social issues that are locally present as cause and consequences of the energy poverty manifestation, it is possible to create scenarios of the technology application, ideally based in a bottom-up approach that co-construct an application empowering local people to be responsible of their own solutions. Demonstrating each possibility's co-benefits gives a practical input for decision making and the creation of policies, which is part of the main objective of this work.

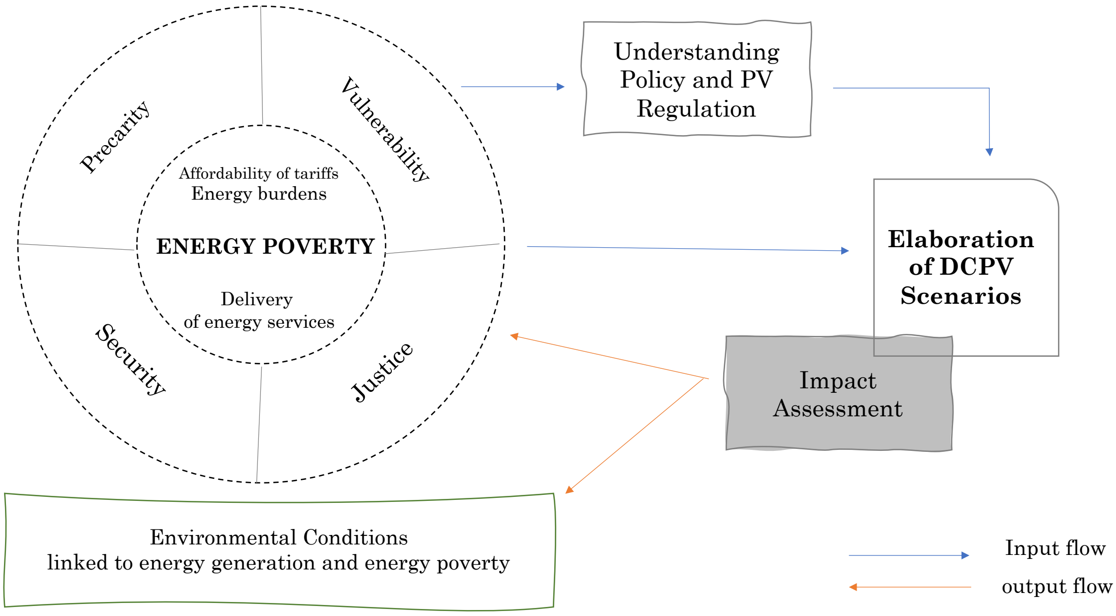


Figure 9. The perspective developed to approach the research problem

Chapter 3. Methods

This section is focused on describing applied methods, techniques and data selection for the research and its application on the case study. The methodology of this research is characterized as mixed, due to its qualitative and quantitative integrated nature. For better comprehension, the proposed methods and techniques are described according to each general topic of the specific objectives and a visual representation of the methodological scheme is presented in the end of the chapter (Figure 14). Before continuing, it is important to state that original predicted methods and data collection of this research have been adapted to fit the unavailability to go to the field due to the COVID-19 contingencies, especially related to social participation and acceptance. A better explanation is given in cases where this is applied.

3.1. Energy Poverty Assessment in La Pila

3.1.1. Energy Poverty Scale

To construct the energy poverty scale, an adaptation of the methodology developed by García Ochoa & Graizbord Ed (2016) is applied. The chosen methodology is consistent with the national Mexican scenario and its aligned with the theoretical approach chosen for energy poverty, which is based on the concept of energy service satisfaction considering the existence of material conditions inside the home to allow its materialization. The considered home appliances and energy services by the original methodology, shown on Table 7, take into account the cultural background of energy use in the country and are based on a national inquiry on energy use developed by the National Secretariat on Energy (SENER) combined with the socioeconomic conditions module of the Household Income and Expenditure Survey (ENIGH). Energy poverty degrees are demonstrated by the combination of deprivations found, built with the construction of clusters with k-means clustering method (Kodinariya & Makwana, 2013).

Table 7. Energy services considered in García Ochoa & Graizbord Ed (2016).

No	Energy service (Indicator)	Variables	Fulfiment Threshold	
			Function	Definition
1	Lighting (ELS)	F = number of fluorescent lamps and bulbs R= number of rooms	$ELS = 1, if\ F/R \geq 1$	Have at least a lamp for each room of the house
2	Entertainment (Et)	T= Have at least a TV I= Have Internet access C= Have at least a computer or laptop	$Et = 1 \rightarrow TUC \cap I$	Have at least a TV or Pc or Laptop with internet access
3	Water heating (WH)	B= Have water heating (Lpg, natural gas, electricity or sun power) S= Have strong (LPG, natural gas, electricity or sun power)	$WH = B$US	Have water heater or stove using gas, electricity or sun
4	Food Refrigeration (Refri)	Refri = Have efficient refrigerator (model 2003-2012)	Refri $= 1 \rightarrow R2003UR2012$	Have at least a refrigerator (model 2003-2012)
5	Food cooking (FC)	ST= Have stove (LPG, natural gas, electricity or sun power) F=Consumption of LPG, natural gas, electricity or sun power as a fuel for cooking)	$FC = 1 \rightarrow$ STUF	Have a stove using gas, electricity or sun
6	Air conditioning and ventilation (AV)	AC= Air conditioning F= Fan H=Household size (number of people)	AV= 1 → ACUF/H≥0.5	Have at least one fan for two peope or air conditioning in the main rooms

To bring García Ochoa & Graizboard Ed's methodology to the context of the case study, qualitative methods, specifically focus groups (Lune & Berg, 2017) were predicted to identify any other energy service that belongs to its cultural background and could compose or modify Table 7 (García Ochoa & Graizbord Ed, 2016). For La Pila, there was a particular interest in knowing if water supply could be considered a fundamental energy service for households. It is located in a semi-arid region that depends on underground water, it has been reported interrupted grid water supply present in the delegation and the reliance on wells (Cisneros Vidales, 2018), that commonly work with electric motors. Also, due to technological advances and its influences on local culture and habits, there was the hypothesis that smartphones are locally used as economic goods that satisfy the entertainment indicator. These questions remain not answered due to the inaccessibility to field caused by COVID-19 contingencies.

Still, the fact that energy poverty diagnosis was based on secondary data required some adaptations on the original proposition that are further explained in the section Secondary Data Selection. Due to that, the existence of a ventilator or air conditioning, the year of fabrication of the refrigerator and information on internet access on the entertainment component were left outside the variables. Energy services considered for energy poverty analysis in this research are represented in Table 8, which presents as limitation not considering the efficiency aspects of food refrigeration, internet access for the computers and the thermal comfort service.

Table 8. Energy services considered for the energy poverty analysis in this research.

No	Energy service (Indicator)	Variables	Fulfiment Threshold	
			Function	Definition
1	Lighting (ELS)	F = number of fluorescent lamps and bulbs R= number of rooms	$ELS = 1, if\ F/R \geq 1$	Have at least a lamp for each room of the house
2	Entertainment (Et)	T= Have at least a TV C= Have at least a computer or laptop	$Et = 1 \rightarrow T \cup C$	Have at least a TV or Pc or Laptop
3	Water heating (WH)	B= Have water heating (Lpg, natural gas, electricity or sun power) S= Have strong (LPG, natural gas, electricity or sun power)	$WH = B \cup S$	Have water heater or stove using gas, electricity or sun
4	Food Refrigeration (Refri)	Refri = Have a refrigerator	Refri = 1	Have at least a refrigerator
5	Food cooking (FC)	ST= Have stove (LPG, natural gas, electricity or sun power) F=Consumption of LPG, natural gas, electricity or sun power as a fuel for cooking)	$FC = 1 \rightarrow ST \cup F$	Have a stove using gas, electricity or sun

The second adaptation consists of the data analyzing and classification of groups of inhabitants. Here, the k-mean cluster analysis method is complemented with a manual classification of households, which gives the study a more precise result. As the k-means cluster method looks for similarities in the data to form groups (Bhagat et al., 2016), the results of iterations and its classification into the clusters with closest mean center can make individual observations lose particularities, which are important to this study due to its limited sample size (40 households). The sample and number of variables give the possibility of a personalized and manual analysis for the number of deprivations and classification of the households. This part is, then, held in Microsoft Office Excel with the use of a spreadsheet as main tools, using techniques such as filters, conditional formatting and formulas to analyze the results. To have more specificity, one more level was aggregated to the scale used by Garcia Ochoa for Mexico, and the scale chosen for the group formation is composed by: non-energy-poor, energy poor, strong energy poor or extreme energy poor (Table 9). The k-means cluster method is used to identify the set of deprivations that are most common among the degrees of energy poverty, and it is held using as tool IBM SPSS Software, with the technique of “K-means Cluster Analysis”.

Table 9. Energy poverty scale built for this study

Classification	Number of energy services' deprivation
Non-energy poor	0
Energy poor	1
Strong energy poor	2
Extreme energy poor	3 or more

The quantitative information is complemented with a documental research on previous researches held in La Pila and internet bibliographical research to compose the systemic socio-energy perspective proposed. The searches scope information relevant to the topics of energy tariffs, vulnerabilities, justice, supply and precarity, prioritizing official sources such as websites of the responsible institutions.

To conclude the EP methods, a special consideration and register is here aggregated regarding the energy service of air conditioning and ventilating in the application of García-Ochoa & Graizbord Ed's (2016) methodology for specific climate conditions of the case study. Their methodology adopts the assumption of Howell et al. (2005), in which ventilators are recommended an essential home appliance to keep indoor thermal comfort in regions where the maximum average monthly temperature is above 26°C (ASHRAE, 2013). According to his study, San Luis Potosi would be, then, a city where the energy service of air conditioning or ventilation must be taken into consideration to meet its inhabitants' essential fundamental needs.

For a further and complementary understanding of the matter, a study locally developed by the Autonomous University of San Luis Potosi (Rivera Vásquez, 2014) on the monthly thermal comfort ranges developed for the city and its edifications was considered. The considered model is based on the Effective Temperature (ET) Index developed by Hentschell (1986) that aims to calculate the effective thermal sensation experienced by a human in the city. For that, climate factors of relative humidity and wind speeds are combined with the average external temperatures observed between 1970-2010 in San Luis Potosi city. It is important to mention that ET considers young, healthy, wearing light clothing and submitted to light activity.

Figure 10 shows the results of ETs contrasted with limits of the ideal thermal comfort temperatures calculated by Rivera Vásquez (2014) on a monthly average basis. ET is considered inside the thermal comfort zone in about half of the months. In months of lower temperature (November, December, January and February), the average ET reaches 12 to 16°C, considered te range where people are exposed to a zone outside of the calculated thermal comfort because of the cold. The number of hours of the incidence of average extreme temperatures is night and early morning periods of the winter season (Rivera Vásquez, 2014). Translating this fact to a thermal comfort satisfier, this study shows that, in fact, heating should be an energy service considered essential for people's well-being.

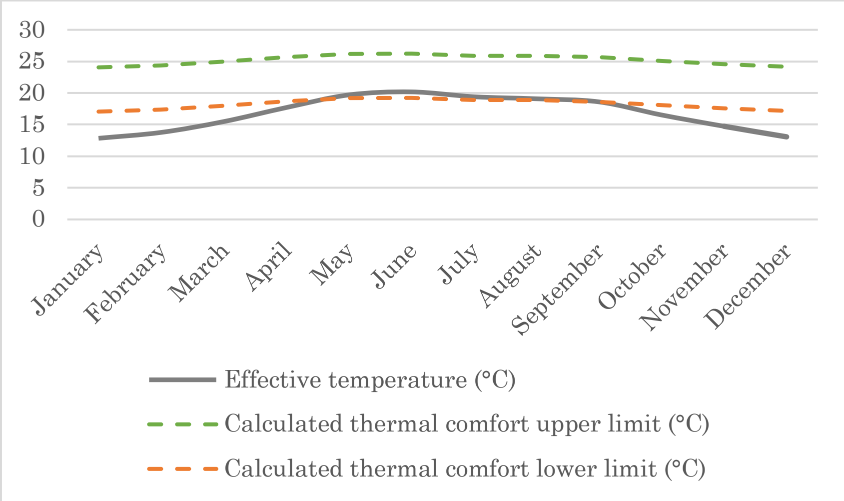


Figure 10. Monthly temperature in ideal thermal temperature perspective. Rivera Vazquez (2014).

Nevertheless, even in the previously cited months of cold, the average thermal sensation is still classified as "Pleasant" applying the scale considered by the study of Cervantes & Barradas (Cervantes & Barradas, 2010) (
Table 10).

Table 10. Thermal Sensation in SLP (Cervantes y Barradas, 2010).

Month	ET (°C)	Thermal Sensation
January	12,84	Pleasant
February	13,77	Pleasant
March	15,48	Pleasant
April	17,7	Pleasant
May	19,7	Pleasant Warmth
June	20,18	Pleasant Warmth
July	19,41	Pleasant Warmth
August	19,09	Pleasant Warmth
September	18,6	Pleasant Warmth
October	16,53	Pleasant
November	14,74	Pleasant
December	13,07	Pleasant

Both studies show, then, contrasting perspectives regarding the need and type of necessary equipment to be applied as a thermal comfort satisfier. I consider a limitation of both using average temperatures, that in the case of San Luis Potosi may limit the representation of the reality, considering strong variations found within seasons and the characteristic daily thermal amplitude found in its climate.

Rivera Vásquez's (2014) results for edifications, even considering other climate factors and the monthly averages for its conclusion and methods, can hardly be applied to La Pila due to its emarginated and vulnerable characteristics, where inhabitants do not count with well-planned houses and high-quality materials for its edifications. The study leaves an important contribution that in special hours of autumn and winter (approximately 4 months) people are exposed to intense hours of cold that, even being tolerated young and healthy people, may be harmful to elders, children and babies.

To complement the quantitative methods perspectives, a qualitative method was predicted (interviews) to get the local perception of whether a thermal comfort satisfier would be considered or not an essential energy service and which one would it be, considering especially local climate variations the city has been facing since the measurements. With the impossibility of its realization due to COVID-19 contingencies, a conclusion regarding the real need of the thermal comfort energy services remains an open question and as a limitation of this work. For the purpose of executing the energy poverty analysis, it is left outside of the essential energy services due the unavailability of information regarding the existence of ventilators, air conditioning and heaters in the secondary data sources.

3.1.2. Energy expenditures and income situation

To complement the energy services delivery approach contained in García Ochoa & Graizbord Ed's (2016) methodology, an energy affordability analysis is also executed. For that, two methods were predicted: analyzing the total number of people who get disconnected from the grid for not paying the energy bill (Bartl, 2010), data that was asked to the National Commission of Electricity (CFE – Comisión Federal de Electricidad), and an analysis of the financial situation of households regarding energy expenditures (energy burdens). In the moment of finalization of the thesis, CFE had not provided the requested information, the reason why energy disconnections data could not be used to compose this analysis.

Since there is not a national study to determine a minimum ideal energy consumption or thresholds to income energy poverty and affordability issues, I compare the inhabitant's average energy burden with the reality found in the State of San Luis Potosi. This is done in order to understand if its characteristics are within the pattern regionally found. The state information is preferred due to its proximity to the climate and cultural reality of La Pila when compared to a national parameter. Values used for reference and analysis come from inquiries of the National Institute of Statistics and Geography (INEGI) on home expenditures. Here, results of the National Inquiry on Home Incomes and Expenditures (Encuesta Nacional de Ingresos y Gastos en los Hogares - ENIGH, 2018) and National Inquiry of Home Expenditures (Encuesta Nacional de Gastos en los Hogares - ENGASTO, 2013) are considered. ENGASTO (2013) presents results dated from 2013, showing that San Luis Potosi's homes had an average of MXN 190 per month[1] in electricity expenditures and gas expenditures of MXN 225 (Instituto Nacional de Estadística y Geografía (INEGI), 2013). ENIGH (2018) has available parameters for San Luis Potosi state in a category englobing the sum of electricity and fuels for home, which corresponds to MXN 408[2] monthly and 2,6% of the total income of households. (Instituto Nacional de Estadística y Geografía (INEGI), 2018).

The summarized information of the values that are used as parameters to compare La Pila household's situation to the state averages is represented in Table 11. A restriction of using this method is that San Luis Potosi state has 39% of its households living in EP according to energy services deprivation method (García-Ochoa & Graizbord, 2016). In practice, it means that values are not reflecting the energy consumption and, consequently, the expenditures of a population that fully attends its energy basic needs.

Table 11. Values of reference for affordability analysis.

Indicator	Monthly Value	Source
Electricity Expenditure	190,00 MXN	ENGASTO 2013
LP gas Expenditure	225,00 MXN	ENGSTO 2013
Energy burdens	408,00 MXN	ENIGH 2018
Average households' income	15.500,00 MXN	ENIGH 2018
% of energy burdens in household's income	2,63%	ENIGH 2018
% of electricity expenditure in households' income	1,23%	ENGASTO 2013 ENIGH 2018
% of LP gas expenditure in households' income	1,45%	ENGASTO 2013 ENIGH 2018

To compose this analysis, qualitative data available on Cisneros Vidales (2018) on the perception of the inhabitants regarding energy bills and interruptions of the electricity supply are considered. Quantitative data on the number of blackouts and brown-outs were requested in the energy distribution responsible institution (CFE), but it had not been provided until the finalization of this work.

[1] Values were updated considering an accumulated inflation of 22,98%, corresponding to the period of December 2013 to December 2018, according to INEGI's inflation calculator (https://www.inegi.org.mx/app/indicesdeprecios/calculadorainflacion.aspx)

[2] Value was not updated because information available on the sample is also from 2018.

3.1.3. Secondary Data Selection

For the energy poverty and energy expenditures assessment, three main databases that count each with different samples were considered: available data of the Mexican 2010 Census (Instituto Nacional de Estadística y Geografía - INEGI, 2010), Cisneros Vidales' (2018) research on a group of local households and estimations made by the Estate Council of Population (Consejo Estadual de Población – COESPO, 2020). Its main strengths, weaknesses and appliances are going to be mentioned in the next paragraphs. It is important to clarify that the application of additional interviews and questionnaires (Lune & Berg, 2017) were considered to complement and update essential aspects of data. Nevertheless, due to COVID-19 contingencies, this step was not applied.

The first considered database is INEGI's. Its data counts with information on the last official census nationally executed, in 2010, and consists of door-to-door interviews in the whole delegation. It is the official measurement with the most complete and numerous information of La Pila, being also the base of the poverty index realized by CONEVAL. However, the main limitation found in the database is its age of already 10 years old, which limits the representation of the current situation of the delegation. Moreover, it does not contain all the home appliances used in Garcia Ochoa & Graizboard's methodology and the variables taken into consideration are insufficient for the energy poverty degrees analysis. In the moment of realization of this thesis, another official census was being held in Mexico, but its results were still unavailable.

The second available data comes from a previous researcher that is part of this thesis' main project. The data provided by Cisneros Vidales (2018) is based on a sample composed by 40 households of La Pila delegation, randomly selected from the list of parents of the Francisco González Bocanegra Primary school. Forty-five minutes interviews were realized by her and members of UASLP's project in the months April and May of 2018. Questions included topics of general information of households on energy, water and food, including expenditures, sources and home appliances. Its main restrictions concern the representativeness of the sample when compared to La Pila's population (Cisnero Vidales, 2018). While it gives a good perception of the reality of families of Francisco González Bocanegra school including important qualitative perceptions not contemplated by INEGI, it excludes social groups that do not belong to the universe of the education institution. The available information is limited to families composed of 5 to 12 years old children that are receiving formal education.

The last possibility comes from data provided by COESPO, which is a state-level institution responsible for providing statistical estimations of indicators for policy applying in San Luis Potosi municipalities. Even though not having specific information for the case study area, the institution projected estimations to La Pila delegation for the year 2020, that were specially developed for this thesis realization under a partnership with the Autonomous University of San Luis Potosi. The calculations were made based mainly on INEGI's database and the microdata for La Pila. Its main strengthen is being the most reliable recent available data provided by an official governmental institution. It contains socio-demographic updated information for indicators of poverty, population and deprivations that quantitatively builds the background of La Pila delegation population. As an estimation, it has the limitation of being a statistic-based prediction exercise that counts with uncertainty. For the calculations, the behavior of indicators of the San Luis Potosi municipality is taken into consideration. For that, its results may not represent what is seen in fact in the emarginated reality of the case study for not consider specific demographic, cultural, economic and historical factors that are specific of the area. Regarding its feasibility to run the energy poverty analysis, for being based on INEGI and official institutes information, the output of the estimations is also limited to home appliances considered by INEGI's questionnaires, which only cover three energy services of the selected energy poverty methodology.

Considering each data and its respective samples' strengthens and limitations, they are all used in different moments of the Energy Poverty diagnosis. For the construction of Energy Poverty degrees and its cluster analysis, Cisneros Vidales' data and sample were selected for being the most updated and complete in the information that is required for the application of Garcia-Ochoa's method. It also contains local perception of energy expenditures and their quantification in its interviews. In the construction of the community's energy scene description and analysis, available qualitative and quantitative information of all databases are considered. COESPO's data is used to give a general view of home appliances and energy services deprivation scenario on the delegation, and it is also used to compare Cisneros Vidales' (2018) sample with the reality estimated for the population.

3.2. Mexican Policy Analysis

The policy comprehension is made through an *ex-ante* policy impact analysis (Großmann et al., 2016) focused on the specific social group of poor and energy poor. Its objective is to comprehend the current policy and explore possibilities it may open to this research's main objective. For that, the qualitative method of an exploratory case study (Großmann et al., 2016; Yin, 2018) is selected. Its central limitation is the interference of the researcher's subjectivity and interpretation.

For time and circumstances constraints, a pure documental analysis was held. This case study design is presented Figure 11. All the steps, mainly steps 1, 2 and

3 were enhanced with active feedbacks of the thesis committee. As specific steps got feedbacked, subsequent stages were also updated and revised.

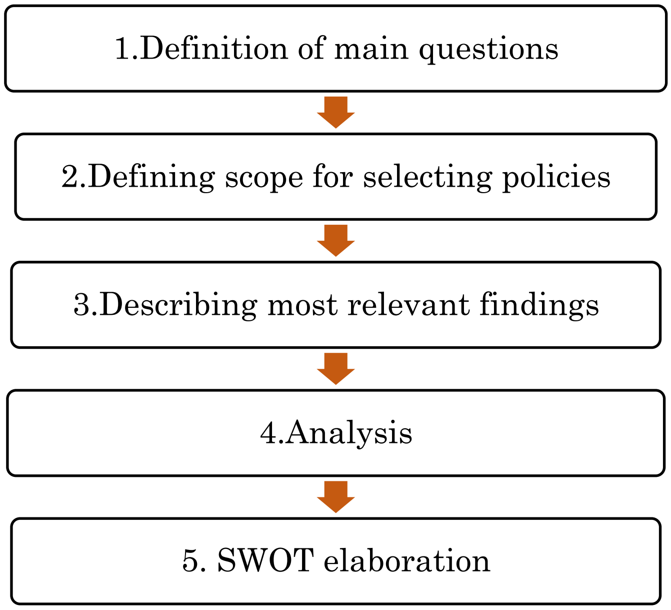


Figure 11. The method applied for policy analysis.

The questions conducting this policy analysis are:

- How is policy contemplating the use of DCPV in vulnerable/poor areas?
- Is it being effective to tackle energy-related issues of poverty/ energy poverty?
- Which possibilities does regulation provide?

As the previously analyzed literature already provides the information that Mexico does not count with a specific policy for EP (García Ochoa & Graizbord Ed, 2016), the national policy on energy and social housing are the main target of this analysis. Due to common interests, it also contemplates some aspects of the climate change and energy transition policies. The scope set for searching is the intersection of policies contemplating DCPV and poor or emarginated areas. Policies, funding and programs considered are described and further analyzed under three main perspectives, referring back to the three key themes of Chapter 1 that are the conceptual underpinning of this work.

To analyze the collected data, the three questions were guiding the reading and composing the text of the case study. The analysis also contemplated the technique of *pattern matching* (Yin, 2018), using the descripted policies of the session "Policies Supporting Energy Poverty Alleviation" to read and compare the data with the European and Latin-American approach. Definitions of poverty and energy poverty previously defined were also used as underpins to answer the questions. The tools applied for summarizing qualitative information and graphical analysis are the construction of tables and a summarizing matrix on its strengths, weaknesses, opportunities and threatens (SWOT analysis).

The results of the analysis are used as input to the construction of the scenarios for La Pila delegation.

3.3. Scenarios of DCPV for La Pila and Impact Assessment

The scenarios are developed according to the possibilities discovered in the policy and regulation analysis and to match this research's objectives.

For this last part, it was also predicted the use of participatory social methods with a sample of inhabitants to identify PV to check the technology and scenarios acceptance using as underpin community participation methods developed by Geilfus (2008). Because of COVID contingencies and time restrictions, the social participation regarding acceptance and co-creation does not compose this part and are limitations of the method.

The scenarios were built considering two different DSPV technical applications: grid-connected and grid-connected with a battery system that works as a backup system in case of interruptions on the grid supply. The option of considering the impact of a system with a battery was aggregated to the method after the identification of energy security issues that are crucial elements in the particular study case. For La Pila, the other main feature that differentiates the scenarios is the DPCV's ownership and stakeholders that could be benefited from the generator. Corresponding to pre-settled interests of this research and the project which this work is part of, three ownership approaches are contemplated: the household ownership due to the potential direct impact on energy poverty; application in public schools with local government's ownership, in a system where inhabitants can also be beneficiaries to attend a specific interest in knowing the co-benefits of scaling up the PV system to other schools; or an option of considering DCPV with community ownership, where families are the beneficiaries and owners of the energy system. Crossing these factors, six scenarios are presented to the case study.

The generated scenarios contain an impact assessment for each one. According to the consulted literature, there is no existence of a single method or tool that is capable of measuring all the impacts in terms of costs and co-benefits that DCPV application can bring (Denholm et al., 2014), especially when the research question has such a micro social level component such as this work does. Due to the complexity of evaluating all existing variables in the case study, the assessment is made with different methods for three main areas, focusing on local benefits in environmental, social and financial dimensions. Figure 12 summarizes the methods used for each one, which will be further described in the next paragraphs.

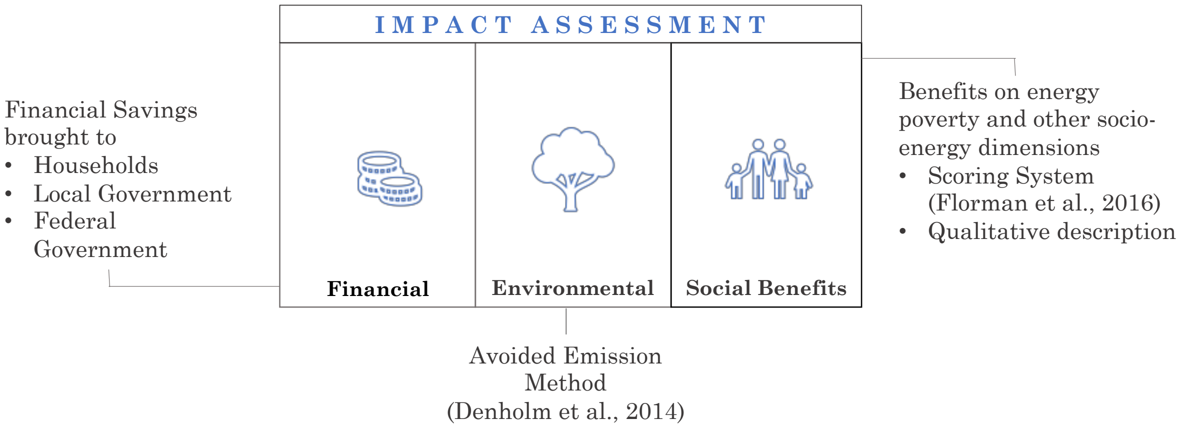


Figure 12. Methods contemplated for the impact assessment.

3.3.1. Social Impact Assessment

The method chosen for visualizing and analyzing the social impacts of each scenario is a scoring system (Florman et al., 2016), applied through a matrix composed of the proposed scenarios and factors from the social-energy diagnosed situation. Since the scope of this work is to understand the impacts in the energy poverty system of the case study, such factors are selected from the main contributions found and described in the discussion section of the energy poverty and energy expenditures assessment results.

The matrix is built with tools of the Microsoft Excel software. The scoring system is a scale from one to three, where 1 is considered a low impact, 2 a medium and 3 a high impact. Attributions are made according to the researcher's perception, mainly considering the reach and limitations of the PV application who are the beneficiaries in each case. After the individual scoring, averages formulas area applied for each category and subcategory.

The scoring matrix is used to have a comparison basis between the scenarios since they summarize and offer an "easy to digest data on social impact" (Florman et al., 2016). Nevertheless, it is prudent to say the scoring system is prone to subjective bias in its process, which is influenced by the researcher's experience and comprehension of the reality (Florman et al., 2016). To overcome this limitation and characterize the assumed impacts that are behind the numbers, a descriptive version of the matrix is done and brought to discussion, that interprets the type of expected impact on each identified critical factor. Even with this second matrix, the chosen methods still have the limitation of being a human analysis influenced by the researcher's perception.

3.3.2. Environmental Impact Assessment

To calculate the environmental impact, it is necessary to know the marginal environmental benefits of DCPV generation and then apply it to each scenario. The chosen method to illustrate that is the avoided emission method (Denholm et al., 2014), which describes the emissions avoided per kWh generated by a DCPV having as reference another power plant. The method suggests a second step that aims to monetize the avoided emissions in order to indicate the avoided costs (Denholm et al., 2014). Given that the focus of this assessment is quantifying the environmental benefits associated with PV generation and it has other approaches to compare costs, only the first calculation is made.

In the case study, it is possible to identify which regional power plant is its main electricity supplier with a consult on the diagrams of the national electric systems (CENACE, 2018), so data concerning its specific emissions is considered. The geographical localization is chosen as criterion to determine the supplier plant recognizing the restriction that, as a single national grid, it is tough to predict the exact origin of the electricity that is being used at that moment. In Mexico, emission information is public and available in a report entitled Costs and Reference Parameters for the Formulation of Investment Projects in the Electricity Sector (Comisión Federal de Electricidad, 2015), which had its last online available version published in 2015 with data from 2014. Data availability allows the calculation of avoided CO_2, CH_4, N_2O, CO, NMVOC (non-methane volatile organic compounds), NO_x, So_2 and particles. Given that La Pila is in a semi-arid area with water as a scarce natural resource, avoided water consumption is also considered.

The information is available in kg/MWh, and a conversion is made to kg/kWh due to the small-scale production of the considered DCPV scenarios. To water, the available information is provided in m^3.

After the conversion, the encountered values are applied to the DCPV scenarios. Data regarding the average consumption of La Pilas' households and public schools was requested from the CFE, but with no return until the finalization of this work. Relying on the available secondary data, for households, it is considered the average consumption of 92kWh per month found by Cisneros Vidales (2018) in her sample. For public schools, it is considered the average consumption of 225kWh/month correspondent to Francisco González Bocanegra school in the period of December 2017 to December 2018. This period is the range available in CFE's customer application, which was consulted in May 2020. After the PV system started operating in December 2018 the school has reduced its consumption to zero and, therefore, no register of its consumption is available.

Finally, the method is summarized in Figure 13. For having a focus on the marginal environmental impacts of DCPV, the avoided emission method may not consider implications related to the technology lifecycle. This element will be brought to the discussion with values for the Mexican reality, also available in the report Costs and Reference Parameters for the Formulation of Investment Projects in the Electricity Sector (Comisión Federal de Electricidad, 2015).

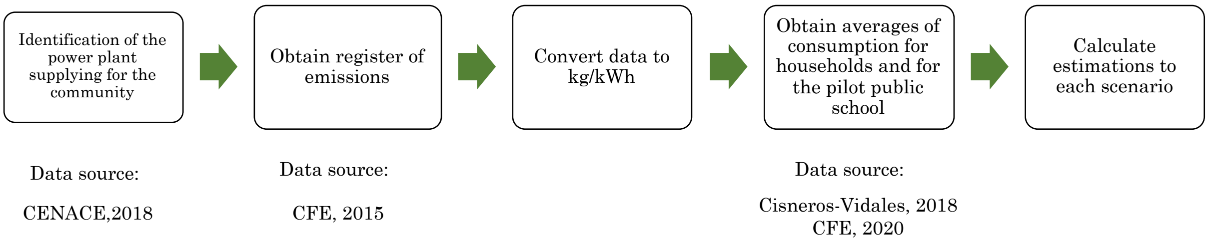


Figure 13. Stages of the Environmental Impact Assessment

3.3.3. Financial Impact Assessment

Since this research is scoped to consider a low penetration and its impacts on a micro and meso social level, the method for its quantification contemplates the financial impacts calculating the potential savings associated with an expected reduction on energy bills. It categorizes savings brought to the household, the local and federal government. The necessary specific data could not be obtained from CFE, therefore, the same assumptions made for the environmental impact assessment are here established. Table 12 shows the considered information for the financial impact assessment. All the data regarding energy tariffs were withdrawn from the CFE official website for April 2020.

Table 12. Description of the variables used in the financial impact assessment

Definition	Variable
Energy consumption within Residential Basic Tariff	Eca
Energy consumption within Residential Intermediate Tariff	Ecb
Total Energy Consumption of the pilot school	Ecps
Taxes	Tx
Energy tariff applicable to residential basic consumption	Eta
Energy tariff applicable to residential intermediate consumption	Etb
Energy tariff in its non-subsidised price	Etns
Energy tariff applicable to public schools	Etps
Fixed fee for PDBT tariff	Ff

The potential savings estimation for each stakeholder are done applying the following formulas, using as tool Microsoft Excel spreadsheet:

- Potential savings for the federal government per beneficiary household (PS1)

$$PS1 = [(Etns - Eta) * Eca + (Etns - Etb) * Ecb]$$

- Potential savings for the household(PS2)

$$PS2 = (Eta * Eca + Etb * Ecb) * Tx$$

- Potential savings for the local government (scenario contemplating PV application on public schools -PS3)

$$PS3 = (Etps * Ecps) * Tx$$

For scenarios predicting an application under the net billing scheme, Mexican regulations consider the following method for payment (RES/142/2017, 2017)

$$CFn = \sum_{h=0}^{n} (EEGh * PMLh)$$

Where:

- CFn – Consideration for the electric energy in a given n period
- EEGH – Electricity delivered at the given h time, to the distribution grid in the billing period n
- PMLh – Local marginal price at the given h time, in the node corresponding to the interconnection point of the central power plant, in the billing period n

Once this study does not scope the dimensioning of the DCPV and its generation capacity, there is not enough data for quantifying the net billing scheme profits. To overcome this, it is assumed that under this scheme households receive a minimal amount capable of paying their energy bill. Potential savings will, therefore, be considered the same as for a family under the net metering scheme.

Other potential financial impacts that cannot be quantitative estimated will be described and discussed.

Concluding this description, it is relevant clarifying the focus of this method does not include an assessment on economic benefits relative to gain or losses relative to the electric system infrastructure when adding DCPV systems to the grid. It is proven and known that the federal government receives economic benefits from avoided losses and costs on transmission, distribution (Denholm et al., 2014; Manfren et al., 2011; Saviuc et al., 2019), especially with a higher PV penetration. There is a range of methods that contemplate the use of models and software to simulate different applications and its such techno-economic impacts (Manfren et al., 2011) that would be relevant and recommended when predicting the scenarios scaling-up.

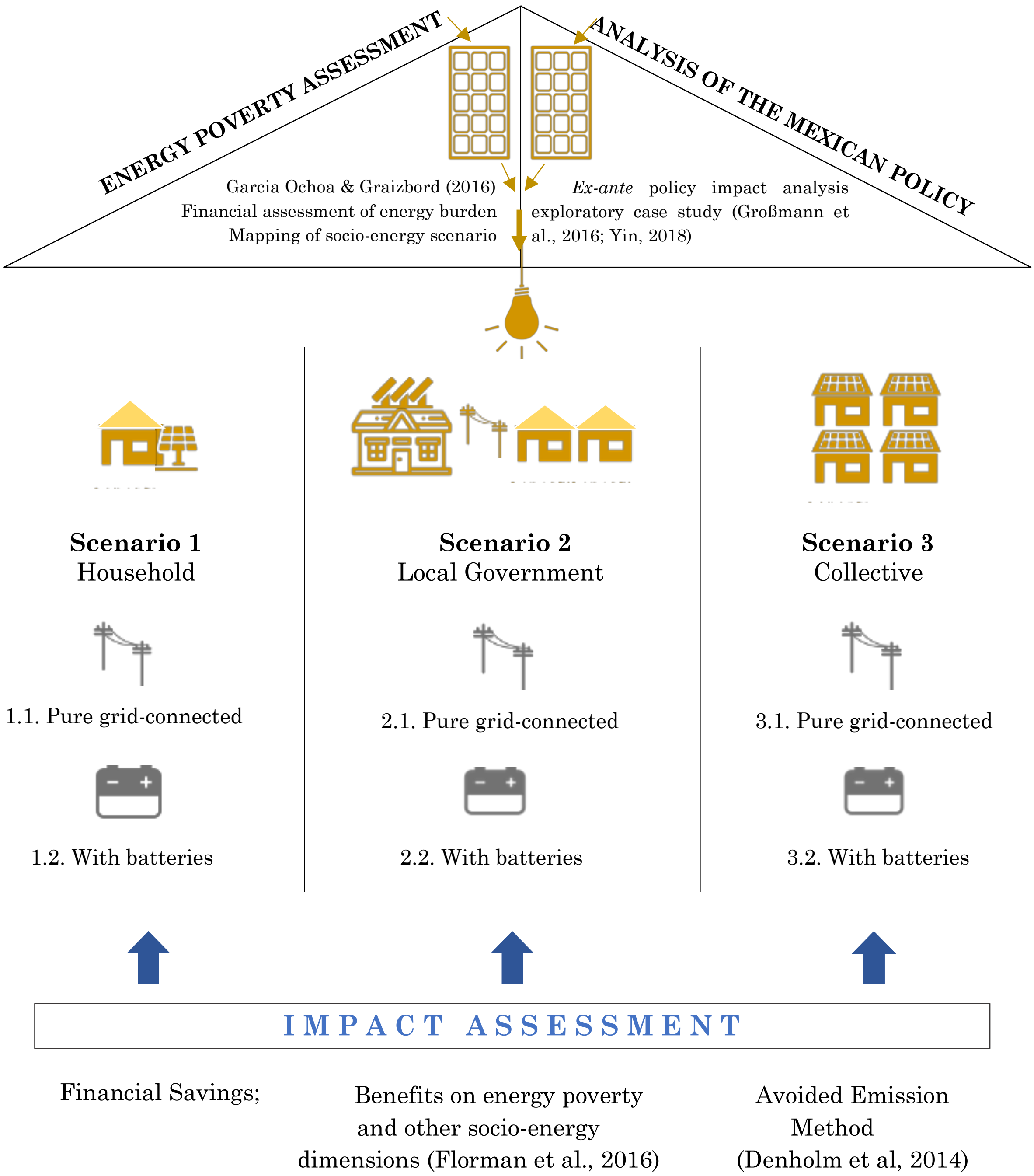


Figure 14. Representation of the Methodological Scheme

Chapter 4. Case Study: La Pila Delegation

4.1. General information and social indicators

La Pila is a delegation situated in the southeast borders of the municipality of San Luis Potosi, Mexico, close to its growing industrial zone and connected to the city through it (Figure 15) . It is considered an urban area by the National Institute of Geography and Statistics (INEGI) but peri-urban[3] for the project, due to its still transitional landscape and lack of access to basic infrastructure that will be further described.

The rapid growth that the city of San Luis Potosi has been facing during the last years has not been followed by a sustainable planned development (Martinez et al., 2010). The population living in the metropolitan area of the city, especially in rural and peri-urban areas, is affected by environmental and social problems that are resulting from the growth process. Unlike peri-urban communities that are characterized for being suppliers and producers for the city (Mycoo et al., 2006), La Pila is an area that is the result of San Luis Potosi's urban growth and marginality scenario and highly dependable on the city for its basic supply (Cisneros Vidales, 2018).

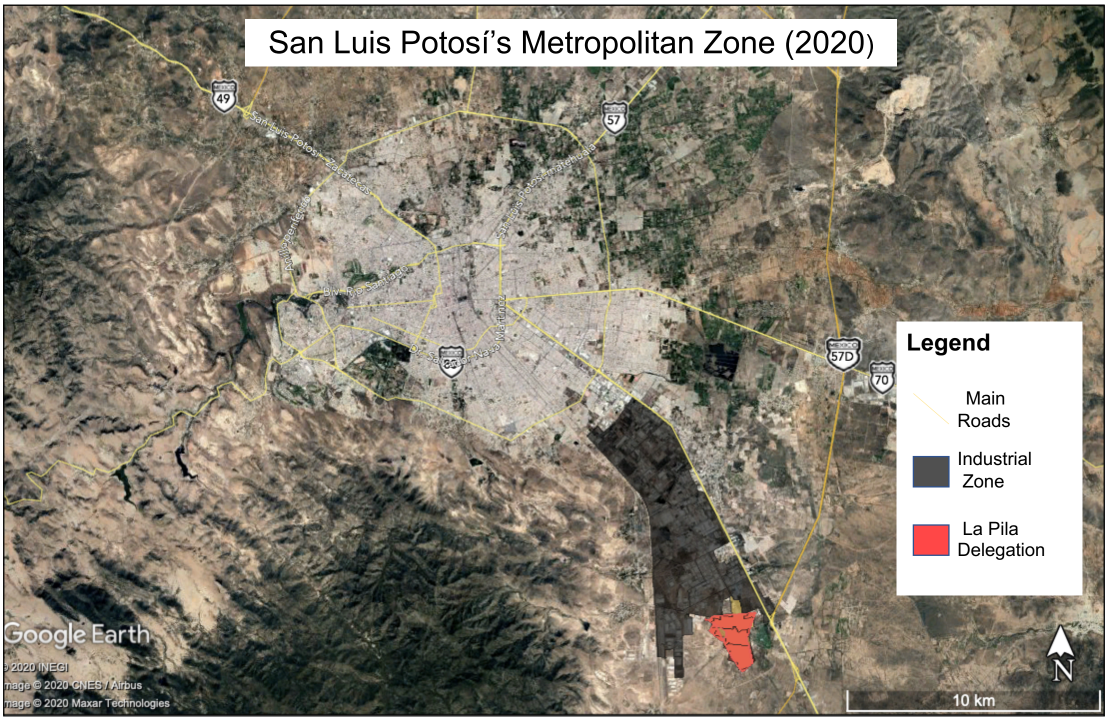


Figure 15. La Pila's location in SLP city.

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[3] According to Phillips et al (1999, p. 5), "the peri-urban interface is characterized by strong urban influences, easy access to markets, services, and other inputs, ready supplies of labor, but relative shortages of land and risks from pollution and urban growth." It is an encounter of rural and urban landscapes.

Its geographical features (22°02'02.4"N 100°52'04.2"W) are characterized by its location in a highland area a few kilometers away from the Tropic of Cancer, with a semi-arid climate and annual precipitation of 340 mm (Rzedowski, 2006). The surrounding vegetation of the community is composed of species such as Yucca sp. and other subshrubs plants. This region of San Luis Potosi state is considered a transitional zone to the aridest and most desertic areas of Mexico (Rzedowski, 2006).

Due to its localization and climatic conditions, it is one of the regions in Central and North America with higher solar irradiation (Figure 16). It presents a direct normal radiation of 2294 kWh/m²/year (SolarGis & World Bank Group, 2019), meaning approximately 6,3 sun peak hours per day[4]. The period that La Pila receives its highest irradiation is from December to May, as shown in Figure 17.

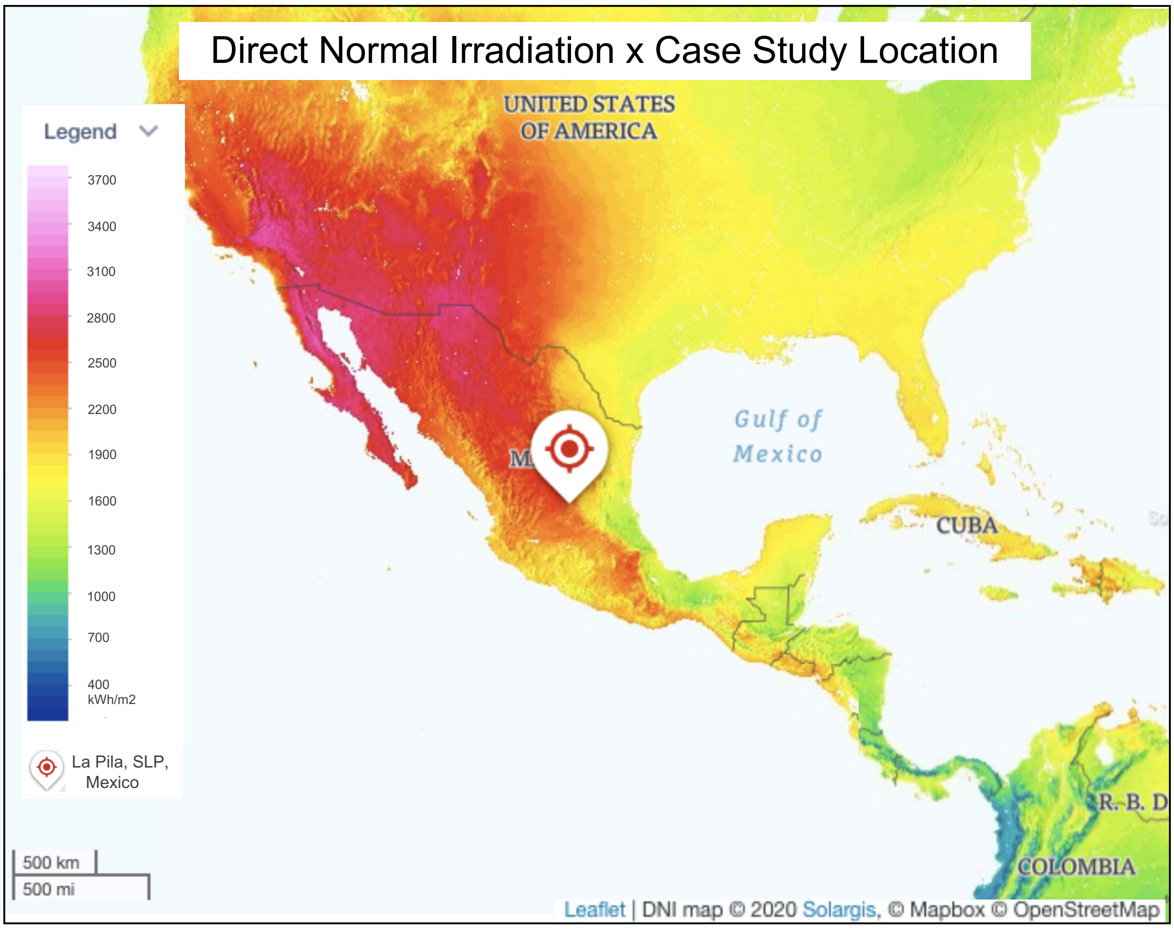

Figure 16. Regional Map for Direct Normal Irradiation. Based on SolarGis, 2020.

[4] The term "peak sun hours" corresponds to the solar insolation which a location would receive considering that the sun is in its peak radiation of 1kW/m2, contemplating its maximal shining. The unit is given in hours per day.

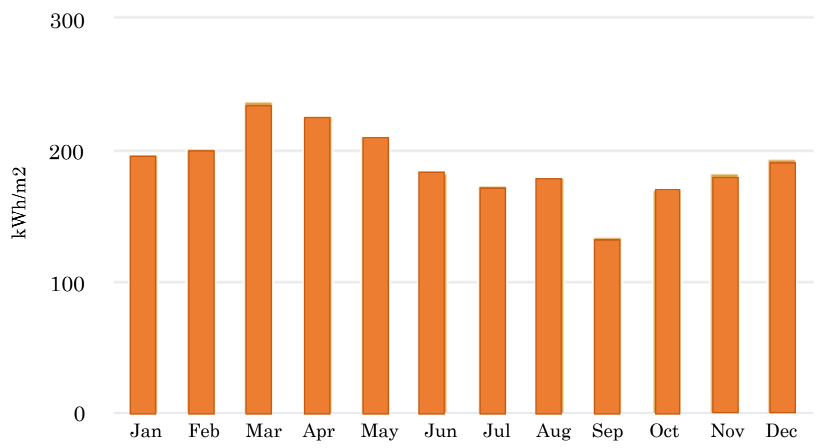

Figure 17. La Pila's monthly solar radiation (SolarGis & World Bank Group, 2019).

The area is politically considered a delegation of San Luis Potosi, meaning it has an auxiliary government body with responsibilities of maintaining the order and security, the public service supply and law appliance. It is composed of nine communities and has a total area of approximately 90km² (Ayuntamiento de San Luis Potosi 2015-2018, 2015).

According to projections of the State Council of Population (Consejo Estadual de Población – COESPO, 2020) it has a total of 6,985 inhabitants living in 1410 occupied houses, with an average of 5 inhabitants per house (COESPO, 2020).

In a visit to the delegation, it is possible to see unpaved roads, a poor-quality infrastructure of light poles and intense activity of informal workers selling food on the street. Quantitative available information shows that 116 households (8%) lack basic infrastructure drainage, 89 (6%) water supply and 150 of houses are composed of ground floor (COESPO, 2020). Problems with public lighting and interrupted basic services were also reported, especially in homes that are in the newest and away areas of the communities' commercial center (Cisneros Vidales, 2018). Earlier research shows that 25% of households had uninterrupted access to water. Its inhabitants perceive that environmental quality is affected by air pollution from the industrial zone (Cisneros Vidales, 2018).

Conversations with other researchers who have worked on the zone and San Luis Potosi inhabitants shows that the delegation's inhabitants suffer social stigmatization. Apart from being located in a peri-urban area in the margins of the city, the delegation is commonly associated with a state prison's presence, which has the capacity of 1875 persons, both man and woman (Montejano Villaseñor, 2016). Local news shows frequent conflicts and violent acts inside of it (Montejano Villaseñor, 2016).

The National Council for Evaluation of the Social Development Policy (Consejo Nacional de Evaluación de la Política de Desarrollo Social – CONEVAL) considers la Pila a high emarginated and vulnerable area. Multidimensional poverty affects 24% of its population (COESPO, 2020) and it is geographically presented in three different degrees in the community (CONEVAL, 2018). The partner school of the project, which is one of the 23 schools of La Pila delegation (Buendía Oliva, 2019), is located in a high multidimensional poverty zone and is also marked in the map. In 2010, about 5% of kids between 6-14 years old did not assist school (INEGI, 2010)

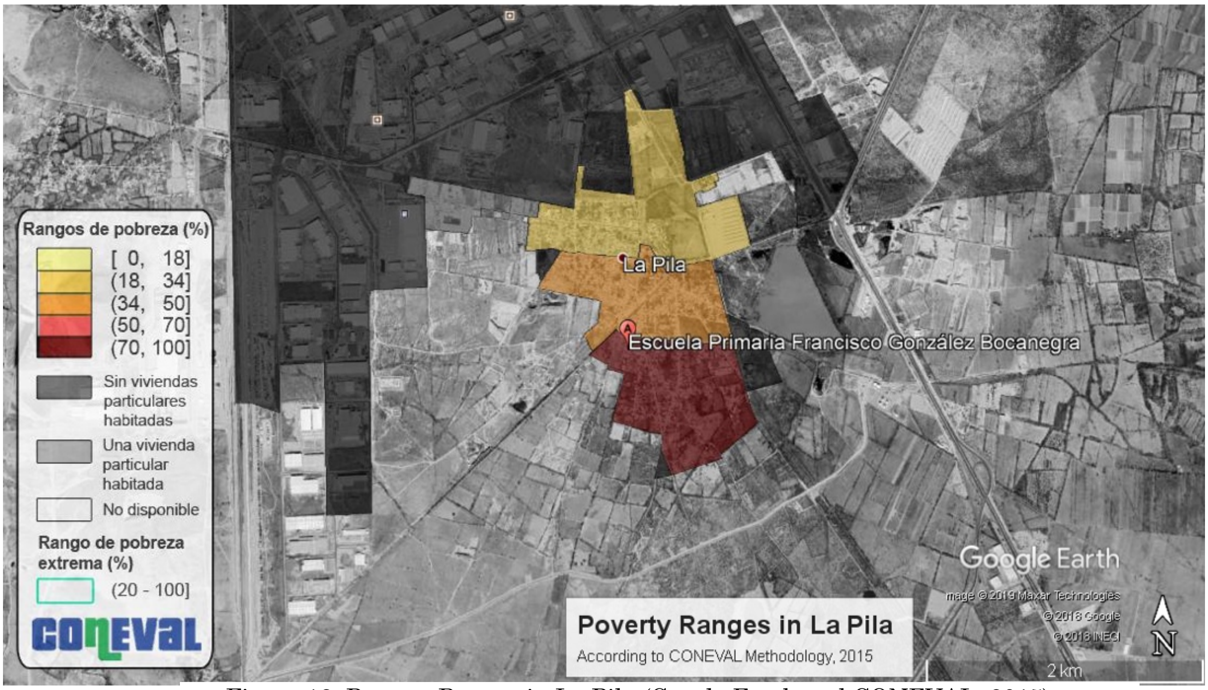

Figure 18. Poverty Ranges in La Pila (Google Earth and CONEVAL, 2015).

Poverty incidence occurs through different sets of dimensions (Table 13). COESPO (2020) predicts that only 35% of the population is entirely absent of any poverty and vulnerability degree (COESPO, 2020). The main deprivations that affect La Pila are, in the first place, social security, followed by lack of health services access, food access and access to basic services inside the home (which includes energy access). Fifty-five percent of people have at least one aspect of social deprivation considered by CONEVAL, meaning 3842 persons live under such circumstances.

Table 13. Deprivations and income poverty in La Pila (COESPO, 2020)

Indicator	%
Deprived of social security access	41,17%
Deprived of health services access	14,12%
Deprived of food access	13,29%
Deprived of access to basic services inside home	6,38%
Deprived of quality and housing installations	5,15%
Population with at least one social deprivation	54,27%
Population with three or more social deprivations	8,23%
Population with income below wellfare line	34,75%
Population with income below minimum wellfare line	8,77%

Income poverty affects 34,75% of the population (approximately 2440 inhabitants), which lives below the threshold of social welfare of MXN 3208 per month (CONEVAL, 2020, COESPO, 2020).

The margination and poverty situation is also noted in the delegation's schools (pre-school, elementary, middle and high schools). Its aspects include lack of basic infrastructure and also deeper structural characteristics of the communities, such as the cultural level, low academic performance the bad use of natural resources, low nutritional level (Becerra-Hernández, 2017). As mentioned in this thesis' introduction, this research is part of the project "Sustainable model for the governance of vulnerable communities". This initiative has as objective raising welfare levels of members of the scholar community of the elementary school Francisco González Bocanegra in three main spheres: education, environmental protection and social justice. In 2019, the school received 270 kids between 6 and 12 years old and it was selected as the pilot for representing a space of living that, on a small scale, works similarly to La Pila society (Buendía Oliva, 2019).

The purpose of this initiative is that communities' own members are capable of deciding their destiny and self-manage their resources (Buendía Oliva, 2019). Field research results that are part of the projects match with statistical data provided in the last paragraphs, also stretching cultural factors like corruption and interruption on basic services supply (water and electricity) in cases where households are grid-connected (Cisneros Vidales, 2018). With observation and interviews with authorities and professors, it was found by Buendía Oliva (2019) that four problems reported both in the community were affecting with the educational infrastructure aswell. Insufficiency of potable water service, neglected recreational areas, unhealthy and precarity sanitary services and high costs for electricity service are cited by the study. In this sense, five ecotechnologies were applied in the school within a participatory approach that started in 2016 and ended in 2019: rainwater collection, a photovoltaic system (Figure 19), a greenhouse, a school orchard and wastewater treatment (Buendía Oliva, 2019).

Apart from Francisco González Bocanegra school, there are 22 more schools in La Pila delegation that possibly goes through the same problems encountered. The structural and infrastructural difficulties that schools face constitute an obstacle of proper education and opportunities to children of the delegation (Buendía Oliva, 2019).

Figure 19. Ecotechnologies on the Pilot School. Project Database.

4.2. Energy in La Pila

Energy consumption in La Pila comes from four main sources: gas, wood, fuels and electricity. Liquified petroleum gas (LPG) in the main source for cooking and water heating, meanwhile electricity is used to provide energy to equipment like chargers, televisions and microwaves (Cisneros Vidales, 2018). Transportation in

La Pila occurs based on fossil-fuels based private and public vehicles that depend on technology that is based in this type of source. Due to the focus of this work of analyzing the benefits that electricity generated by PV technology can bring to the community, an emphasis will be given in this type of energy and the evaluation of energy used to transportation is not explored. It is essential to mention that in the cultural scenario of la Pila, stoves and water heating remain on technology that uses liquified petroleum gas or wood, being electricity not relevant for those specific energy services.

The electric energy that feeds the grid in La Pila comes mainly from a conventional thermoelectric centralized power plant located in a neighbor municipality, the *Villa de Reyes* Thermoelectric (CENACE, 2018) (Figure 20). This plant has as main source natural gas and fuel oil derivated from petrol extraction processes and has two unities with a total installed capacity of 700 MW (Jimenez-Garcia et al., 2018). Because of the process of energy generation, a significant amount of water is required for its operation. Electricity comes straight from the thermoelectric until it reaches a substation in La Pila, where it feeds the Industrial Zone, the delegation of La Pila and part of the south of San Luis Potosi city (CENACE, 2018).

Figure 20. Villa de Reyes Thermoelectric. (González, 2019)

Even though no official data from the responsible organization was obtained on interruptions of the electricity service and its frequency, 20% of interviewed people reported frequent interruptions in the energy supply (Cisneros Vidales, 2018). Further data shows that the community is affected by a seasonal energy insecurity that affects Energy Poverty inside households: in the months of higher temperatures (April, May and June), 25% of the inhabitants do not have access to electricity (Cisneros Vidales, 2018), probably due to brownouts originated by a higher demand coming from the industrial zone.

According to the statistical projections of COESPO, La Pila has 96% of its houses connected to the electricity grid (51 households do not count on the service).

Electric energy is an economic good and service provided by a federal institution, the Federal Commission of Electricity (CFE), which has rights of distribution for the community and charges bimestrial bills according to the number of kWh consumed. In 2017, a reform in the electricity tariff system to residential consumers was applied in Mexico subdividing the national territory into eight different categories of tariffs, that changes according to the climate zone. Extreme hot regions get an extra subsidy in summer season to make energy more affordable to, within other reasons, deliver the energy service for thermal comfort. La Pila is considered by CFE a temperate climate zone; thus, this special subsidy is not applied.

Households in La Pila have access to a subsidy for residential tariffs nationally applied by the Mexican government, in a scheme that depends on the amount of consumption of the household. La Pila belongs to the region that has the lowest range of consumption for subsidy appliances and the most expensive tariffs. For the first 75kWh/month, the price applied is 0,837 Mexican pesos. If the household exceeds this consumption, the next 65kWh/month will be charged using as reference the price of 1,012 Mexican Pesos. Following the same logic, the next 108kWh/month will be charged upon MXN 2,96. For the consumption of more than 250kWh/month, the subsidy is not applied. Table 14 shows how the scheme works for La Pila (Tariff type 1) using prices for April 2020.

Table 14. Residential Electricity Tariffs applied in La Pila in April 2020. Source:(CFE, 2020)

Type	Price (MXN/kWh/month)	Range (kWh/month)
Basic Consumption	0,837	0-75
Intermediate Consumption	1,012	75-141
Exceeding Consumption	2,96	142 -250
Non-subsidized (DAC Tariff)	4,37*	250 +

*Plus a Fixed Fee of 108,05

Public schools are categorized, according to their consumption, as small business (PDBT tariff) or big business (GDBT). Assuming that public schools in La Pila have a similar consumption as the pilot school Francisco González Bocanegra, the PDBT tariff is applied. In this case, there is a fixed maximum monthly power capacity of 25kW. The tariff has a fixed fee, regardless of the consumption, and the tariff comprehending the monthly consumption. In April 2020, the cost was MXN 3,6/ kWh/month (Table 15).

Table 15. PDBT tariffs applied in April. Based on CFE, 2020

Type	Cost (MXN/month)	Price (kWh/month)
Fixed Fee	47,69	-
Consumption Fee	-	3,6

Since the adoption of this new scheme, CFE has managed to keep La Pila's tariffs below the inflation adjustment until 2020, as shown in Figure 21. According to the CFE, the price has increased 5 cents in the last 3 years for the basic consumption range, from MXN 0,79 to MXN 0,837[5]/kWh per month. In fact, Mexican residential tariffs were the second cheapest in the Latin American region at the end of 2018 (OSINERGMIN, 2019). Nevertheless, it is relevant to mention that the current government has an explicit plan to prioritize the oil industry over renewable energy, a fact that predicts a rise in electricity tariffs. The government announced that it will deal with population dissatisfaction through "dialog" (Plan Nacional de Desarrollo 2019-2024, 2019).

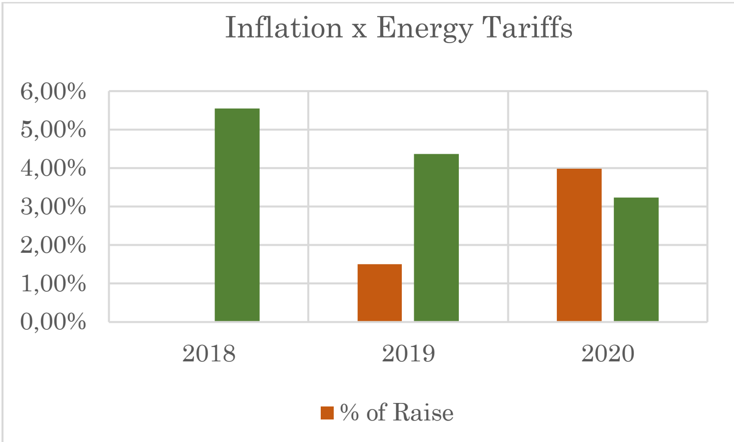

Figure 21. Comparison between inflation and energy tariffs (2017-2020). Based on CFE, 2020 and Banco de México, 2020

Even with national efforts on making electric tariffs affordable, the perception of the local population on energy tariffs shows that 47% of interviewed inhabitants consider electricity expensive (Cisneros Vidales, 2018). COESPO (2020) estimates that monthly MXN 509 are spent on electricity and fuels, corresponding to 5% of total expenditures. The average electricity consumption found in Cisneros Vidales (2018) sample is 92kWh/month. Before the installation of PV panels, the pilot public school paid the average of MXN 900/month.

In La Pila, poor, energy poor and vulnerable inhabitants do not count on extra policy protection because of its social conditions or against disconnections due to the lack of payment. CFE contracts are clear in their disconnection clauses, that implies sending a 3-days advance warning of disconnection and only reestablishing the supply when the bill is paid (Comisión Federal de Electricidad, 2013). With an overview of the National Law of Consumer Protection, it is possible to note that no distinction is made between ordinary consumers and vulnerable

[5] Equivalent to 0,033 Euros, considering the currency of 1Mexican Peso = 0,039 Euro, provided by Morningstar in 14.04.2020.

and poor consumers (Ley Federal de Protección al Consumidor, 2012). There is also an absence of special procedures regarding a profile and vulnerability analysis of the user before the electricity disconnection happens, or to ensure a minimum supply to keep essential energy services in case of disconnections. The only special observation regarding energy is that the provider should reestablish the supply immediately in case the user enters with a conciliatory procedure (Ley Federal de Protección al Consumidor, 2012). Moreover, there is an inexistence of a culture, funding or law for debt forgiveness in the CFE.

Public schools are also not protected from energy disconnections. Nationally, it is possible to find cases of public educational institutions that have been disconnected from four months to six years (Comunicación del Senado de la República, 2020). Such cases have complex and bureaucratic resolutions. In February (2020), an urgent exceptional measure approved by the Mexican Senate requested that National Education Secretariat (Secretaría de Educación Pública) uses its budget to get into a negotiation with CFE in order to reestablish electricity in such public institutions. Even though CFE didn't provide this research with official data for La Pila, it is known that its public schools also face difficulties in affording electricity (Buendía Oliva, 2019). Before the installation of PV in this project's pilot school, parents were asked to pay a monthly contribution of MXN 50 to cover the school's electricity bill and keep the school operating.

As for the households, the estimated 4% that remain with no access to the electricity grid practice its resilience to provide them with basic energy services and not stay in the dark. An interviewed household reported the monthly expenditure of MXN 300 in candles to ensure lighting, more than the average spent on electricity bills by the community, relying on wood for cooking (Cisneros Vidales, 2018).

The LPG, primary source used for cooking and heating water in the delegation, is locally provided by seven private companies and costs from MXN 17,77 to MXN 20,46[6] per kg (Comisión Reguladora de Energía, 2020). Cisneros Vidales (2018) found that 92% of the interviewed parents rely on gas for cooking, 5% on firewood and 3% on both (Figure 22). Even having a LPG stove, it was reported by a household that inhabitants sometimes switch to firewood to cook or heat water due to high expenditures with gas, which is considered an expensive good to 80% of people (Cisneros Vidales, 2018).

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[6] Accesed in July 6, 2020.

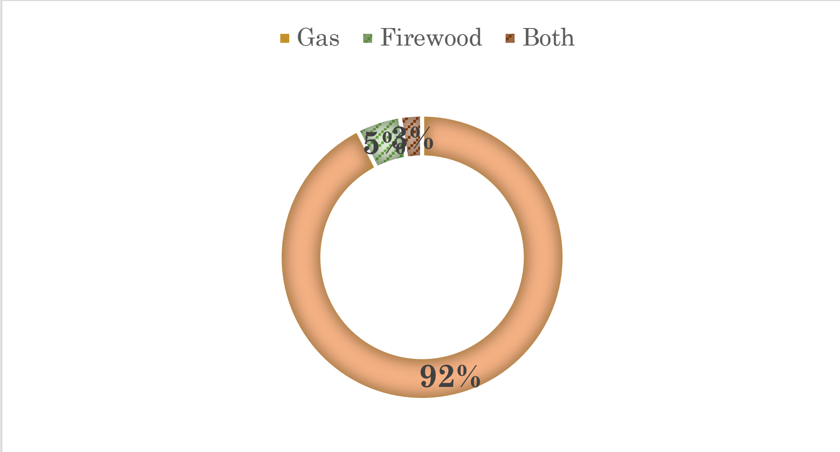

Figure 22. Energy sources for cooking in La Pila.(Cisneros Vidales, 2018)

Zooming in inside the household's walls, available information for La Pila population shows a preliminary situation of its energy services deprivations. In 2010, 601 families (38%) were deprived of refrigerators in La Pila population, while 19% (304) households declared not having a television or computer (INEGI, 2010). With this, it is inferred that at least 38% of the population had a level of energy poverty. According to COESPO's estimations for 2020, the situation of home appliances related to energy services has improved in these ten years (Figure 23): 371 households do not have refrigerators (26%), 9% have a computer inside the home and only 5% have internet service. Currently, at least 26% of the population would have a level of energy poverty. Estimations show that entertainment is seen as a priority energy service over food: 95% of the households have television, and 65% own a cellphone (COESPO, 2020).

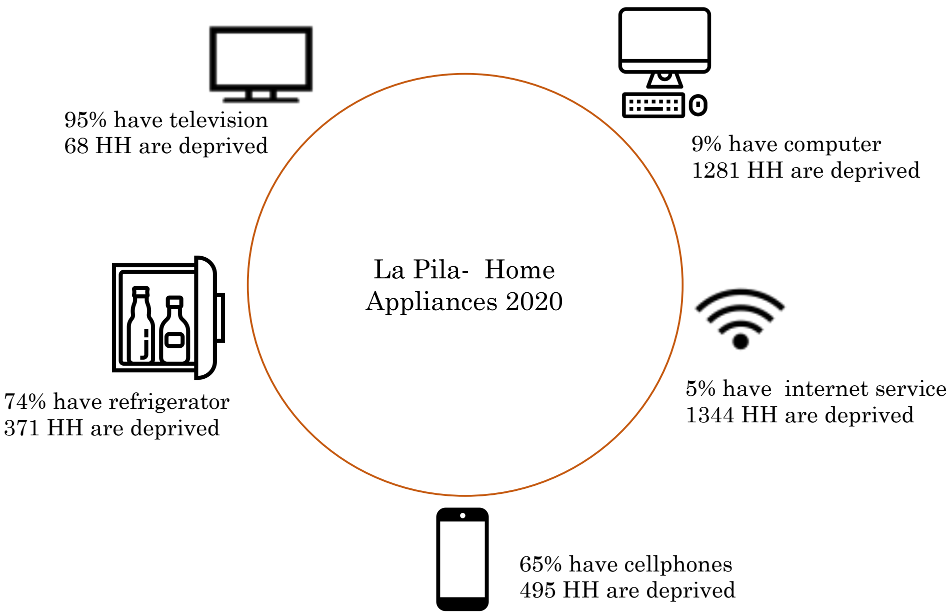

Figure 23. Home Appliances in La Pila. (COESPO, 2020)

Chapter 5. Data for Energy Poverty and Burdens

5.1. Energy poverty

The answers contained in Cisneros Vidales' data were evaluated and classified according to categories and formulas defined in Table 8. Final data is composed of binary numbers, where 1 indicates the presence of the related home appliance and 0 its absence. The final table is available on the Appendix A.

Nineteen total incidences of energy services deprivations were encountered in the sample. When describing the frequency of the energy service deprivation among the sample, food refrigeration leads the ranking, followed by entertainment, lighting and food cooking in the same position and, the last, water heating (Table 16). Refrigerators and television/computer are the most common missing home appliances.

Table 16. Energy deprivations found in the sample.

Energy Service	Deprived Households
Water Heating	2
Food Cooking	3
Lighting	3
Entertainment	5
Food Refrigeration	6

5.2. Energy expenditures

Of the 40 households considered interviews, twenty-five gave information on energy expenditures and their income. Figure 24 shows a boxplot with the initial data on expenditures, where information is represented on a monthly basis. Electricity bills start at MXN 40 and have a maximum value of MXN 1900. The median in the sample is MXN 100, while the average, that is influenced by an outlier value that represents more the double than the previous maximum amount found, is MXN 229,68. Most of the data is between MXN 90 and MXN 200.

Liquified petroleum gas (LPG) energy bills start at MXN 83,30 per month and have a lower variation than electricity expenditures, having the maximum value of MXN 1050. Values are concentrated in the range of MXN 100 to MXN 400. As household number 10 is considered an outlier in both cases, it was discarded for the analysis.

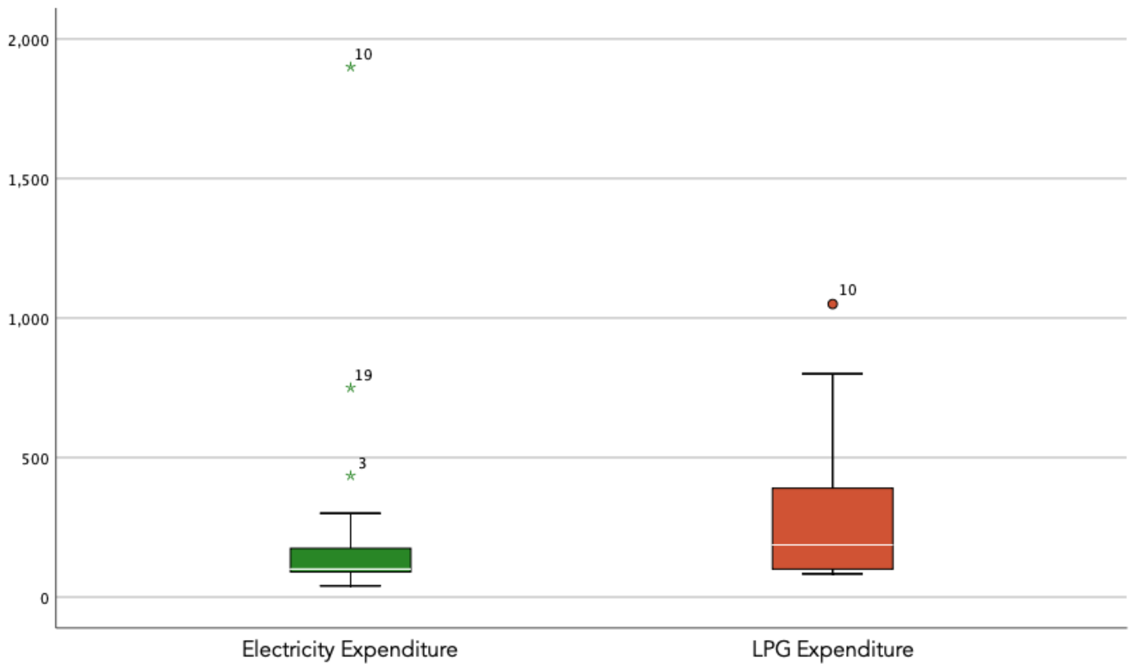

Figure 24. Boxplot - Energy and LPG expenditures. Cisneros Vidales(2018)

With the final sample of 24 households, new central tendencies are available in Table 17. The average value for electricity expenditures is MXN 160, while the new maximum value is MXN 750. The LPG burden is higher than electricity, with an average of MXN 272,88 and a median of 185. Total energy burdens are, in average, MXN 432,97.

Table 17.Central tendencies values for the expenditure data.

	Electricity	LP Gas	Total in Energy
Average	160,08	272,88	432,97
Standart Deviation	151,69	216,76	276,63
Minimun	40,00	83,33	173,33
Maximum	750,00	800,00	1100,00
Median	100,00	185,00	320,00

The frequency visualization available in Figure 25 shows that 19 households (about 80% of the sample) spend between MXN 40 and MXN 200/month with electricity. The five other observations are distributed as four families between 200 and 500, and one representation of MXN 750.

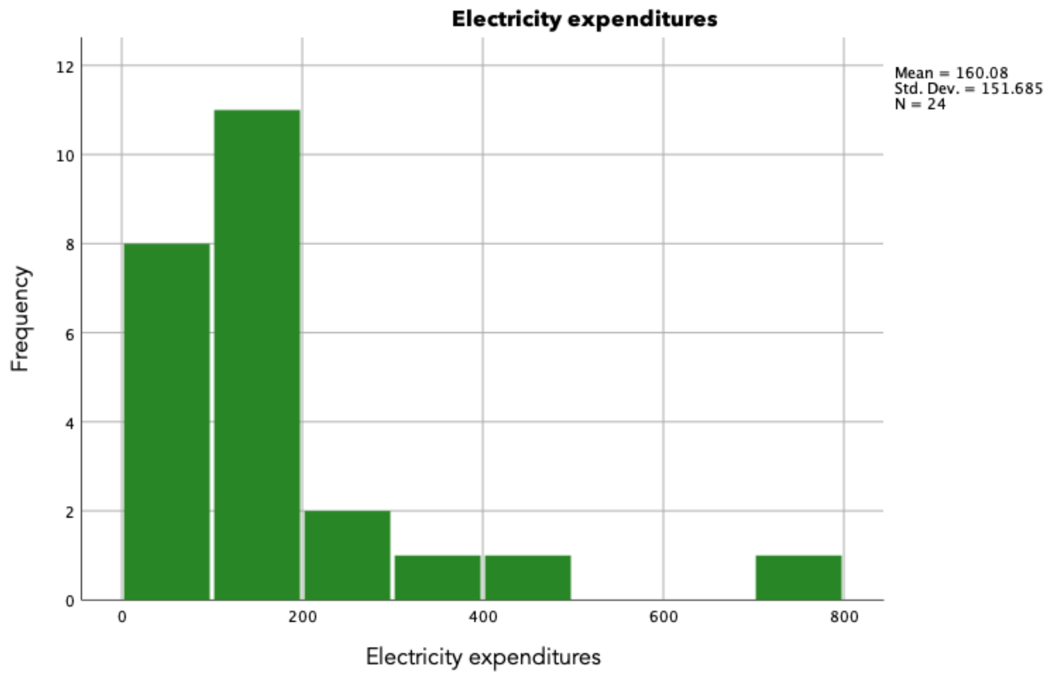

Figure 25. Histogram – Electricity expenditures

LPG expenditures present a higher variation than the electricity burden in the analyzed sample. It is seen in Figure 26 that 12 observations (50% of the sample) are between MXN 100 and MXN 200, having other ranges represented by one to three households. The maximum value of MXN 800/month has two observations.

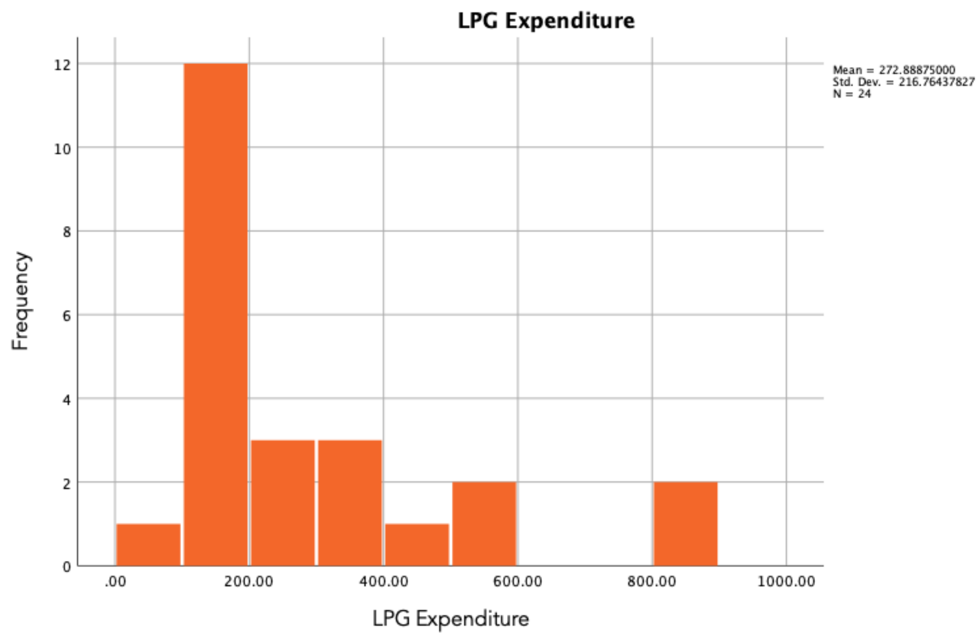

Figure 26. Histogram – LPG expenditures.

The total energy expenditure histogram (Figure 27) presents that the most common range in the sample is within the range of MXN 200 to MXN 400/month. The maximum value found is MXN 1100.

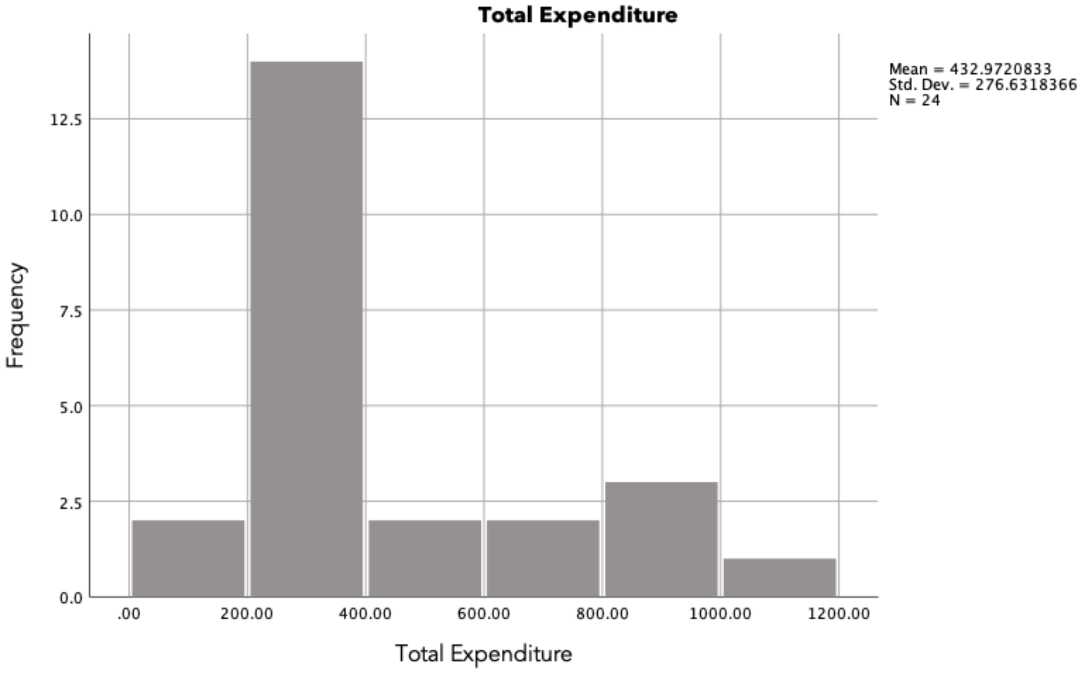

Figure 27. Histogram – Total Monthly Expenditure

When it comes to households' monthly income, the average found is MXN 5963,17. The minimum value is MXN 2010, and the maximum represents an income of 10332 Mexican pesos per month. The central tendency indicators are described in Table 18.

By analyzing the histogram (Figure 28. Histogram – Monthly Income), highlights can be given to some facts: only three households (12,5%) earn more between MXN 8000 and MXN 10332 per month, 25% of the sample is in the range of 5500-6000 Mexican pesos being the higher frequency found in the data. The second most frequent observation is an income between MXN 7000 and 8000, which represents 20,83% of this study sample.

Table 18. Central tendencies values for the income data.

Indicator	Income
Average	5963,17
Standart Deviation	2099,99
Minimun	2010,00
Maximum	10332,00
Median	5622,50

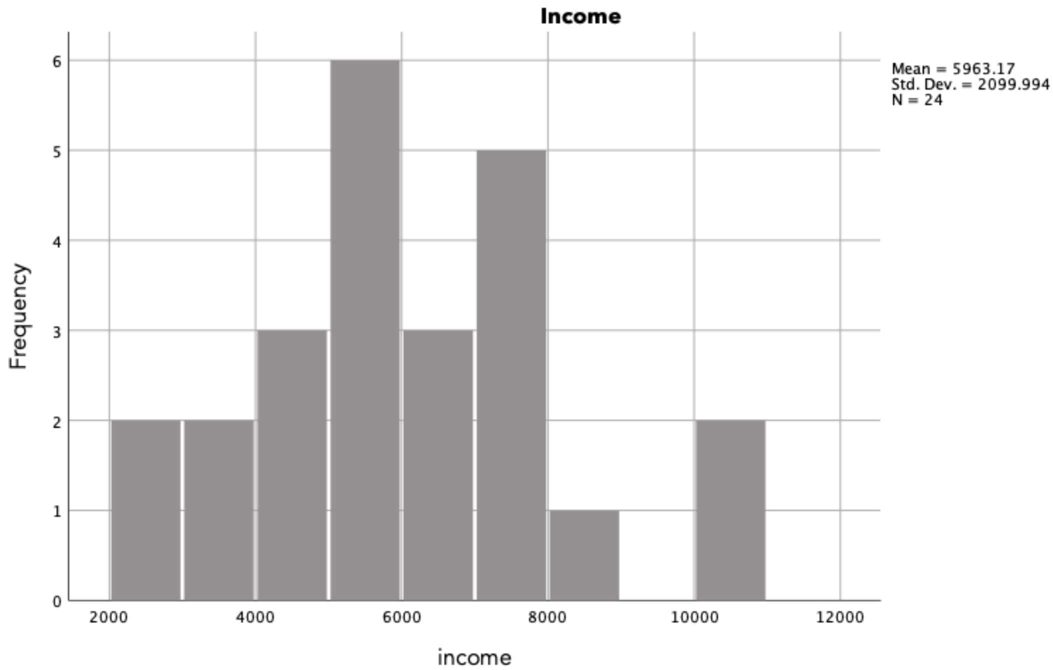

Figure 28. Histogram – Monthly Income

At last, Table 19 represents the central tendency values and the distribution of the energy burden between LPG and electricity expenditures according to the total income. The average found is 3,30% for electricity and 5,23% for LPG. Nevertheless, a considerable standard deviation was found, cases where families spend 1% and other where it corresponds to 22% of the family income. The LPG expenditures minimum value is 1%, while the maximum is 24%. Together, they represent an average burden of 8,51% of families total income. Still, within the sample a considerable variation was also found, having a case where such expenditures represent 46% of a family income. The median is of 6%.

Table 19. Central tendencies values for energy expenditures.

Indicator	% of Electricity Expenditures on income	% of LPG Expenditures on income	% of Total Energy Expenditures on income
Average	3,30%	5,23%	8,51%
Standart Deviation	0,4467	0,5047	0,8793
Minimun	1%	1%	3%
Maximum	22%	24%	46%
Median	2%	4%	6%

Chapter 6. Results of Energy Poverty Diagnosis

6.1. Energy Poverty Degrees and Groups in La Pila

The results of the processing and analysis of energy satisfiers data indicate a division among parents of Francisco González Bocanegra School representative of the Mexican scenario (García Ochoa & Graizbord Ed, 2016), where 70% of the interviewers have material conditions to satisfy their energy needs inside home and are classified as non-energy poor (Figure 29). On the other hand, thirty percent present some kind of energy service deprivation due to the lack of home appliances and are considered to have a degree of energy poverty. Among them, the biggest group is composed by households who have one type of energy service deprivation (9), labeled energy poor. At the same time, one is considered to live in strong energy poverty and two are classified as extreme energy poor for having three or more energy services deprivations (Table 20).

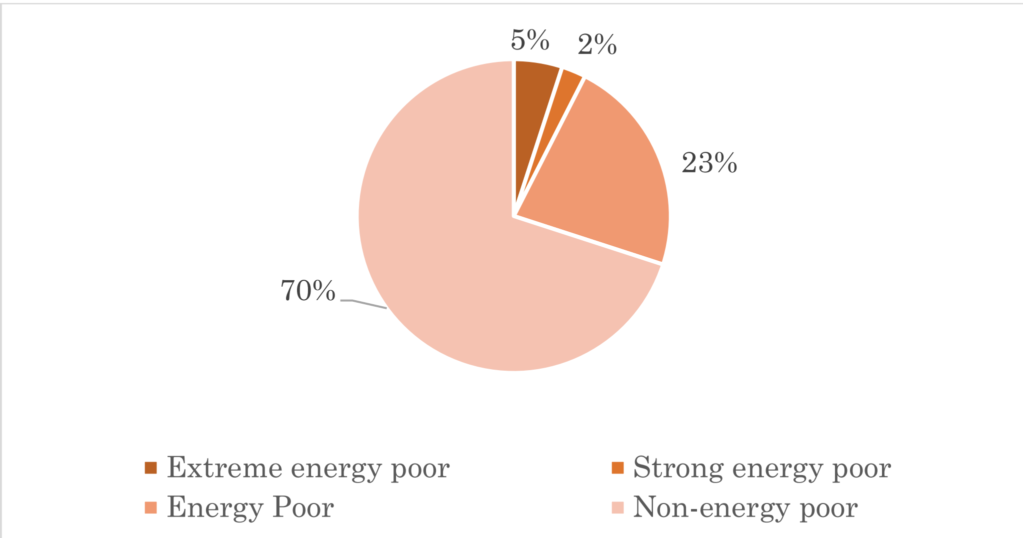

Figure 29. Levels of Energy Poverty encountered in the Sample

Table 20. Energy Poverty degrees and groups for the sample.

Classification	Deprivation of energy services	Number of households	% of the sample
Non-energy poor	0	28	70%
Energy poor	1	9	23%

Strong energy poor	2	1	3%
Extreme energy poor	3 or more	2	5%

Results of the statistical analysis based on the formation of clusters with k-means method are presented in Table 21. In the "Energy Poverty dimensions" columns, the number 1 indicates the satisfaction of the energy service, while 0 represents the deprivation. As the sample size is small and it was possible to count with the precision of manual analysis to form the EP degrees, the cluster analysis contribution is used mainly to identify how is the set of deprivations on each group. The criteria used to choose the number of clusters were capturing the collective reality of the sample, and k=4 was the limit for having at least 2 members on each cluster.

Table 21. Result of the k-means cluster analysis.

Clusters			Energy poverty dimensions				
Nr.	Households	%	Lighting	Entertainment	Water Heating	Food Refrigeration	Food Cooking
1	31	78%	1	1	1	1	1
2	2	5%	0	0	0	1	0
3	4	10%	1	1	1	0	1
4	3	8%	0	0	1	1	1

The cluster number one represents the most prominent group, previously classified by me as non-energy-poor, containing the group of people that fully or are the closest of satisfying all considered energy services. Cluster 2 represents people living in extreme energy poverty (2 households), where the only basic energy service attended is food refrigeration. The presence of a refrigerator is also determinant to cluster 3, where its absence characterizes the only deprivation suffered by its four families, which are the energy poor. The last group, cluster 4, is composed of three households that are deprived of lighting and entertainment.

The deprivation of food cooking and water heating affects 5% of the families, that rely on wood or firewood as energy sources to cook or heat water. Therefore, the deprivation of energy services related to LPG is only found in the extreme poverty group and is the less common in the sample.

Hence, a marked characteristic of this sample is that the deprivation that keeps 22,5% of people on energy poverty is food refrigeration, or in other words, the material presence of a refrigerator. Also, "strong energy poor" and "energy poor" groups, that represent the majority of EP in La Pila are deprived of material satisfiers that have electricity as an energy source.

Finally, Table 22 compiles the results that compose the energy poverty scale built for Francisco González Bocanegra's school sample.

Table 22. Final characterization of energy services deprivation in the sample.

Degree	Number of households	%	Energy Services Deprivation	Related energy source
Extreme energy poor	2	5%	Lighting; Entertainment; Water Heating; Food Cooking	Electricity and LP gas
Strong energy poor	1	3%	Lighting and Entertainment	Electricity
Energy poor	9	23%	Food Refrigeration	Electricity
Non-energy poor	28	70%	None	-

Zooming in in the energy poverty groups and the energy source for the missing home appliances, it is verifiable that electricity is present is all the groups. Still, it is the exclusive source for deprivations that characterize the "energy poor" and "strong energy poor" (83% of energy poor people).

6.2. Energy expenditures analysis

Considering average values, the most significant part of the MXN 432,97 energy burdens of a La Pila household come from the LPG expenditure, that represent 63% of its total versus 37% of the spending in electricity. San Luis Potosi state (SLP) has a more balanced proportion between both.

Figure 30 compares both energy burdens composition, where LPG represents 9% more for a La Pila household.

Figure 30. Proportion of LPG and Electricity in Energy Burdens.

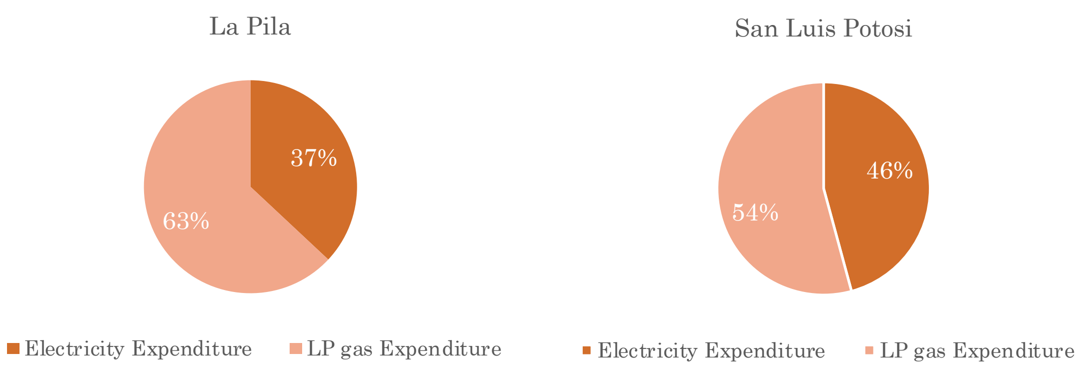

Table 23 represents the comparison of the results found in the sample with the state averages values. LPG expenditure is approximately 45 Mexican pesos higher than the state average, while its market price in La Pila is very similar to SLP's. The per capita value for each location is MXN 56 for SLP and MXN 54 for La Pila, showing that a possible explanation for the difference is the size of house occupants: in the sample it is 5, meanwhile ins SLP state it is approximately 4 persons per house (ENIGH, 2018). Its monthly payment represents on average 5,23% of the income, about 3,5 fives more compared to SLP's average.

Table 23. Comparison between SLP's and sample's indicators of Energy Expenditures

Indicator	San Luis Potosí state	Sample´s Results	Comparison
Electricity Expenditure	190,00 MXN	160,08 MXN	Below
LP gas Expenditure	225,00 MXN	272,88 MXN	Above
Energy burdens	408,00 MXN	432,97 MXN	Above
Average households' income	15.500,00 MXN	5.963,17 MXN	Below
% of energy burdens in households' income	2,63%	8,51%	Above
% of electricity expenditure in households' income	1,23%	3,30%	Above
% of LP gas expenditure in households' income	1,45%	5,23%	Above

The electricity expenditure is, on the other hand, MXN 30 below the state average of MXN 190 and represents a per capita level below SLP's. Nevertheless, it represents the double of the income proportion (3,30%) compared to a San Luis Potosi household (1,23%).

An analysis of the proportion of the income shows that its indicators are above the average line of San Luis Potosi state (SLP), in all three cases. While in SLP a household spends on average 2,63% of its income in energy burdens, for a Francisco González Bocanegra's parent these expenditures weight more than the double for its budget, with an average of 8,51% of his income. The sample has values also higher than the average predicted to La Pila delegation, which is of 5% (COESPO, 2020). This scenario is the reflection not of a high energy expenditure, but of a low-income situation faced by parents, since a household earns 1/3 of the average observed in the state and has a higher energy burden probably due to the size of its family.

6.3. Intepretation of Results

The results of the analysis show that the EP situation found in the study case is more related to the absence of fundamental home appliances that are supplied by electricity. Applying a broader view on the scenario, it is essential looking at the identified aspects influencing affordability and access to electric energy, since they are the primordial factors influencing energy service delivery (Bouzarovski & Petrova, 2015). Being so, only the presence of the necessary material goods without a secure and uninterrupted electricity supply and a proper capacity to pay for the energy bills will still let people stuck into an energy poverty state.

Not less important and related to the unaffordability of people is the existence of households relying on firewood to satisfy the energy services of cooking and water heating within the sample. This feature was expected to be found in the sample and it is probably higher in La Pila, since in SLP 20,3% of households declared to use wood for cooking (ENIGH, 2018). As well stressed by González-Eguino (2015), cardiovascular and pulmonary diseases are highly attributed to the particles that come from indoor pollution and are a real exposition for the extreme energy poverty group of households due to EP in the case study. Beyond health issues, this fact may lead to a situation that is often seen in other peri-urban areas: the existence of a local environmental degradation related not to selling natural resources or other forms of income, but to the supply of population's basic needs (Mycoo et al., 2006). Even though no evidence on the origin of the wood was available on the data, in La Pila delegation case, environmental degradation (including air pollution) might be related explicitly for supplying the energetic needs of food cooking and water heating equipment.

Following the relation built by García-Ochoa & Graizbord, (2016) based on Max-Neef, (1992), it is possible to track which fundamental human needs satisfaction are being affected by the deprivations found in the EP analysis. Table 24 summarizes the interpretation. Namely, subsistence, protection, entertainment, creation, idleness and creation are being affected because of their non-supplied correspondent satisfier, exhibited on the column with a similar name.

Table 24. Fundamental human needs that are affected by energy poverty in the case study.

Degree	Number of households	%	Energy Services Deprivation	Affected satisfiers	Related Fundamental needs	Energy source
Extreme energy poor	2	5%	Lighting; Entertainment; Water Heating; Food Cooking	Physical Health; Food; Mood; Free time; Working Creating; Inventing; Drawing; Self-care; Researching; Studying; Literature; Games.	Subsistence; Protection; Entertainment; Creation; Idleness; Pleasure;	Electricity and LG gas
Strong energy poor	1	3%	Lightning and Entertainment	Mood; Free time; Working Creating; Inventing; Drawing; Self-care; Researching; Studying; Literature; Games.	Entertainment; Idleness; Creation; Protection; Pleasure.	Electricity
Energy poor	9	23%	Food Refrigeration	Physical Health; Food;	Subsistence; Protection	Electricity and LG gas
Non-energy poor	28	70%	None	-	-	-

Regarding electricity-related material goods, six related fundamental needs are being impacted: entertainment, idleness, creation, protection, subsistence and protection (Table 25). The deprivation of a refrigerator affects the availability of food, having impacts feeding and physical health satisfiers.

Table 25. Fundamental human needs affected by electricity-related goods

Energy Services Deprivation	Affected satisfiers	Related Fundamental needs
Lightng and Entertainment	Mood; free time; working; creating; inventing; drawing; self-care; researching; studying; literature; games.	Entertainment; Idleness; Creation; Protection; Pleasure.
Food Refrigeration	Physical Health and Food	Subsistence; Protection

In this point, it is essential to reaffirm that human development is directly related to an increase in energy consumption (Niu et al., 2013) and a positive rebound effect is expected within households with energy poverty and poverty alleviation (Omic & Halb, 2019). Concerning the current situation of the case study, two main crucial points are highlighted: first, a rise in consumption will raise electricity bills and raise the energy burdens, that already has a considerable weight in families' total income. Secondly, more electricity will be required on CFE's grid, both from the presented situation. Summed up with this, the encountered situation on energy reliance and security are energy vulnerabilities that tend to raise if the positive scenario for human development happens. In this sense, a significant energy poverty amelioration per se may be a threat to the electricity system security and a poverty trap for the population if not followed by a proper improvement plan.

In the case study, decisions coming from political and economic spheres that happen outside of household's walls are influencing in their energy poverty state (Petrova, 2018) and generating an energy injustice scene by excluding people from a secure and uninterrupted energy infrastructure. Namely, La Pila's closeness to the industrial zone is considered a hazard to its energy security (Cisneros Vidales, 2018). The area presents a growing electricity demand and is supplied by the same substation as the delegation. In seasons where it presents a high demand (usually summer), La Pila delegation suffers of more interruptions, facing a seasonal energy poverty related to its geographical location. Often, managerial decisions favor the supply to economic activities when having to make decisions in the distribution system.

Hence, it is also possible to identify energy vulnerabilities (Bouzarovski & Petrova, 2015) coming from the production process of the main power plant that supplies La Pila and are also consequences of its energy precarity situation: the water used in the thermoelectric Villa de Reyes comes from San Luis Potosi aquifers, that is a semi-arid area with low annual precipitation level (González, 2019; Medellín Milán, 2002). Secondly, it depends on fossil fuels for its operations, which has costs and its own supply chain that is exposed to market and extraction risks that may increase the value of production anytime. As other thermoelectrics, it is considered a highly pollutant and inefficient form of energy generation, that liberates great amounts of carbon dioxide. Its emissions also contemplate considerable amounts of sulfur dioxide, nitrogen oxide, carbon monoxide and toxic heavy metals in the soil and water such as lead, cadmium, arsenic, and mercury (Medellín Milán, 2002). All these aspects count as energy vulnerabilities to La Pila population, which is geographically located near the place where these emissions happen.

When it comes to affordability, the financial analysis regarding energy burdens and its comparison to SLP state gives this study a hint of a strong energy vulnerability regarding the ability to pay energy bills. Its low-income characteristics and high expenditures proportion expose people to not afford changes in energy tariffs. This aspect feedbacks directly in their access to electricity and the capability to have the necessary energy services inside the home. Hence, prospecting the positive rebound effect on this situation, even if energy poor households acquire equipment to satisfy their basic energy needs, the raise on consumption and energy bills would still represent a vulnerability to introduce them into energy poverty again because of their current financial situation. This situation is also extended to the 70% non energy poor. Affordability in the case study is, then, an important point of attention to the energy poverty situation.

Some other factors in the case study influences this vulnerability, coming from external decisions and political gaps that also characterizes its energy precarity scene and exposition to possible energy poverty states.

The first is the energy tariffs situation, since the current government already announced a likely raise on energy tariffs on the short-term. The second factor of attention is the tariff subsidy scheme. In a short-term, the current applied scheme positively impacts the affordability of the delegation, primarly because of its low-income characteristics. Nevertheless, until the extent of knowledge of my research, subsidies do not follow a clear approved plan to its end and is exposed to change of governments and its priorities. Like other parts of Mexico, the delegation is exposed and vulnerable to subsidies sudden drop out in mid and long-term. The subsidy discontinuation would mean the elevation of tariffs to the non-subsidized category, that is worth four times more than they currently do (see Table 14). This would increase the percentage of electricity burdens in the family's finances, which may sacrifice expenditures in other necessary spheres of their lives in order to keep electricity supply. With the observed weight it already has on the total income and the inexistence of any other consumer or social law to protect people from disconnections, population could rapidly face energy unaffordability and enter into energy poverty or worse multidimensional poverty states. As a matter of fact, this phenomenon had already been observed in other countries and is seen as the leading cause of energy poverty in some world regions (Bouzarovski, 2018), as mentioned in the Subsection "Geography and manifestations of Energy Poverty".

Moreover, this condition is also extended to collective interest places that face unaffordability even with the subsidized tariffs, illustrated by the payment parents made in Francisco González Bocanegra school to keep its basic infrastructure. The school case stresses that reactions to adapt to its energy conditions also goes also the other way around, where solutions come from inside the household walls to keep electricity supply in communitarian spaces. Ironically, the solution found used to put parents in a more energy vulnerable position that compromises their affordability to its own electricity bills, since the fee corresponds to half of the median value found in the considered sample.

Finally, the lack of social protection for vulnerable people's disconnection on law and policy is a fact that also composes the energy precarity situation and energy vulnerability in La Pila. Here, considerations of energy justice field can also interpret the situation of the case study. Through the lenses of some of its authors (Jenkins et al., 2016) energy poor are seen as victims due to distributional mechanisms failure, and for not giving special treatment to these people, this own system is excluding them for being in conditions of unaffordability.

Being so, all mentioned aspects regarding energy precarity, justice and vulnerabilities affect energy affordability and access, that are the primordial aspects influencing energy services delivery. As a grid-connected neighborhood with energy poverty levels, it is vital to guarantee these two aspects in first place since current policies do not identify and locally tackle them. If not followed by strategies that ensure mid and long-term affordability, families may be limited of making a total use of equipment that supply their energy needs even owning them.

Since electricity is the energy source that feeds home appliances that could take 83% of the sample of energy poverty states, ensuring an affordable and secure electric energy is a key point for reducing energy poverty in the case study. This is precisely where the potential applications of DCPV can bring benefits to the community, matter that will be discussed in the next session.

Chapter 7. DCPV Scenarios for La Pila

Having identified La Pila's principal vulnerabilities and injustices and diagnosed its energy poverty and energy-related financial situation, this chapter will focus on building scenarios of decentralized photovoltaic systems (DCPV) applications for the community and describing its social, environmental and economic impacts.

Understanding how Mexican policy supports, regulates and contemplates DCPV application in energy poor and poor zones is necessary to draw these scenarios properly. Based on that, the first part of this chapter will describe and analyze existing Mexican national policies, meeting one of this thesis' objectives of leaving as a contribution to the field a brief analysis covering its current efficacy combating poverty, energy poverty through energy and DCPV support scheme.

With the correct understanding of the national situation and regulation, the second part of this chapter is focused on meeting another objective of this research, presenting the three designed scenarios for La Pila delegation. Policies and funding will be linked to each one. Its potential impacts in economic, environmental and social spheres and on key energy dimensions of the community are adequately described.

7.1. Mexican Supporting Policies

In Mexican political agenda, the environment, poverty and energy are axes present in a disarticulated form (García Ochoa & Graizbord Ed, 2016). As described earlier, Energy Poverty is not explicitly recognized by not being officially in Mexican political agenda policy. To cover possible programs and policies using DCPV to fight energy poverty aspects, a broader view was applied on searching criteria method, analyzing policies that englobed social housing and specific energy policy that contemplates emarginated and poor population and decentralized photovoltaic systems (DCPV). Also, guidelines found in the National Development Plan for 2019-2023 will be commented and the regulations on DCPV will be described.

7.1.1. Energy Policy

Mexican Energy Policy is stated by the National Secretariat on Energy (Secretaría Nacional de Energía – SENER) and regulated by the Regulatory Commission of Energy (Comisión Reguladora de Electricidad – CRE). The Energy National Center of Control (Centro Nacional de Control de Energía – CENACE) is the responsible organism when it comes to the energy market and carbon certificates trading. Current energy policy is mainly based on the Law of the

Electric Industry (Ley de la Industria Eléctrica, 2014) and the Energy Transition Law (Ley de Transición Energética, 2020), that reflects previous compromises of sustainable development and climate change agreements.

Due to their relevance for the theme, two main policies are analyzed and findings concerning PV applications for poor and vulnerable are descripted in this session: National Electric System Development Program the (Programa de Desarrollo del Sistema Eléctrico Nacional – PRODESEN, 2018) and the Public Policy to Promote Distributed Generation (Política Pública para Promover la Generación Distribuída en México, 2018). Also, conditions and guidelines of the Fund of the Universal Electric Service (Fondo del Servicio Universal Eléctrico – FSUE) are described and commented.

PRODESEN is the central policy that dictates general guidelines and goals for the period of 2018-2032 regarding the Mexican electric system. It is a crucial document guiding Energy Policy towards Mexican energy transition, having the ambition of reaching 38,6% of clean energy in the generation mix until 2032, of which 9% is projected to be with solar technologies. It is essential to mention that the expansion of solar applications is linked to a distributed generation (DG) model predicted by the National Renewable Energy Laboratory (NREL).

When it comes to poverty scenarios, PRODESEN's focus is on electrification. According to its numbers, 98,5% of the Mexican population have electricity supply, but there are still 1,8 million people lacking electricity access (Programa de Desarrollo del Sistema Eléctrico Nacional, 2018). The policy cites specifically PV modules as a strategy for isolated areas. There is a specific mention to the creation of a Fund – The Fondo del Servicio Universal Eléctrico (FSUE) – that should be used to electrification projects in rural and emarginated areas.

In 2017, SENER launched guidelines and strategies regarding the use of FSUE through the official Policies and Strategies for the Electrification of Rural Communities and Emarginated Urban Zones (Políticas y Estrategias Para La Electrificación de Comunidades Rurales y Zonas Urbanas Marginadas, 2017).

Firstly, the targeted population is specifically emarginated urban communities (defined as areas that have at least one house and a population bigger than 2500 inhabitants and a margination level of medium, high or very high) and rural communities (places with less than 2500 inhabitants) that do not count with electricity access. In those areas, the FSUE provides funds to projects that implement electrification actions. These actions are composed of three main axes: electrification projects, the supply of efficient bulbs and basic supply to final users in conditions of margination.

The policy's focus is on the provision of the energy services of lighting, communication and food conservation and in bringing electricity supply to develop basic infrastructure to health, education, food, open communitarian spaces, and communitarian dining halls.

Guidelines predict that in the case of areas where there is a proximity to existent electricity grids, that is usually the case of emarginated urbans communities, the extension of the electricity grid will be considered to provide them. On the other hand, in cases of remote areas, it states electricity will be delivered through distributed generation micro-systems, prioritizing clean technologies such as PV.

For the selection of projects, the fund takes into consideration the degree of margination, another complementary index occupied by Mexico on poverty issues. This index takes into consideration some of the aspects contained in CONEVAL multidimensional index, like energy access. It also considers the % of the population with income lower than two minimum wages. Land tenure aspects are considered, as strategies of social participation, free competition and the number of houses in the locality in order to prioritize projects.

One year after launching guidelines on the FSUE, SENER has emitted a specific policy regarding the modality of distributed generation. A highlight is made to the point 3, that emphasizes the discourse of the use of DG to reach electrification goals but also states it should promote ways of bringing democratization of electricity generation. It explicitly states that "growth of distributed generation should contribute to the democratization of electric energy generation and the universal access to electric service" (p. 29, Política Pública para Promover la Generación Distribuida en México, 2018). No specific description is given to what the policy considers democratization.

Among described actions and programs to the goals achievements, there is a mention of a pilot program, Bono Solar, that is being developed by a partnership of SENER and the Mexican Climate Initiative (ICM). Its idea is to slowly shift the investments of tariff subsidies to financial incentives in the application of DCPV in subsidized household's rooftops, with the idea to end unlimited subsidies slowly. The scheme would work based on the rental of equipment where the user would not pay for electricity, but instead, it would contribute with a fixed tariff for the rental. The applied tariff must be about 15 or 20% less then he used to pay before. In the end, the user pays 30 or 40% of the PV system, while the other 60%-70% comes from government investment (Iniciativa Climática de México, 2017).

The targeted public for the implementation of its first pilot phase are houses that present with good structure, space, isolation and available capital. The program's management is intended to be in charge of the Federal Electricity Commission (Comisión Federal de Electricidad – CFE) (Iniciativa Climática de México, 2017).

Current regulation on the application of decentralized and distributed energy is fixed by the National Law of the Electric Industry and regulated by the Resolution RES/142/2017, emitted by CRE. In general lines, the distributed generation is characterized by systems with the maximum capacity of 0,5MW, which must be formalized following specific norms. These systems are exempted from having a generation permit, but they must have a formal agreement with the CFE to access the grid and join existing energy trading schemes. Nowadays, its application is permitted in an individual level in three different possibilities, that can be chosen by the user. In cases where energy selling is possible, the national local marginal price used in the Mexican wholesale market is applied (RES/142/2017, 2017). The resolution also establishes the possibility of collective generation, of which rules are being reformulated and are possible in two different schemes.

Regarding individual generation, the first established scheme is the net metering resolution, which allows users to generate energy for self-consumption and inject the energy surplus in the CFE grid. In the moments where the DCPV is not generating enough energy to cover the user's consumption, the missing energy is provided by the grid. This electricity exchange is possible due to a bidirectional meter that registers the exchange on a bimonthly basis, as explained in Figure 31. A particular feature of the Mexican Net Metering system is the possibility of selling the credits of the energy accumulated after 12 months to CFE at the determined local marginal price (RES/142/2017, 2017).

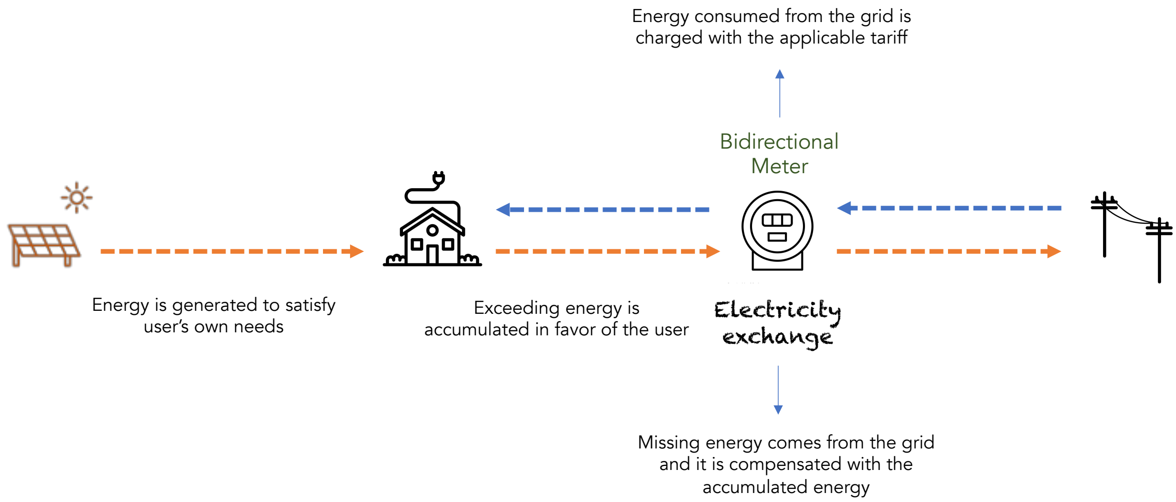

Figure 31. Illustration of the Mexican net metering system. Based on CRE, 2019.

Secondly, net billing regulation is also available in the Mexican Distributed Generation regulation in individual generation possibilities. In this case, the DCPV is applied in the user's roof or space, but the generated energy feeds the grid directly and it is sold considering the local marginal price to CFE Distribution. The consumed energy is charged with the commonly applicable tariff (RES/142/2017, 2017). Figure 32 shows an illustrative scheme of its operation.

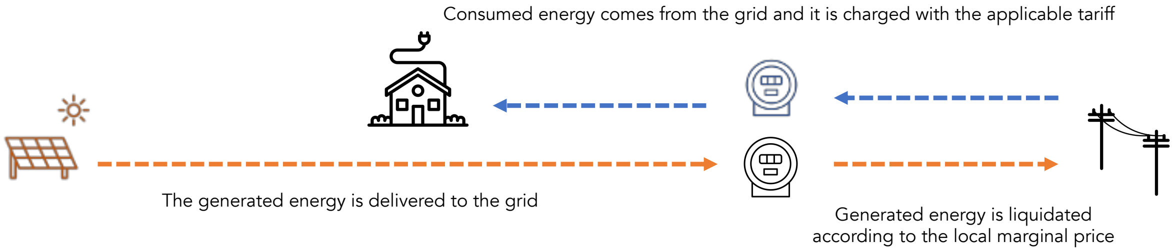

Figure 32. Illustration of the Mexican net billing system. Based on CRE, 2019.

The last individual DCPV generation possibility is characterized by having a generator in a site with no consumption, in a scenario where the user wishes to sell all the energy to CFE at the local marginal price under a specific agreement (Figure 33). This case is possible when respecting the capacity limit of 0,5MW (RES/142/2017, 2017).

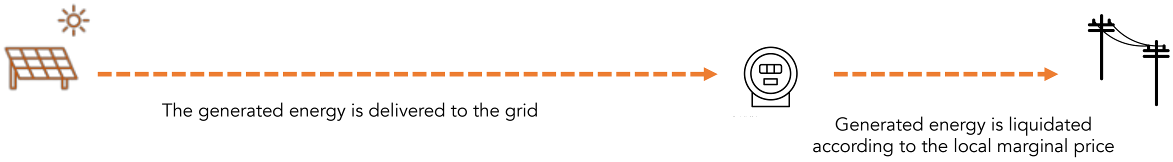

Figure 33. Illustration of the Mexican total selling system. Based on CRE, 2019.

The RES/142/2017 also allows collective distributed generation systems. This term is used to describe when two or more people have ownership of the PV micro-generator and share its generation. In Mexico, it is fixed in the resolution emitted by the CRE. Until the finalization of this thesis, the official document regarding its application rules was already approved but still not published in the DOF, the official government diary (Jiménez, 2020). Its publication is predicted to occur in 2020 (Granados Rojas, 2019). Nevertheless, an available final draft in the official website of the Mexican government (Acuerdo Num A/XXXX/2019, 2019) was used as a reference to describe its possibilities.

Collective Generation can work either under the net metering scheme or the net billing scheme. A contract is signed between CFE and the generator, which includes a list containing the users that are beneficiaries and the correspondent energy generation proportion received by each of them.

Under the net metering scheme, the previous system of exchanging energy with the grid is applied in each energy bill, considering what was consumed and the corresponding part delivered to the grid by the collective generator (Figure 34). The user and the generator may share a common interconnection point, and users must be under the same tariff regime. As in the net metering individual rules, after 12 months it is possible to sell the energy credits to the CFE after 12 months (Acuerdo Num A/XXXX/2019, 2019).

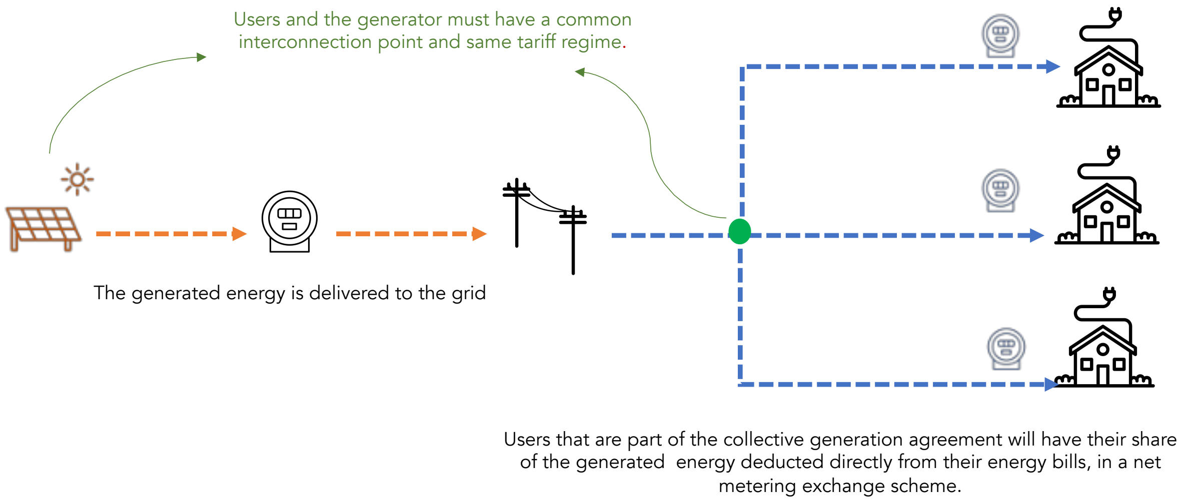

Figure 34. Collective Distributed Generation – Net metering scheme. Based on Acuerdo Num A/XXXX/2019, 2019.

There is also the possibility of registering the system under the net billing scheme, previously described. In the case of a collective generator, this possibility allows users to be located in different areas and being under different tariffs, since the energy is directly sold to CFE and the value discounted from their energy bills (Acuerdo Num A/XXXX/2019, 2019). An illustration of the scheme is shown in Figure 35.

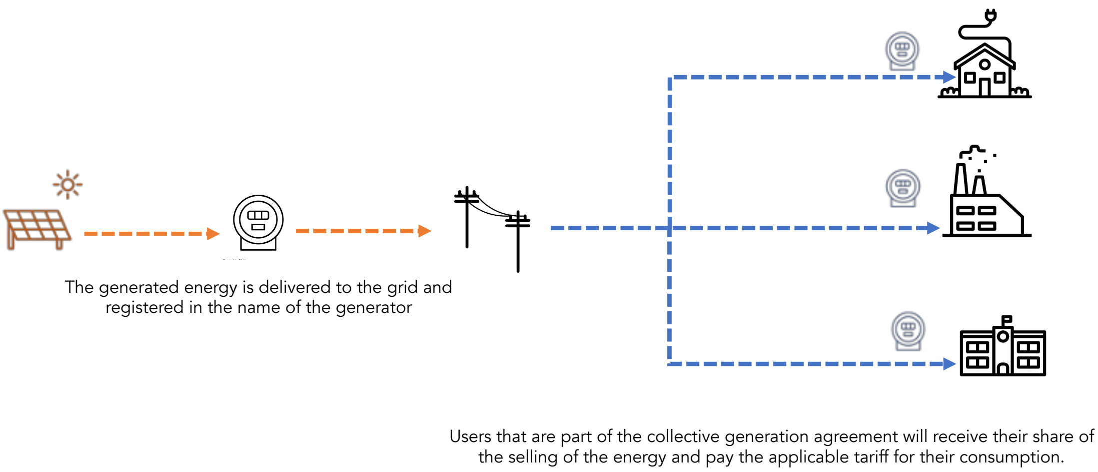

Figure 35. Collective Distributed Generation – Net billing scheme. Based on Acuerdo Num A/XXXX/2019, 2019.

Further in the regulatory aspect, Mexico counts with a market for carbon certificates for promoting clean energy generation, translated in Clean Energy Certificates (Certificados de Energía Limpias – CEL). Large-scale users and generators of the electric industry are obliged to have established numbers of CELs. Mexican rules determine that for each 1 MW of clean energy delivered to the grid, 1 CEL can be emitted (SENER, 2014). The maximum price per CEL was 20 USD in 2016 (CRE, 2017).

In the case of PV Distributed Generation Systems, SENER allows the emission of Clean Energy Certificate for the period of 20 years (SENER, 2014). CENACE organizes annual trading events to foment its commercialization. Specifically for DG, they can be sold to the energy distribution company in which it is registered, which is CFE.

Finally, it is prudent making a special consideration to current updates on Mexican energy policies, as they are instruments that are prone to adequations and changes as the federal government changes. The current federal Mexican government presents a different position regarding the strategy adopted by the previous administration, when most market liberalization and renewable energy incentives were approved. In its National Development Plan (Plan Nacional de Desarrollo 2019-2024), it has expressed a clear focus on strengthening the national oil industry and increase government interference on the energy market, already adapting laws and market mechanisms to its interests and priorities. Even though shocks between central renewable energy players and the government have been occurring (Villa y Caña & Morales, 2020), current decisions and announced strategies are pro DCPV growth, stressing the potential of its social impact. In the energy policy section, the National Development Plan states that sustainable development will happen by incorporating population and communities into energy production with renewable sources. Specific mention is made to electrification projects in small isolated communities. Quoting the plan in a free translation, "Mexican energy transition will impulse the emergence of a social sector in the field (of DG), as also encouraging the reindustrialization of the country" (p.15, Plan Nacional de Desarrollo 2019-2024, 2019). Until the finalization of this thesis, all the regulations and promulgated laws reaffirm the compromise of DG and leave DCPV scenario in a concrete position.

7.1.2. Social Housing Policy and Programs

One of the central institutions regarding Housing Programs in Mexico is the National Commission on Housing (Comisión Nacional de Vivienda – CONAVI). Current main leading strategies and funds tackling social housing programs are influenced by the partnership of Mexican and German institutions that compose different National Appropriate Mitigation Actions (NAMAs). The fact that in Mexico sustainable housing is a strategy of greenhouse gas reduction and count as a NAMA is a worldwide innovative measure that is motivated by the compromise assumed in the Kyoto Protocol (Muñoz, 2018). The three existing NAMAs for sustainable housing in Mexico (Muñoz, 2018) – NAMA Vivienda Sustentable Nueva, NAMA Vivienda Existente and Urban NAMA – penetrated different institutions and market players of the residential sector (Theumer et al., 2014).

The central institution materializing programs and funding to a share of poor households is the Institute of the Housing National Fund for Workers (Instituto del Fondo Nacional de la Vivienda para los Trabajadores – INFONAVIT). According to Mexican Constitution (1917), formally registered workers have a right to housing. For that, Mexico promulgated a Law creating the INFONAVIT in 1972. The institution is responsible for administrating a fund composed of taxes paid by employers ,that conceives credit for formal workers' housing.

Since 2018, INFONAVIT has a mandatory rule demanding that all financed houses install basic ecotechnologies in order to promote savings for the families and environmental and energy efficiency (Figure 36). Even though grid-connected PV systems are not listed as mandatory, it is possible to apply for extra credit or use remaining credits to buy a PV system under specific circumstances of income (MXN 7131 monthly in 2020) and authorized credit in a program called Green Mortgage (Hipoteca Verde) (INFONAVIT, 2020). The first version of the program was launched in 2007, as a result of the compromise established with Clean Development Mechanisms, that comes from Kyoto Protocol (Muñoz, 2018).

Resource	Ecotechnologies
Water	Toilet flush of maximum 5L Shower with ecological level Solar water heater Kitchen and bathrooms must have water-saving taps
Energy	Sectioning valves 6 residential led lamps Thermal insulation in the roof Inverter Air conditioner (for hot climates only) Grid-connected Photovoltaic Systems Voltage optimizer
Gas	Quick recovery gas heater
Required, optional	

Figure 36. Available Ecotechnologies in INFONAVIT Programs. Based on INFONAVIT, 2020.

INFONAVIT credits are directed to formal workers registered in the Mexican Institute of Social Security. The credit of Green Mortgage is conceived only in cases where the user is either buying a house or wants to improve its own house (INFONAVIT, 2020). It is relevant to mention that all houses go through a process of evaluation of savings and environmental benefits for a closer measurement of Green Mortgage results. The methodology, advising of recommended technologies and financial support comes from NAMA project.

7.1.3. Policy Analysis

Referring back to the three main themes of Chapter 1, the policy analysis is here done under three perspectives: Alleviating poverty, energy poverty (EP) and whether DCPV support scheme favor applications and innovative business models in poor areas. Table 26. National Support Scheme and Public Funding on DCPV. and Table 27 summarize encountered and considered Programs, Funding and Policies that were taken into consideration for the analysis, that had as main criteria that consider DCPV applications for poor households.

Table 26. National Support Scheme and Public Funding on DCPV.

Target Group	Type of policy	Initiative	Institution	Summary
Government institutions Households Private Constructors Poor Households	Awareness Funding	NAMA on Sustainable Social housing	GIZ, CONAVI	Technical knowledge, advising and funding.
Small, micro and medium companies	Funding	Financiamiento para Acceder a Tecnologías de Energías Renovables – FATERGED	SENER	Funding for the acquisition and application of PV.
Emarginated urban communities Rural isolated communities	Funding Subsidies	Fondo de Servicio Universal Eléctrico – FSUE	SENER	Funding for programs comtemplating rural and emarginated community electrification and basic energy equipments projects (off-grid PV).
Government institutions Companies Private market	Funding Subsidies	Fondo para la Transición Energética y el Aprovechamiento Sustentable de la Energía – FOTEASE	SENER	Funding for programs on energy efficiency, affordability and clean generation projects.
Companies Households Poor Households	Incentive	Fiscal Incentive	SAT	User can have the PV system cost deduced from the income tax.

Colective generators Households Owners of DSPV Poor Households	Regulatory	Certificado de Energía Limpia (Carbon credit market)	CRE	Gives the possibility of selling CELs to the CFE for each injected MW ($20 per CEL in 2016).
Companies Households Poor Households	Regulatory	Individual grid-connected generation schemes	SENER, CRE	Incentives and norms for prosumers under Net Metering Net Billing and Total Selling possibilities.
Companies Households Industries Poor Households	Regulatory	Collective Distributed Generation schemes	SENER, CRE	Incentives and norms for prosumers
Companies Households	Subsidies	Fideicomiso para Ahorro de Energia Eléctrica – FIDE	CFE	Provides subsidies and special interest rates for PV acquisition

Table 27.Current relevant programs on DCPV for emarginated people

Target Group	Initiative	Institution	Level	Summary	Focus
Households (Under previous subsidised tariff scheme)	Bono Solar	ICM + SENER	National	User rents a CFE solar roof, paying about 15 to 20% less on energy bill	Energy Affordability
Poor Households (Registered formal workers with ownership of the house, with income higher than MXN 7,131)	Hipoteca Verde	INFONAVIT	National	User can request extra credit to buy a PV System	Energy Affordability and Efficiency
Households (under DAC tariff, small and micro business	Programa de Apoyo a la GD	FIDE	National	Of the total cost for buying the PV, 10% is subsidized and 90% financed with preferential rates	Energy Affordability
Poor Households (Users with house ownership and income lower than MXN 12,251.20)	Programa de Mejoramiento Integral Sustentable	CONAVI + FIDE	National	User can buy a PV System with a 40% subsidy (SENER + CONAVI) plus a interest rate of 18% yearly. The payment occurs	Energy Affordability and Efficiency

				through CFE electricity bill.	
Poor communities (Emarginated and socially risked communities)	Programa Electrificación	SEDESORE + FSUE	State + Municipalities	Electrification through PV systems	Electrification

7.1.3.1. Poverty

For analyzing the efficacy and use of DCPV on poverty alleviation, it is important to briefly recapitulate conceptualization and the official measurement of poverty for Mexico. As mentioned in Chapter 1 and previously summarized in Figure 1 Mexico has a multidimensional vision of poverty and its own methodology. Energy is contemplated in "Quality of House Spaces and Basic Services at home" dimension by an access indicator.

As described, Mexican energy policy provides guidelines to the use of DCPV for electrification in isolated areas and grid extension to emarginated urban areas, with the specific creation of the FSUE. PRODESEN is coherent in poverty alleviation by providing a specific program tackling electricity access. It is interesting to highlight that FSUE text also recognizes that electricity is a required underpin to satisfy other dimensions also considered in its multidimensional index, like health, education, social cohesion and food and nutrition. In a free translation, the FSUE aims to “promote electricity access to rural communities and emarginated urban zones, in the lowest cost to the country and pushing the use of clean energy to satisfy illumination, communication and food conservation of its beneficiaries and the electricity supply to basic infrastructure development to health and education provision, development of productive activities, open spaces for convivence and communitarian dining rooms.” (Políticas y Estrategias Para La Electrificación de Comunidades Rurales y Zonas Urbanas Marginadas, 2017). By using the margination index as a criterion for project selection, it is automatically including the most income poor part of the population.

From this perspective, the FSUE can be considered a successful energy policy targeting poverty alleviation for providing energy access and space to supply emarginated communitarian spaces that directly impact other dimensions of what is considered poverty. A point of attention is that the FSUE is focused on communities and not households, and it is accessible by local governments. In this point, corruption might count as a barrier to projects executions. An example of the use of FSUE is through the Program “Electrificación” (Table 27) that is articulated between State governments and municipalities.

DCPV technology is also positioned in projects of energy electrification, energy efficiency and affordability, which have indirect and direct impacts on other dimensions of poverty.

On the other hand, when it comes to its Social Housing Policies, the NAMA on sustainable housing and Green Mortgage program both contemplate DCPV and target specifically poor households, but in a controversy excluding form. Among INFONAVIT’s criteria for conceiving credit for PV acquisition are income, the ownership of the house and citizens with formal work. This means that the program is inaccessible to the most emarginated and poor people – with informal work, living by rental contracts, problems with land tenure and lowest incomes. Ensuring household’s energy efficiency and affordability are long-term and potential measures for poverty alleviation, since it makes bills more affordable, needs satisfiers more accessible and has an impact on the household's income. Here, a window of opportunity is the creation of an ecotechnology fund administrated by a different institution that has specific scope in poor people, using as criteria dimensions of the existing Mexican multidimensional poverty index.

Finally, collective generation possibilities and the idea of the current government to open a social field with DG may also directly impact all dimensions of Mexican multidimensional poverty. It carries the potential to give autonomy and empower communities to have their own power generation and supply for communitarian spaces and institutions of public interest like schools and hospitals, enabling irrigation systems and electricity to houses. These guidelines, if well traduced with proper funding, subsidies and a coherent scoping, can have a significant impact on poverty indicators.

In summary, electrification measures provided by energy policy are coherent and have a proper scope to what Mexico considers poverty. On the other hand, the existent criteria of the programs on social housing are only capable of reaching a part of poor households and exclude the poorest of its beneficiaries. With a better scoping and use of the existent technical guidelines, it could contribute to the poverty alleviation in its most critical scenarios.

7.1.3.2. Energy Poverty

Mexican main policies and guidelines targeting poor people still reflect the joint Latin-American movement of electrification and energy securitization to disconnected and isolated areas. This can be seen in the guidelines of PRODESEN, in the creation of the FSUE and also DG Policy focus on universal access to energy. It is interesting to note that FSUE goes a step beyond electrification and recognizes energy services and its material satisfiers in its text. However, it limits its application to the provision of light bulbs and electrification equipment that are necessary, but not enough to ensure what the policy states. In the same line, DG Policy and The National Development Plan mention the democratization of energy production and the social focus of DG projects, but it is still not possible to see concrete programs and measures to ensure it will reach energy poor and vulnerable population. In this way, it is possible to affirm that the targeted low-income public of energy policies is a grid-disconnected population.

Of the funds contemplated on the analysis (Table 26), the access to available funding that focus on emarginated areas is possible through local governments projects and solicitations. An internal cultural factor that may influence the reach on households is the Mexican reality of corruption, that may private energy poor households getting access to electricity.

In terms of the DCPV regulation, Mexican norms are positively giving room to innovative appliances to address affordability, vulnerability and energy injustice issues present in EP through the application of DCPV in communities. The approval of the collective distributed generation gives room to a range of applications for business models and its coherent with the announced idea of democratization of the generation. Opening the path to community applications brings the potential of making DCPV systems affordable to energy poor who usually could not pay for an individual DG system. Nevertheless, the existence of specific funding for such groups is still a gap, since existing funding is focused on a household level and not in groups and associations of households.

Even though not having a specific EP policy or energy policy focusing on poor population that goes beyond electrification, strategies of other agendas are aligned with some of the commonly adopted EP policies alleviation, such as energy efficiency inside homes and electricity affordability (see column “Focus” of Table 27). Namely, the focus of climate change and social agendas is highly compatible with energy poverty alleviation, stating the example of Green Mortgage, which gives new and existing houses the possibility to own a PV system. The second is the Bono Solar pilot program, aiming to bring a sustainable and cheaper way to bring affordability to residential tariffs. In the analyzed programs (Table 27) PV technology is contemplated either in its off-grid applications (rural electrification) and its grid-connected forms (affordability). In fact, more programs are contemplating the use of DCPV in energy affordability and efficiency projects than in classical rural electrifications projects (column “Focus”), showing a coherence, penetration and synchronization of DG regulations and policies into other agendas.

The main issue of applying such policies to EP scenarios and perspective is its public scoping. As shown in Table 27 (column “Target Public”), although these programs and available funding give a good support scheme for households and small businesses who want to adapt their properties with a DG PV system, they fail to reach and include energy poor people for firstly not even recognizing the existence of people in this conditions in its guidelines.

Bono Solar program is the only official document where the term energy poverty is cited. Specifically, it is expected that subsidized solar roof installations will eventually reach energy poor and help tackle EP (Iniciativa Climática de México, 2017). Even though this citation can be interpreted as a positive flag of policy penetration, it is done superficially, lacking definition, details, and, especially, scoped measures to reach energy poor. In fact, in how its first phases are designed it will rarely achieve the most energy poor people in Mexico for reproducing energy injustices and distributional issues for excluding people with precarious housing conditions. It might even expose more people to EP states with the planned suspension of tariff subsidies. However, it must be recognized that the program is an innovative proposal for tackling electricity affordability and GHG emission from the energy sector with DG and it is aligned with energy policy and climate agenda, that are compatible with EP underpins and causes. Bono Solar has excellent potential to put self-generation in service of human development if better scoped to prioritize energy poor.

On this subject, it is relevant to reinforce the situation described in section 4.2, in which Mexico does not count on particular policy or procedures to protect vulnerable and poor/energy poor people of energy disconnection in case of the non-payment of electricity bills. Tariff subsidies focus on the hottest areas of the country. They are successful in facilitating the use of energy services such as thermal comfort and water access, especially in desertic areas that depend on electricity for desalinization plants and underground water access. Nevertheless, it does not focus on low-income groups that may even stay aside from the tariff scheme due to high consumption originated in the use of inefficient equipment (see Table 14).

In summary, when going a bit beyond electricity access programs, current Mexican policies are incapable of providing necessary measures to tackle energy poverty due to a scoping issue. For not recognizing and not giving space to energy poor in its texts, it may even generate more energy poverty with some of its programs and actions. Low-income and vulnerable users do not have protection against disconnections or social tariffs, and social housing programs for energy efficiency and PV are restricted to the part of the low-income group that has ownership of a house pre-approved credit and formal work. The tariff subsidy scheme is not scoped to special social groups and its continuity is unclear, putting part of the population to an energy vulnerability state. Awareness campaigns and the CRE position to better regulate CFE action concerning vulnerable and low-income were also not found.

With the use of available scientific information and available technical knowledge on energy efficiency, they could be potential tools to tackle affordability and efficiency aspects of EP, having a set of policies addressing in the short and long term. Mexico is one of the first and only countries in the Latin American region to count on a national study on EP based on a scientific developed and adapted method on energy services inside homes (García-Ochoa & Graizbord, 2016). The incorporation of EP aspects in its agendas would permit policies and programs to go beyond the access matter and address also equipment efficiency and existence issues, addressing EP underpins and aspects that go beyond electricity access.

7.1.3.3. Supporting DCPV Application

The Mexican regulation supporting DCPV can be considered in favor of innovative applications, taking into consideration its initial phase. DG regulations and funding seem to be in a right and progressive moment, even with turbulences regarding the new government's position on central renewable energy central plans and recent interventions on the energy market. In a scenario of existing public expenditures for its tariff subsidy scheme, the focus on net metering, net billing and energy selling schemes is suitable compared to the costs and long-term dropping of a possible feed-in tariff scheme. The three available possibilities for individual generation give room to monetization and freedom of choice to the user. As said in Energy Poverty analysis, collective DG opens a path to a range of new business models and innovative applications. In this matter, Table 26 summarizes the support scheme found in this research for DCPV.

Another positive regulation extended to DCPV is the possibility of CEL emissions, which may bring more interesting paybacks to projects, especially to those who focus on selling the energy to CFE.

A critical point is that current regulation does not cover gaps mentioned in the literature review, such as rules specifying the discarding of equipment and programs for capacitating people for maintenance. These are key points for the sustainability of the programs and are crucial threats in the mid and long-term.

Public funding to support DCPV application was also encountered coming from different institutions aiming energy savings, energy transition, electrification programs and energy efficiency programs. This gives a possible interpretation of the holistic vision SENER has of the complementarity DCPV applications can have to different goals of the energy policy and its protagonism on rural electrification programs, since PV is the targeted technology for this kind of funding and policies. Subsidies are also applied in some of these funds to make PV equipment more affordable.

The only policy that could be classified is “Awareness” is the NAMA on sustainable social housing, which shows a gap that is commonly a barrier in countries in an initial phase of DG applications. There is room for specific programs to foster the knowledge and the possibility itself of having DCPV for the final user.

Finally, the analyzed DCPV application policy targets different groups and have a positive penetration strategy through different funds and specific programs. It is possible to conclude that Mexican programs have fostered energy efficiency and tackled climate change especially in the residential sector.

7.1.3.4. SWOT Analysis

To conclude this session, a summary of the main points approached is represented in Figure 37, in a Strengths, Weaknesses, Opportunities and Threats (SWOT) matrix. While strengths and weaknesses come from within the system, threats also contain elements from outside the policy sphere that may impact its goals. The window of opportunities contains already mentioned potentialities to drive the analyzed policy scenario to poverty and energy poverty alleviation contemplating current regulation.

Strengths

- Pro-decentralization
- Contemplate PV System in different applications – off grid and grid-connected
- Existing policy for emarginated urban communities focusing efficiency, affordability and electrification
- Gives space to innovation in DCPV application and businesses models

Weaknesses

- Do not consider the 20-30 years lifecycle of PV System and replacement
- Do not scope the most vulnerable and poor people
- Do not recognize – and sometimes generate more-energy poor
- Funding do not contemplate energy poor
- Regulations do not consider equipment discarding

Opportunities

- To include energy poor as priority in pilot projects;
- To develop specific programs focusing on collective DG for emarginated urban communities;
- Better scoping of existent policies
- To develop a specific policy for energy poverty.

Threats

- Failure of long-term solution due to lack of maintenance and capacitated people
- To end tariff subsidy and generate more energy poverty
- Changes in policy and discontinuity of norms and existing support scheme
- Corruption

Figure 37. SWOT Analysis of Mexican Policies

7.2. Scenarios for La Pila Delegation

This section presents the developed scenarios for the case study, based on the energy poverty assessment and the possibilities contemplated in the regulation. Policy support will be discussed in the end.

As described in the Methods session, the three scenarios contemplate two possibilities that aim to take advantage of the grid-connected characteristics of La Pila and of the available Mexican regulation for distributed and decentralized generation. The first is a simple grid-connected application (GC) composed of solar panels, cables, inverter and bidirectional meter that exchanges energy with the grid. Therefore, it works only when the grid is active. The second is a grid-connected system with a battery bank as a backup system (GC + Batteries) in cases of grid supply interruption, working as an off-grid system. It has the same components of a GC plus a battery bank, and it may contain other specific parts. It depends on whether the system is done using proper inverter technology[7] or with an alternative solution designed by an electrician engineer.

Scenarios do not cover the dimensioning of the DCPV. Financial savings represent the minimal benefit it could bring to families and do not contemplate the system's cost. The full version of the scoring system and the descriptive matrix used in the social assessment are available in Appendix B.

7.2.1. Individual Household DCPV application

This scenario comprises a distributed generation modality in individual applications. The household would acquire and have the ownership of a photovoltaic energy system for its own use applied in its rooftop. The scenario, also referred to as Scenario 1 in this section, considers the application of PV under the net metering scheme (RES/142/2017, 2017).

An individual GC application shows a low impact on the encountered energy poverty scene and a medium impact on the other dimensions (Table 28). Energy security issues are the less impacted by this possibility, while, on the other hand, the affordability issues encountered among the energy vulnerabilities could be majorly solved by the appliance. When adding a battery component to the PV, a high impact is encountered in the dimensions influencing EP, due to capability it has to provide energy security to the user tackling energy injustices and the also access component of energy vulnerabilities (Figure 38). All the positive aspects provided by the pure GC appliance continues, aggregating the security in the supply benefit.

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[7] Inverters that are capable of both working with the grid-connection and of supplying/being supplied by the battery bank. Examples of inverters available in 2020 are the models All-in-one, manufactured by the company Solar Edge, and Victron Outback, manufactured by Victron Solar.

Table 28. Scenario 1 – Scoring of the social impacts

Identified Issues	Individual Application	
	GC	GC + Batteries
Energy Poverty	Low	Medium
Dimensions influencing on energy poverty	Medium	High
Energy precarity	medium	medium
Energy vulnerabilities	medium	high
Energy security	low	high
Energy justice	medium	high

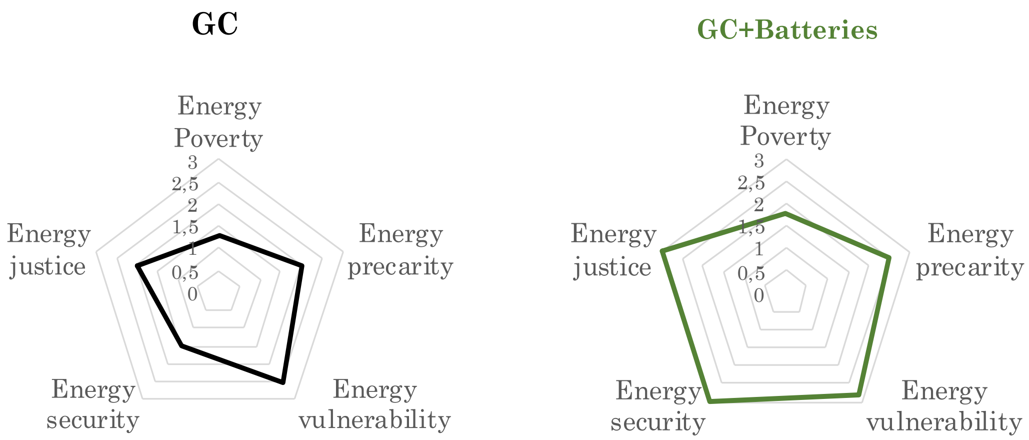

Figure 38. Social impacts predicted in Scenario 1 for the case study

The financial benefits found for this scenario are considered the same for GC and GC + batteries cases (Table 29). This distributed generation PV application provides monthly savings of 92,78 Mexican pesos to its users, representing yearly 1.113,36 for the household, and considering its 30-year lifecycle, 33 400 Mexican pesos. Extra annual incomes can be provided by the emission and sale of clean energy certificates (approximately 20 dollars per injected MWh) and by profiting with the energy surplus annual remuneration predicted on the net metering regulation.

Table 29. Financial benefits for Scenario 1.

Description	Tariff Cost for government	Tariff Cost for the HH	Consumption (kWh/month)	Energy bill - household	Energy bill - federal government (subsidies)
Range 1 - Basic	3,53 MXN	0,84 MXN	75,00 MXN	62,78 MXN	264,98 MXN
Range 2 - Intermediate	3,36 MXN	1,01 MXN	17,00 MXN	17,20 MXN	57,09 MXN
Total (withouht taxes)				79,98 MXN	322,06 MXN
Total (with taxes)				92,78 MXN	322,06 MXN

Since the tariffs are subsidized, the federal government would perceive the higher amount of financial benefits that comes tariffs subside avoidance. Yearly, the savings represent MXN 3864,73 in the scenarios and its 30-year lifecycle, 115 942 Mexican pesos per household that applies it.

Table 30 expresses the environmental benefits, translated on the quantification of emissions that a kWh generated by the PV avoids when comparing by the same amount being produced by the Thermoelectric Villa de Reyes. For this first scenario, the environmental benefits are the same for both analyzed PV applications, where a single PV individual application would avoid the emission of 25 tons of carbon dioxide in its 30-year lifecycle. Figure 39 represents the amount of kg avoided concerning other pollutants. The second most significant impact is on the SO^2 avoided emission, that sums up 607 kg in the lifecycle, followed by NO^x representing 40kg avoided kilos. All the other pollutants have their avoided emissions between 0 and 5 kg in the PV lifecycle.

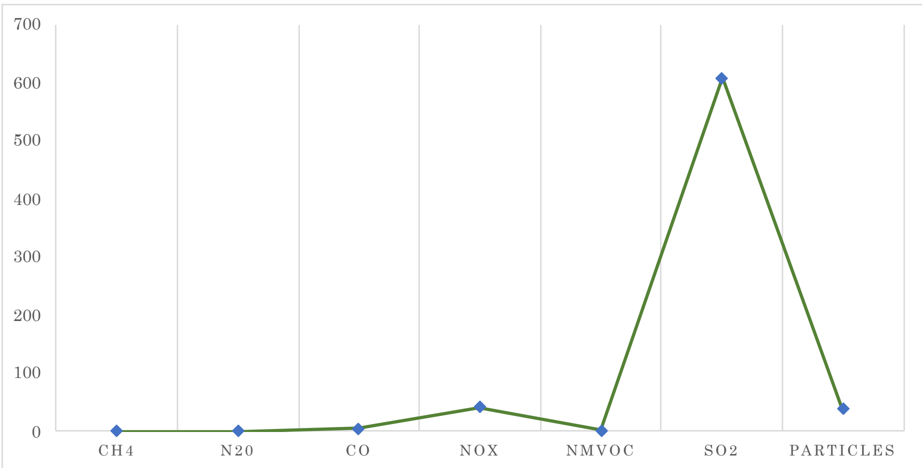

Figure 39. Comparison of avoided emissions for Scenario 1 (excluding CO_2)

Table 30. Monthly, Annual and lifecycle's avoided emissions for Scenario 1.

Period of time	Pollutant (kg)							
	CO2	**CH4**	**N20**	**CO**	**NOx**	**NMVOC**	**SO2**	**Particles**
Montlhy	71,43	0,00	0,00	0,01	0,11	0,00	1,69	0,11
Yearly	857,11	0,01	0,00	0,17	1,34	0,03	20,25	1,28
Lifecycle	25713,21	0,30	0,10	5,07	40,14	0,76	607,45	38,49

Assuming a linear generation of 92kWh/month

The water consumption avoidance per kWh generated by the PV system is of 333 L in its entire lifecycle and 11,13L per year (Table 31).

Table 31. Water consumption avoidance for Scenario 1.

Period of time	Water Consumption (m3)	Water Consumption (L)
Montlhy	0,001	0,93
Yearly	0,011	11,13
Lifecycle	0,334	333,79

7.2.2. DCPV application in Public Schools

This scenario comprises of a decentralized generation modality applied in public schools' rooftops or available areas. The ownership of the system would be of the public school (local government), having as beneficiaries of the electricity production the school itself and group of La Pila's inhabitants. In this case, the battery system would be physically installed in the school and would be able to feed its load only. This scenario (Scenario 2) takes into consideration the application of the collective distributed generation modality under the net billing scheme, since beneficiaries would not have the same types of tariff (Acuerdo Num A/XXXX/2019, 2019). The regulation does not offer a limit on the maximum number of participants, but the installed capacity of the generator must respect the limit of 0.5MW predicted by law.

Both grid-connected and grid-connected applications of Scenario 2 are considered to have a low impact on energy poverty scene found for La Pila (Table 32). Its contribution can be summarized in benefits brought by releasing the energy burden coming from electricity tariffs. Nevertheless, it has other positive impacts on some energy precarity aspects of the community, especially for avoiding that parents pay extra fees to schools so they can maintain electricity working and for the ability of protecting people from energy tariffs fluctuations coming from political decisions. Vulnerability matters are also tackled and affected in a medium scale, specifically the aspects involving affordability.

Table 32. Scenario 2 - Scoring of the social impacts

Identified Issues	**Public Schools**	
	GC	GC + Batteries
Energy Poverty	Low	Low
Dimensions influencing on energy poverty	Medium	Medium
Energy precarity	medium	high
Energy vulnerabilities	medium	medium
Energy security	low	medium
Energy justice	medium	low

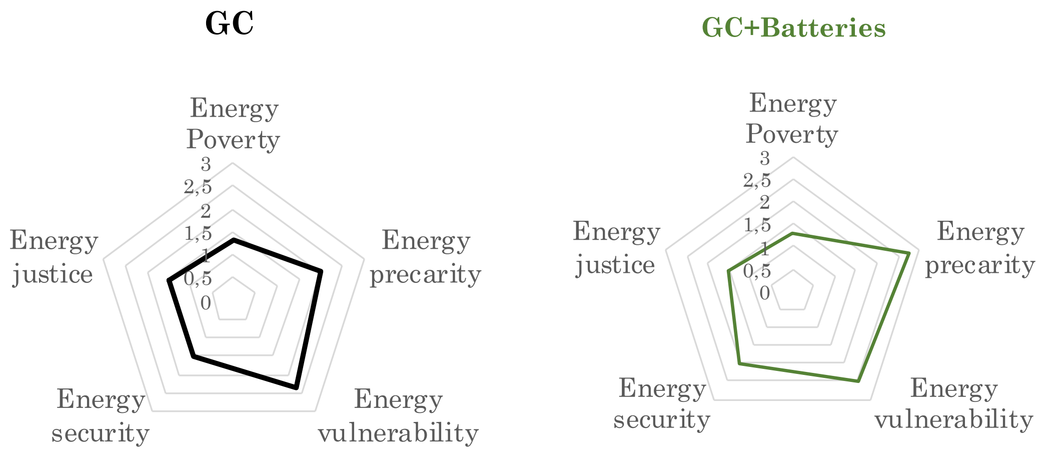

Figure 40. Social impacts predicted in Scenario 2 for the case study.

For the fact that the battery system would be linked to the inverter present in the school, Scenario 2 does not have the potential of providing energy security to households. Nevertheless, it is capable of assuring reliable energy to the school that is also affected by energy interruptions, affecting precarity issues in a higher intensity than the pure GC (Figure 40).

This scenario provides more distributed financial benefits, since savings coming from energy tariffs of the public school (owned by the local government), La Pila households and the federal government. The quantification can be described as aggregating to Scenario 1 the amount paid by the public schools, which is calculated to be approximately 1000 Mexican Pesos per month. In the year, the local government would save close to MXN 12 000, and in the 30-years lifecycle, MXN 355 thousand.

Table 33. Financial benefits for Scenario 2.

	Cost for government	Cost for the HH	Consumption (kWh/mes)	Energy bill - household	Energy bill - local government
Fixed Fee	47,69 MXN				47,69 MXN
PDBT Tariff	3,60 MXN	-	225		810,00 MXN
Total (without taxes)				- MXN	857,69 MXN
Total (with taxes)				50,00 MXN	987,29 MXN

The savings are scaled-up to the number of inhabitants that would compose the scheme. As a net billing modality, some additional practical bureaucracy is added up here, such as the need for an invoice emission by the system administrator (which could be the responsibility of a group of parents) and only after the subsequent discount on the energy bill.

The avoided pollution for this scenario follows the same pattern as Scenario 1, but with higher quantification and a more significant impact because it englobes a higher generation in total. The emissions avoidance for the public schools sums up 62t of CO_2 in the system lifecycle, 1485,62 kg of SO_2 and 94 and 98kg for particles and NO_x (Table 34).

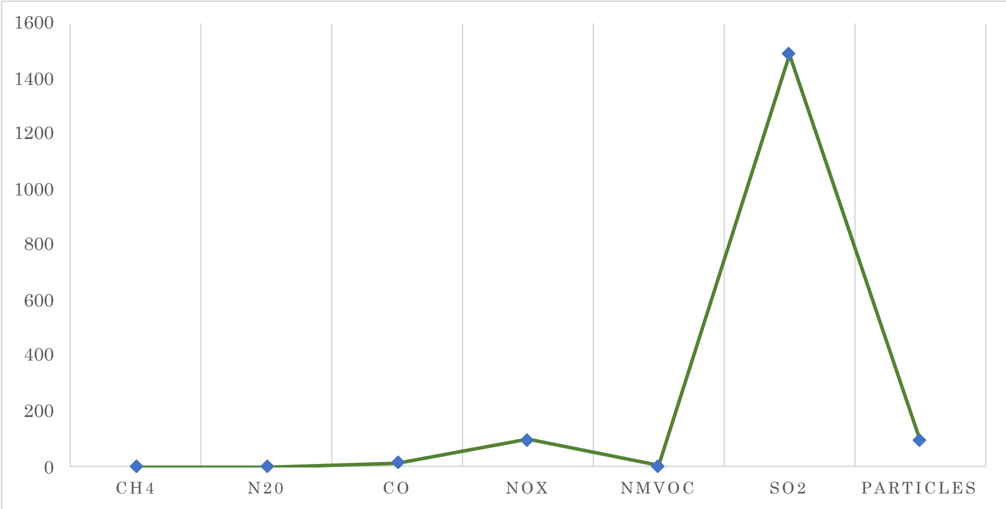

Figure 41. Comparison of avoided emissions for Scenario 2 (excluding CO_2).

Table 34. Monthly, Annual and lifecycle's avoided emissions for Scenario 2.

Period of time	Pollutant (kg)							
	CO2	CH4	N20	CO	NOx	NMVOC	SO2	Particles
Montlhy	174,68	0,00	0,00	0,03	0,27	0,01	4,13	0,26
Yearly	2096,19	0,02	0,01	0,41	3,27	0,06	49,52	3,14
Lifecycle	62885,57	0,73	0,24	12,39	98,17	1,86	1485,62	94,12
				Assuming the pilot school's consumption of 225kWh/month				

Summed up with these benefits are the numbers found in Scenario 1 for the individual household application (see Table 30. Monthly, Annual and lifecycle's avoided emissions for Scenario 1.), meaning 25t of CO_2 per beneficiary household.

The avoided water consumption is also applied to the generation provided by the school system, which would be of 164430L in its entire lifecycle (Table 35). Summed up to it is the amount of 333L per household that enters as beneficiary.

Table 35. Water consumption avoidance for Scenario 2.

Period of time	Water Consumption (m3)	Water Consumption (L)
Montlhy	0,457	456,75
Yearly	5,481	5481,00
Lifecycle	164,430	164430,00

7.2.3. Community Ownership DCPV Application

This scenario (Scenario 3) comprehends a decentralized generation modality applied either as a microgrid between a group of households or a single system implemented in an available private area. The ownership of the system would be collective, having as beneficiaries the same group of La Pila's inhabitants that owns the DCPV. In this case, the battery system would be physically installed in each house as an optional item. This scenario takes into consideration the application of the collective distributed generation modality under the net metering or net billing scheme, depending on whether the group of households shares an interconnection point or not (Acuerdo Num A/XXXX/2019, 2019). As in the last scenario, the regulation does not offer a limit of maximum participants, but the installed capacity of the generator must respect the predicted limit of 0.5MW.

The social impacts of Scenario 3 are the same as Scenario 1, because it would consist of scaling up the individual findings to a group of households. Effects on EP and the other dimensions are higher when the battery is added (see Table 36 and Figure 42), It provides energy security and, consequently, addresses different aspects of energy justice, precarity and the access component of energy vulnerability. Nevertheless, because of the collective ownership that this scenario proposes, it has benefits and impacts on community capacity building and social cohesion which are particular of it and will be better discussed in the next session. There is also a viability aspect that will be further mentioned.

Table 36. Scenario 3 - Scoring of the social impacts

Identified Issues	Community Ownership	
	GC	GC + Batteries
Energy Poverty	Low	Medium
Dimensions influencing on energy poverty	Medium	Medium
Energy precarity	high	high
Energy vulnerabilities	medium	high
Energy security	low	high
Energy justice	medium	high

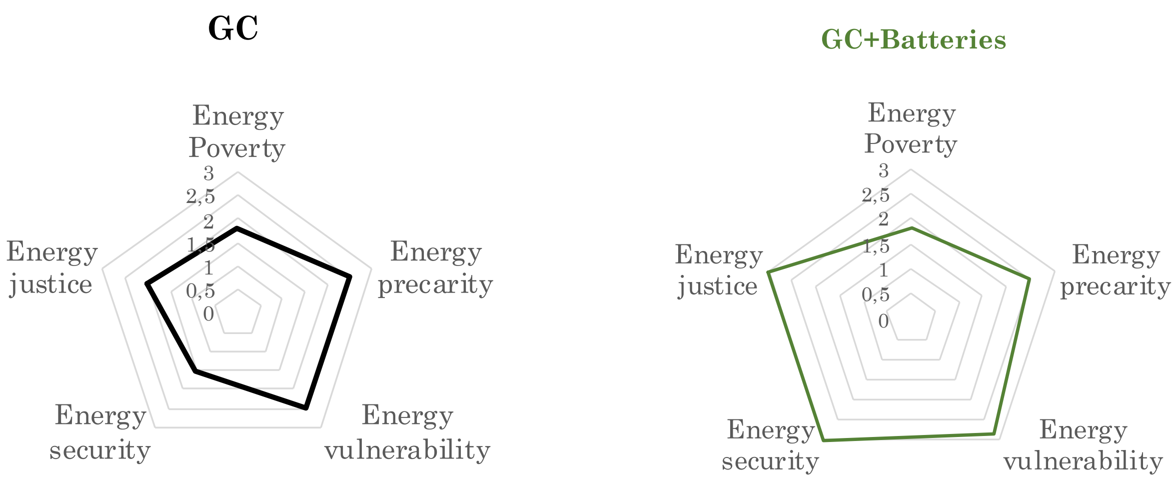

Figure 42. Social impacts predicted in Scenario 3 for the case study.

The financial benefits for Scenario 3 are also described as scaling up the results of Scenario 1 to a group of households (Table 37. Financial benefits for Scenario

1.) For each group of 10 families, the government would earn MXN 3220 per month, summing up MXN 38640 per year. Households could also benefit from selling the energy surplus and clean energy certificates to the CFE.

Table 37. Financial benefits for Scenario 1.

Description	Tariff Cost for government	Tariff Cost for the HH	Consumption (kWh/month)	Energy bill - household	Energy bill - federal government (subsidies)
Range 1 - Basic	3,53 MXN	0,84 MXN	75,00 MXN	62,78 MXN	264,98 MXN
Range 2 - Intermediate	3,36 MXN	1,01 MXN	17,00 MXN	17,20 MXN	57,09 MXN
Total (withouht taxes)				79,98 MXN	322,06 MXN
Total (with taxes)				92,78 MXN	322,06 MXN

Environmental impacts can also be translated by applying the individual values found in Scenario 1 to a household group. Simulating a group of 10 households, the emission of 257t of carbon dioxide would be avoided during the system's whole lifecycle. SO2 levels would also be multiplied by 10, representing 6070kg.

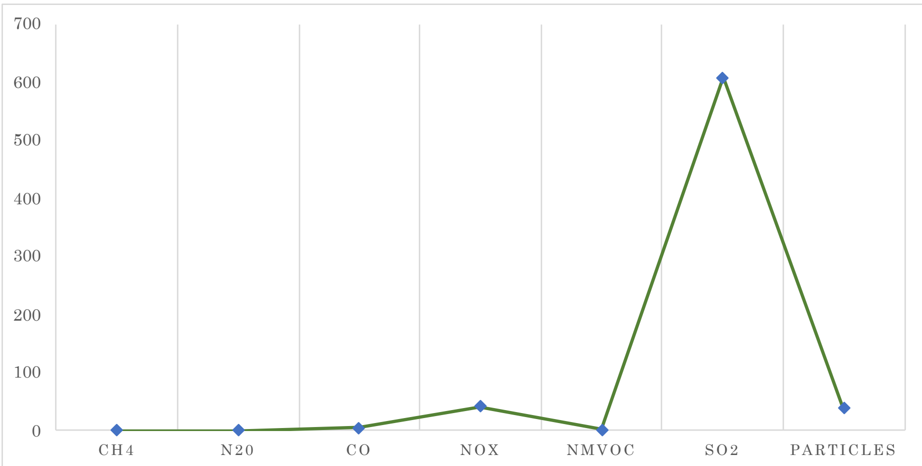

Figure 43. Comparison of avoided emissions for Scenario 1 (excluding CO^2)

Table 38. Monthly, Annual and lifecycle's avoided emissions for Scenario 1.

Period of time	Pollutant (kg)							
	CO2	**CH4**	**N20**	**CO**	**NOx**	**NMVOC**	**SO2**	**Particles**
Montlhy	71,43	0,00	0,00	0,01	0,11	0,00	1,69	0,11
Yearly	857,11	0,01	0,00	0,17	1,34	0,03	20,25	1,28
Lifecycle	25713,21	0,30	0,10	5,07	40,14	0,76	607,45	38,49

Assuming a linear generation of 92kWh/month

The water consumption avoidance would also escalate 10 times, representing 3337L of water in PV's lifecycle.

Table 39. Water consumption avoidance for Scenario 3.

Period of time	Water Consumption (m3)	Water Consumption (L)
Montlhy	0,001	0,93
Yearly	0,011	11,13
Lifecycle	0,334	333,79

7.3. Discussion – Contribution of the DCPV Scenarios to La Pila

The impact assessment results on energy poverty show that Scenarios 1 and 3 with the battery component would have the most considerable impact on energy poverty, since it is a phenomenon observed within four walls and its benefits go straight to the household (Table 40). Nevertheless, in any of the scenarios DPCV is a panacea for the energy poverty scene encountered in the case study for leaving two open gaps in the identified aspects.

Table 40. Summary of the impact assessment results

	Individual Application		**Public Schools**		**Community Ownership**	
	GC	GC + Batteries	GC	GC + Batteries	GC	GC + Batteries
Energy Poverty	Low	Medium	Low	Low	Low	Medium
Other socio-energy dimensions	Medium	High	Medium	Medium	Medium	Medium
Energy precarity	medium	medium	medium	high	high	high
Energy vulnerabilities	medium	high	medium	medium	medium	high
Energy security	low	high	low	medium	low	high
Energy justice	medium	high	medium	low	medium	high
Avoided CO2 Emissions	25713 kg		25713 kg per household		25713 kg per household	
Avoided Water Consumption	333L		333L per household		333L per household	
Household's Savings	MXN 33 400		MXN 33 400 per household		MXN 33 400 per household	
Local government	-		MXN 355 000		-	
Federal Government	MXN 115 942		MXN 115 942 per household		MXN 115 942 per household	

First, even if electricity is affordable and secure, it does not directly affect the degrees of energy poverty found in the delegation (see Table 20. Energy Poverty degrees and groups for the sample.) since it has no direct impact or can ensure the presence of the necessary economic goods that deliver the energy service, such as refrigerators. Even though savings provided by DCPV alleviate the energy burdens and may create financial opportunities for buying missing home appliances and the called desired rebound effect, it cannot be assured that families will do it. An effective energy poverty alleviation contemplating the application of DCPV needs to be complemented with strategies to ensure the acquisition of the necessary economic goods.

Secondly, in any of the proposed scenarios, DCPV would have direct contributions to water heating and cooking and, consequently, cannot wholly contribute to the energy service delivery of the extreme energy poverty group. Figure 44 expresses with the red colored squares the impact of DCPV on the energy service delivery of the case study, considering the five energy service contemplated in this research. LPG's affordability would still be a problem, since inhabitants express a more serious concern in affording LPG bills than electricity bills. With the DCPV's implementation, there is also a window of opportunity on checking the community acceptance of migrating to stoves and showers that rely on electricity. Even though they are culturally not used in La Pila, they are available in the Mexican market, and their adoption would allow DCPV to have an impact on all La Pila's fundamental energy services. Nevertheless, this possibility is recommended only in scenarios where batteries are applied due to their potential of ensuring energy security to its users, otherwise, their energy vulnerability is increased by diminishing their energy flexibility and putting then in total dependence of electricity to supply their fundamental energy needs.

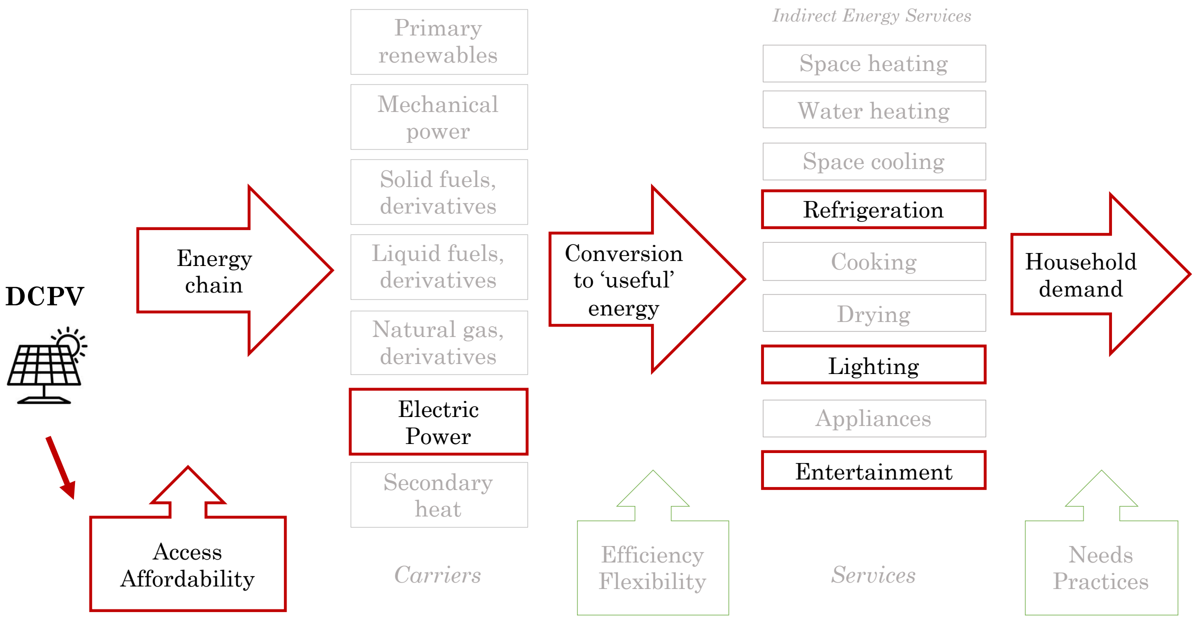

Figure 44. Impact of DCPV on the energy service delivery of La Pila. Adapted from Bouzarovski & Petrova, 2015.

Concerning the energy precarity aspects, the impacts of all three scenarios are similar and remain on the independency provided by DCPV regarding the electricity market and its tariff variations. The GC + batteries possibilities are able to provide extra protection to the users of decisions regarding energy interruptions, either because of grid instabilities or by seasonal increase in the regional demand. The only scenario that would be able to avoid that parents pay a monthly fee to keep school infrastructure, considering that this reality is also present in other public schools, is when the public school is also a beneficiary of the DCPV (Scenario 2). This explores a potential allowed by Mexican regulations, where public spaces are also affected by energy precarity and vulnerabilities found in the delegation. Even though the concept of EP is restricted to household level, people are also affected by the electricity deprivation in spaces of public interest, especially when it is also so related to poverty as schools. When such spaces can also be secured and involved in DCPV participation, it has the potential of tackling more aspects of poverty and its indicators.

Regarding the energy vulnerabilities, all scenarios have a considered high impact on the affordability aspects contemplated in the matrix. With an energy self-generation, the household, groups of families and the school registered as beneficiaries can be immune to tariff variations and of changes in policymaking or regarding tariffs. This is especially true in Scenario 1 and 3 with the application of net-metering schemes. The calculations for consumed and injected energy occur first and duties are only charged when there are not enough energy credits to be debited. Moreover, all three scenarios will positively impact families' energy burdens for bringing zero expenditures with electricity. Although the appliance of the savings provided by the DCPV is an individual household decision, it is expected that more available money will also contribute to the positive rebound effect. Therefore, it can alleviate the low-income scenario, as the considered sample energy burdens on electricity represent 1 to 22% of their total income.

In any scenario, DCPV systems can provide energy access to the part of the community that remains grid disconnected. The impacts would then be unable to reach the 3% of La Pila's delegation that does not have access to electricity, which could not be benefited from the application of DCPV since the penetration of DCPV itself depends on access to the grid. For the grid-connected inhabitants, the application of batteries would provide security against the energy supply interruptions reported by the interviewers, present both in energy vulnerability and security aspects. Hence, all DCPV scenarios also bring protection against factors described by Jenkins et al. (2016) as part of the energy security emergent insecurities. In La Pila case, the price variations or scarcity of natural resources used as inputs to traditional electricity generation refer to the thermoelectric generation, namely water and oil.

An important discovery of the impact assessment is the contribution of DCPV to the seasonal energy poverty described. According to the registers, the period of March to May is the greatest output potential of DCPV for La Pila region (SolarGis & World Bank Group, 2019), and it partially coincides with the higher demands and most frequent energy interruptions. The battery backup system plays an important role in this aspect. With houses having the capacity of self-supply and a backup system, it alleviates the grid overload and protects them interruptions that cut their electricity-related energy service delivery. In Scenario 2, it would especially provide energy security for the school activities, ensuring electricity related infrastructure for its activities and ending the existence of this energy injustice that could also influence the delivery of educational services, essential to poverty alleviation. On the other hand, the pure GC appliance would not protect the inhabitants or the school of the seasonal energy poverty with the current grid conditions. The main impact on energy injustices, however, rely on the fact that in all considered scenarios and technical applications DCPV would protect its beneficiaries from the gap found in the policy analysis regarding special protection to the low-income population. When producing their own electricity and not having to pay electricity bills, protection form electricity disconnections due to the unaffordability of energy bills are an automatic benefit.

For all that has been described in the last paragraphs, it is possible to conclude probably the main finding of this study: even though DCPV has a limited impact on addressing the found levels of energy poverty on the community directly, it has the potential of tackling other socio-energy related issues that contribute to the maintaining and formation of EP, considering the current Mexican policy and regulation. Because of discovered matters on the grid reliance and stability, this potential is maximizing when adding batteries to houses.

Moreover, decentralizing the property of energy generators to its users bring several social benefits that are described in the social literature considered (Barquero, 2016; Ostrom, 2011; Riutort Isern, 2016; Roberts et al., 2014). This is also applicable to the scenarios proposed, and each one has particular pros and cons.

Scenario 1 predicts individual ownership of the PV system. This type of property brings simplicity in decision-making processes and financing. It is socially less complex than all the other scenarios that are here proposed because only the household and its family would decide what is best for them. Previous research executed to check the acceptability of community energy systems in Chihuahua, Mexico, showed that the inhabitants would prefer acquiring individual systems than financially contributing to a collective one (Barquero, 2016). As in any other scenario, this user obtains emancipation of the current electricity system as an active player on the energy transition (*produser*), which is already a social innovation in the context of the community.

Scenario 2 provides an innovation component for decentralizing common energy systems ownership and distributing energy governance to the local government and La Pila inhabitants. Having the property of the DCPV and including inhabitants as beneficiaries, the local government would be then actively choosing, in the first place, to enter as a player in the energy scene and locally promote the clean energy, transition contributing to local and national goals. There are examples in countries like Germany, England and Denmark where municipalities are the owners and managers of local electricity distribution involving community participation to create energy cooperatives (Roberts et al., 2014).

In second place, it would be actively acting in a geographical area where low-income levels and energy poverty are present, using the electricity as a tool to improve people's life providing them affordable or free energy to satisfy a number of fundamental needs that are put in risk because of the current scenario. As in the other scenarios, this would also mean redirecting energy generation to a socioenvironmental cause and disrupting the paradigm that energy should be exclusively a market good in grid-connected areas. Nevertheless, Scenario 2 exemplifies how the local government's leadership and example can be outstanding, especially to make such kind of project feasible for its costs related to the initial acquisition, replacement of equipment and necessary workforce related to maintenance. Also true to Scenario 3, using common or available areas to collective generation gives the possibility of self-generation to people who either cannot afford a system alone or do not have proper house infrastructure or conditions to receiving PV panels, as also observed by Riutort Isern (2016) in his book.

The proposal of the third scenario of collective ownership contrasts as an alternative to individual generation and purchase. This scenario is the one that requires the highest level of organization and social cohesion among the beneficiary group because it requires people with defined roles for administrating the generator contract and doing or being responsible for the necessary maintenance. At the same time, such spaces allow the creation of social cohesion to enhance the dialog, sociability and the creation of a community that can collectively learn how to manage their own resources and needs (Ostrom, 2011). Previous cases where local collective governance and management of energy exist shows that individual are able to organize themselves about energetic resources, without the need to have external authorities (Ostrom, 2011). Even though such organization is susceptible of tensions and weaknesses like any forms of social organization, collective solutions have been proven to be efficient in many contexts (Riutort Isern, 2016).

As a last observation in the ownership discussion, Scenario 3 has a potential of building community capacity for bringing a possibility where people are the owners of the means that guarantee their livelihood that contribute to local empowerment (Riutort Isern, 2016). If successful, the community can look to extend this type of initiative to other areas of the delegation contributing to the democratization of access to natural resources that are usually centralized in a market logic. This is especially true for La Pila and could also be a key factor in improving its resilience since, as registered by Cisneros Vidales (2018) it has a high dependency on San Luis Potosi city for water and food supply.

A crucial point to the sustainability of the PV system, in any scenario, is capacitating its users to do the system maintenance. Mexico has documented examples in the last decades of the last century, where solar energy projects with high initial investments by governmental and international aid funds became a failure due to lack of proper maintenance and local knowledge on how to handle its problems (Bermudez-Contreras, 2009). In a situation where PV systems are applied to energy poverty alleviation, families would potentially depend on the technology to afford and guarantee their supply to the energy services delivery and are vulnerable vulnerability to falling into EP states again.

For that, the implementation and maintenance of DCPV are expected to create occasional jobs within the community that could contribute to extra income and new professional skills and dissemination of competences to the inhabitants (Denholm et al., 2014; Vezzoli et al., 2018). This has already been observed in Francisco Gonzalez Bocanegra school, where a group of parents is responsible for cleaning and maintaining the PV panels. A growing renewable-energy scene that requires such skills may lead to job opportunities for the involved community members.

As clean energy generators, DCPV provides positive environmental outcomes in all the scenarios. Even though there is a carbon dioxide emission associated with its equipment fabrication, it is still symbolic (approximately seven times less according to COPAR, 2015 values) compared to the total emission of a thermoelectric generation process. The quantified results for the scenarios are low, showing that representative environmental impacts escalate as more beneficiaries are involved.

This study's initial intent to check the existence of local deforestation and local air pollution due to the use of firewood to cook could not be verified. Nonetheless, it is relevant to point out that the situation would not be impacted by DCPV application unless the available economic good is replaced with electricity-based ones.

When it comes to other environmental impacts, the main emissions that could be avoided when using DCPV are namely CO_2, NO_x and SO_2, which are greenhouse gases (GHG) associated with the accelerated climate change that the biosphere is facing today (Medellín Milán, 2002). Notably, the planet's boundaries for carbon dioxide are already reaching its upper limit. Apart from its impacts in the planet biodiversity and general functioning of diverse ecosystems, it also impacts human health (Rockström et al., 2009). Diseases and symptoms associated with the GHG generated by the Villa de Reyes Thermoelectric goes from simple headaches to pulmonary cancer (Medellín Milán, 2002) affecting also La Pila's inhabitants. Hence, it is never enough to reinforce, as well stated by the Intergovernmental Panel on Climate Change (IPCC, 2018), that the most vulnerable people to climate change effects are poor people. In San Luis Potosi, 70% of the existent air pollution comes from energy generation and initiatives to avoid the growth of emissions are considered critical (Ávalos Lozano et al., 2015).

The benefit found in water savings is also more representative in the proportion that more households are benefited from DCPV schemes. Considering Cisneros Vidales' (2018) findings that a single household in La Pila has a monthly consumption of 15616L, the system lifecycle's deliveries a saving of 333L per household is symbolic and would not be impactful for their water security considering a low PV penetration. However, considering that San Luis Potosi is a water scarcity zone, DCPV represents the possibility of untying the energy generation of water consumption and contributing to the region's resilience against climate change effects.

Finally, it is essential to clarify that the implementation of PV technology would not mean the closure of the thermoelectric operations and stop its emissions. However, it illustrates the impact that investing in DCPV to supply the growing energy demand of the region and its communities could have, potentially mitigating the ecological and water footprint associated with residential and small-scale energy consumption. Deeper on this argument, these findings can also be interpreted as the environmental costs linked to the community's electricity subsistence, meaning the price that the environment pays for keeping the current centralized energy plants. In the current scene, the energy generation, that as stated by González-Eguino (2015) is required for their fundamental needs supply and for local human development, has externalities that threaten their own health, quality of life and availability of other natural resources.

Economically speaking, investing in new DCPV power plants is also becoming a competitive option for the government contrasting to new central power plants. In this matter, SENER announced strategies of modernizing the existing conventional thermoelectric to the combined cycle technology to expand electricity generation with lower emissions (Programa de Desarrollo Del Sistema Eléctrico Nacional, 2018). Table 41 illustrates the comparison between the levelized cost of energy (LCOE)[8] of the technologies. Using as a reference the LCOE found by Hernandez-Escobedo et al (2020) for a commercial PV system project in Queretaro, Mexico, the PV technology cost is cheaper than conventional thermoelectric, but eight cents of US-dollar more expensive than the combined cycle. The LCOE value published by CENACE does not contemplate the annual extra environmental costs these type of plan has, meaning the obligation of acquiring CELs of other clean generators. Also, it does not consider the value of the domestic tariff subsidies that PV technology could avoid for the government, as demonstrated in this study results, especially in higher penetration.

Table 41. Comparison between technologies - LCOEs

Type of Technology	Source	LCOE
Combined Cycle Thermoelectric	CENACE (2015)	US$0.076/kWh
Conventional Thermoelectric	CENACE (2015)	US$0.175/kWh
Commercial PV	Hernandez-Escobedo et al (2020)	US$0.155/kWh

*2015 values were updated to 2020 with an inflation of 20,66% (INEGI).

[8] The LCOE is an index used to compare different scenarios for investments in energy projects. It contemplates the initial investment, maintenance and operating costs in the plant lifetime and a discount rate (Hernandez-Escobedo et al, 2020).

The PV technology price is a curve that decreases each year due to its growing adoption and the benefits that scale economy brings to its industry, as stated by Smets et al. (2016). The market has registered short paybacks, meaning that the savings provided by the system are covering its costs after few years of operation (Smets et al., 2016). Regardless no specific study was made for the presented Scenarios, Hernandez-Escobedo et al (2020) found a payback of two years considering a PDBT tariff for Queretaro. For residential cases, the payback is expected to be a bit higher due to the difference of tariffs.

A local solar energy company was consulted in order to have a basis on the initial investment and prices in San Luis Potosi, and a simple GC DCPV system with an average generation of 115kWh/month had an initial cost of MXN 30 000 (approximately 1200 euros)[9]. Bringing the discussion to low-income communities such as the case study, people will hardly have available funds to the system acquisition. In this point lies probably a crucial explanation of the distributional injustice of technologies described by Jenkins et al.(2016), or as in Gündel, Hancock and Anderson's words, "its failure to reach the poor" (Gündel et al., 2001). Since they are inserted in a capitalistic market logic with money as a final criterion for the acquisition of goods, financial support and attractive funding are critical points to its feasibility.

Mexican policy positively provides funding and existing programs that open some windows of opportunity for the proposed Scenarios (Table 42. Available funding for the proposed Scenarios.). In the case of the individual application, only households with the property of the house could apply for the programs or funding which could fit the majority of the families, since in Cisneros Vidales (2018) research, 90% of the interviewed households held the ownership of their houses (Cisneros Vidales, 2018). Nevertheless, reflecting the observed in the policy analysis, funding possibilities exclude the probably most poor and energy poor inhabitants who do not own a house.

Scenario 2 and Scenario 3, on the other hand, can englobe the part of the most energy poor people that are grid-connected in their beneficiary list. The school has different possibilities of funding for being classified as a small business with a PDBT tariff. Considering that in Scenario 3 the ownership would belong to an association or collective form of organization, it could submit the project to available funding with the help of the municipality. Even if not contemplated by this study, the funding possibilities can go beyond the public options, like collective funding or private companies/credit institutions.

[9] Consultation executed in the month of April, 2020, with the company PowerSun. It also includes the services for installing the system. The currency conversion was based in Morningstar registers for 17/08/2020, where MXN 1 = 0,038 Euros.

Table 42. Available funding for the proposed Scenarios.

Scenario 1	Scenario 2	Scenario 3
FATERGED FIDE Hipoteca Verde NAMA Vivienda Sostenible Programa de Mejoramiento Integral Sustentable	FATERGED FIDE FOTEASE NAMA Vivienda Sostenible Programa de Apoyo a la GD	FIDE FOTEASE NAMA Vivienda Sostenible

Even though it has been discussed that the possibilities that contemplate the application of batteries are the ones that produce more social benefits, they also make the cost of the Scenarios more expensive. Batteries add a more expensive initial investment and expenses related to its replacement, negatively affecting the payback and investment indicators. It is also unclear if available public funding and programs contemplate such applications since it is a mixture between the off-grid and the grid-connected appliance. Support or subsidy here would play an important role, based on scientific evidence that having batteries in grid-connected PV systems under self-consumption schemes is only profitable through direct support (Saviuc et al., 2019).

Scaling up

Electricity related energy services are fundamental to satisfy basic needs that are linked to human rights (Décimo Octavo Tribunal Colegiado en Materia Administrativa del Primer Circuito, 2018; Hesselman et al., 2019) and from this approach, one person that has a human rights guaranteed by the application of any of the presented scenarios is already enough reason to its implementation. Even though this study's objective is scoped to a micro social scale that comprises a low PV penetration, we would like to highlight that in the scaling up of this type of application to other vulnerable urban and peri-urban communities resides a great potential impact.

Only in the city of San Luis Potosi (SLP), 207.870 inhabitants live in multidimensional poverty states, probably also presenting degrees of energy poverty (CONEVAL, 2015). Figure 45 illustrates geographically the most preeminent poverty manifestation in the city, which is manifested mainly in peripherical and peri-urban communities. Even though the local impacts on energy poverty are not simple to escalate since it is bounded to the local conditions, some of the characteristics of the socio-energy reality found for La Pila are also applicable to other communities. For also being in the national territory, they are under the same policy gaps and, in the case of SLP, have a regional dependence on thermoelectric power plants.

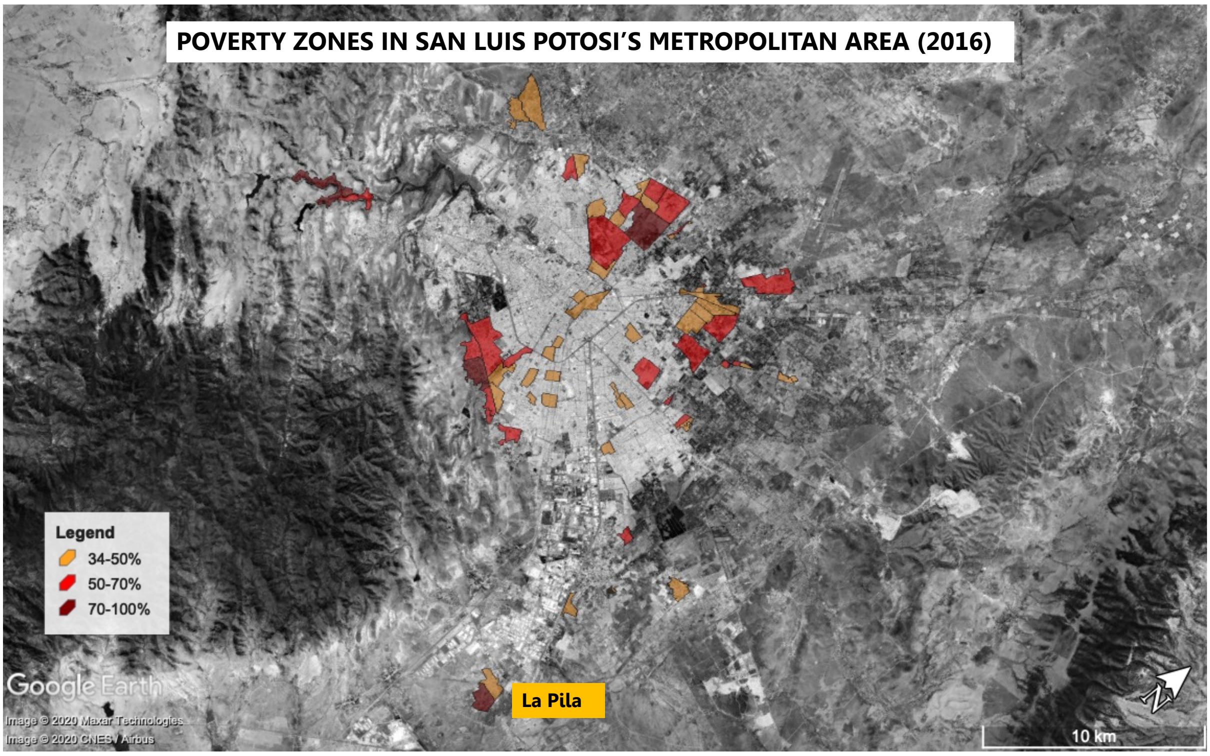

Figure 45. Poverty Zones in SLP's Metropolitan Area. Based on CONEVAL, 2016.

A more quantitative significant manifestation of the environmental and financial effects here found and discussed are expected by disseminating DCPVs to more locations. To illustrate this point, a study conducted by SENER indicated that, if photovoltaic systems corresponded of 1% of the Mexican electric system's total installed capacity, it would be possible to yearly reduce the water consumption in 680 millions of liters of water, reduce 1, million ton of CO_2 emissions and provide annual savings of 1500 millions Mexican Pesos (Secretaría de Energía, 2017).

Contributions to the regional and local electric systems are a co-benefits become visible with a higher PV penetration (Denholm et al., 2014). Acting as a grid supplier, DCPV could avoid the overload and the seasonal energy poverty here described for having its peak generation moment during a time of the day that has the hottest temperatures.

Governments could also obtain financial and economic advantages in investing in the scale-up of this kind of project. An interesting finding of this research is that the national government is the player that could have more financial benefits from the application of the residential DCPV considering the current tariff subsidy scheme. Every household that is a self-supplier of electricity represents a profit for the federal government, as well stated and illustrated by the Bono Solar Program (Iniciativa Climática de México, 2017). Investments in DCPV application in energy vulnerable and poor communities are strategies to give the population autonomy regarding the future of their energy supply and be an alternative to a plan of dropping the current residential subsidies. As argued in this study, it represents a non-sustainable way of guaranteeing energy affordability to the population and an energy precarity matter for low-income Mexican households. In this way, investing in DCPV becomes a smart economic strategy for SENER, being also true here the same logic underpinning the project Bono Solar with a mutual social benefit.

Specifically, the scenario that maximizes the distribution of financial savings to the maximum type of beneficiaries is Scenario 3, which contemplates DCPV application in public schools. The findings of the financial impact assessment demonstrate that it also proportionate savings to the local government. Its scaling up through a public policy contemplating the application of DCPV in public schools, as aimed by this research project, can potentially use the collective distributed generation possibilities to extend its financial co-benefits to the inhabitants, local government and the federal government. Socially, there is a window of opportunity to scope the beneficiaries to a group of energy-poor and energy vulnerable parents, also positively contributing to weaknesses in these communities' socio-energy scenario. Also, for the relation that education has with other poverty indicators, it indirectly contributes to alleviating other manifestations of poverty.

Also, in its scaling up resides the possibility of making significative advances towards goals set by policies and treaties, such to the achievements of a group of Sustainable Development Goals (no poverty, affordable and clean energy, sustainable cities and communities, climate action and decent work and economic growth). It can contribute with significant quantifiable results to the goals set by energy transition (PRODESEN), the democratization of energy and human development.

7.4. Recommendations

A final recommendation to this research project is to expand the current DCPV of Francisco González Bocanegra School and construct a pilot experiment with the appliance of the Scenario 2, where a group of parents of Francisco school would enter together with the school as beneficiaries of the PV generation. In practice, it would imply changing the generator's register with the CFE and creating a contract according to specifications of the resolution XXX, considering its official publication is still pending. The project could benefit from the available funding option demonstrated in Table 42. It is advised that the system is designed to include the predicted rebound effect of the households.

For the next steps, it is indispensable to implement a social participation process and a bottom-up project co-creation of its governance and rules with the parents. The scenario was built according to the project's interests and, due to fieldwork restrictions, did not involve the parents in constructing or checking the scheme's acceptance.

To maximize it reach, it is crucial to develop proper criteria to scope the most energy poor parents, taking into consideration the percentage that energy burdens represent to the families since its main impact will be supporting their energy affordability. In this same issue, it is crucial to align the conditions and period for these beneficiaries to be part of the scheme.

As a suggestion for the experiment's functioning, it is recommended that parents revert part of their savings, even if symbolically, to participate in the scheme and proportionate a better appropriation by the group. The capital can compose a fund that can be used to reward parents responsible for the maintenance of the PV system. Also, to leave a more profound contribution to the families' energy service delivery, the fund can be used to the acquisition of energy-efficient goods that can be redirected to the families who present the most critical levels of energy poverty. The method here used to build the energy poverty scale can be replied to evaluate the reality of the candidates.

More than providing savings and material satisfiers to the inhabitants, the experiment has the potential of breaking the information barrier of the technology's existence and benefits in the community. In other words, it can provide the parents with the opportunity to get familiarized with the PV technology, the existence of a collective scheme, and the co-benefits of DCPVs. It would be ideal that, once parents leave the joint scheme, the project team facilitates paths and information of access to funding for them to organize themselves to migrate to collective or individual DCPVs (Scenario 1 or Scenario 3). This migration would mean a large-term contribution to the energy poverty alleviation scene.

Chapter 8. Conclusions

This study developed a multidisciplinary approach that can be reapplied in other vulnerable communities aiming to understand its energy poverty (EP) and the impact of decentralized photovoltaic energy systems (DCPV) on its alleviation. Its application in La Pila delegation showed that while environmental and financial impacts are more easily quantifiable, impacts on energy poverty are more subjective and extremely tied to the existent socio-energy aspects. Such aspects should be diagnosed with a systemic view in order to understand its relations with the external political environment and socio-technical reality. The approach is not timeless and it is suggested to be revisited and re-evaluated since systems are dynamic and continuously pushed to disruptions and changes (Meadows, 2009).

For La Pila delegation, the energy poverty assessment pointed out that 30% of the sample presents a degree of energy poverty. The majority represents a light EP level, being food refrigeration and entertainment energy services the most deprived. In all degrees of energy poverty, electricity is the base of at least one of the economic goods behind the deprived satisfiers. Even in small proportions, the secondary data also pointed out households that rely on wood to cook and might be exposed to health issues due to indoor pollution.

The financial assessment discovered that the community's energy burdens are more than two times higher than the state average, being liquified petroleum gas (LPG) expenditures the most expensive and representative part of it. It concludes that such a high percentage of energy expenditures is related to the low income that characterizes the interviewed households, which earn approximately one-third of San Luis Potosi's families' income.

The bibliographical and documental research on current social and energy policy uncovered that such policies emphasize the use of off-grid DCPV to provide energy access to disconnected areas through electrification programs, following the classic Latin American approach. Although this discourse is aligned with the alleviation of poverty indicators related to energy, defined by the CONEVAL, policies do not recognize energy poverty or have any specific guideline aiming its mitigation, in a way it might even generate more energy poverty. Protection against disconnections for vulnerable people is also absent in consumer protection law. However, this research found some existent programs and funding under the scope of energy efficiency and energy affordability that contemplate grid-connected DCPV applications. Energy poor and low-income households that fit specific income and house ownership criteria might apply for subsidies and low-rate financing to own a residential PV system.

The current regulation on distributed generation provides possibilities for DCPV generators until 0,5 MW on net metering and net billing schemes or in a total selling agreement. If published, the Collective Distributed Generation regulation gives room to innovation for energy governance and community applications. It opens a path for new possibilities for the appropriation of energy generation and distribution of power to low-income people. Nevertheless, fitting funding for such projects might still be a gap in the execution of such initiatives.

To assess the contribution of DCPV to the delegation, six scenarios were proposed based on the current Mexican regulation. In La Pila reality, DCPV could contribute to the poverty alleviation scene in two essential ways: first, by providing secure and affordable electric energy to the chain of fundamental energy services delivery; second, by positively impacting fragilities of the socio-energy system that directly or indirectly collaborate to the existence of EP in the community. A key finding of this research is exactly this point: the application of DCPV addresses mainly issues orbiting around EP than the EP itself. Scenarios with batteries acting as a backup electricity supplier have been proven to be the most suitable for the case study, providing the energy security that the current electric grid system cannot deliver. By having the potential to provide the community social emancipation regarding its energy governance and generation, it can protect them from policy gaps and political decisions that they have no influence on and affect their daily access to electricity. By generating their own energy using solar photovoltaic (PV) technology, they are changing ownership paradigms and actively being actors of the energy transition to cleaner sources and contributing to the mitigation of GHG gases in their region.

The environmental assessment revealed that as more people are involved in DCPV schemes, the bigger are the positive benefits. The main environmental gains associated with the application of the scenarios are the avoidance of GHG emissions, mainly CO_2 and SO_2. Water savings are also associated with positive impacts and are more visible with a higher penetration of the technology within the community. Still, DCPV could not contribute to the local environmental degradation related to wood consumption unless a replacement of goods happens, since local modern energy services of cooking and water heating in the case study are supplied by liquified petroleum gas. The assessment also demonstrated that the primary potential beneficiary of the non-payment energy tariffs provided by DCPVs is the federal government.

This research also concluded that scaling up DCPV applications to other similar areas has likely quantifiable results on water security and on avoiding the emission of greenhouse gases, highly associated with climate change and Sustainable Development Goals. It also could positively impact a higher number of families tackling socio-energy dimensions, especially their energy vulnerability related to affording energy tariffs.

The project "Sustainability Model for the Governance of Vulnerable Communities" has a window of opportunity to start a pilot experiment expanding the generation capacity of the current PV system and contemplating Francisco González Bocanegra's most energy vulnerable and needy parents as beneficiaries, applying the Collective Distributed Generation scheme presented in Scenario 2.

This initiative would be aligned with Mexican policies' guidelines and goals for energy transition, as well with the current government disposition to promote social innovation for energy democratization through distribution generation.

Nevertheless, it is essential to indicate some limitations and recommendations for the next stages that were not scoped by this research. Even though the available data on the project and previous researches counted with a social participation component, there was a restriction in executing the predicted fieldwork due to the COVID-19 measures. This study executed a top-down approach for the construction of scenarios. Data related to thermal comfort and the relation that electricity has with local water provision could not be checked, as any additional energy service that belongs to the community's cultural background.

Also, an assessment of the acceptance of PV technology is essential to validate the scenarios' feasibility, comprehending a critical component for its next steps. During the realization of this work, informal talk with researchers and professionals working in vulnerable localities reported the experience where households would declare a fear of putting solar panels on their homes due to robbery, violence and esthetic of the house. It is also documented by the literature cases where systems were abandoned after some time because of the lack of the community's acceptance and appropriation (Cota & Foster, 2010). Moreover, the role that energy efficiency has in the local energy poverty and expenditures was not explored by this research and is also an important dimension of its socio-energy reality that should be considered for the next stages.

Some of these thesis results can also provide insights into future research aiming to contribute in the same direction.

It was found that LPG is a substantial energy burden for the families, and it is known that its use to supply fundamental energy services is also frequently observed in other parts of urban Latin America. In this matter, there is an opportunity of investigating the contribution of other decentral eco-technologies, such as micro-scale biodigesters and solar thermal collectors, to the energy poverty manifestation. For being technologies that can be appropriated by vulnerable households and also shift the paradigm of ownership to new players, its complementarity to PV systems as a strategy to energy poverty alleviation could also be assessed. Peri-urban localities such as the case study are potential especially for biodigesters application, usually having small-scale productivity activities that provide their necessary input.

Also, models of governance and social organization around the appropriation of the models of DCPV that uses collective distributed generation schemes and other relevant leverage points for energy poverty alleviation have the potential to be deeper explored. Particularly for Mexico, the approval of the new regulation presents a great momentum for this source of input.

Finally, this study testifies that the aims of climate change mitigation and the alleviation of energy poverty, an invisible phenomenon present in many Latin-American places, are mutually reinforcing and compatible (Bouzarovski, 2008). As stated by Max Neef (1992), when technology is appropriated by communities and put in favor of human development, it can contribute to a life with more dignity, satisfying human being's most fundamental needs.

Chapter 9. References

Alkire, S., Kovesdi, F., Mitchell, C., Pinilla-Roncancio, M., & Scharlin-Pettee, S. (2019). *Changes Over Time in the Global Multidimensional Poverty Index: A Ten-Country Study*. 24.

ANEEL. (2016). *Tarifa Social de Energia Elétrica—TSEE - ANEEL*. Agência Nacional de Energia Elétrica. https://www.aneel.gov.br/tarifa-social-baixa-renda

ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers). (2013). *Thermal Environmental conditions for human occupancy* (pp. 1–54).

Austin, M. J. (2007). Understanding Poverty. *Journal of Human Behaviour in the Social Environment*, *16*(1–2), 1–4. https://doi.org/10.1300/J137v16n01_01

Ávalos Lozano, J. A., Poritlla Rivera, E., Loredo Osti, C., Izaguirre Hernández, J. de J., Ávila Galarza, A., Algara Siller, M., & Roldán Ortiz, M. (2015). *Inventario Estatal de Gases Efecto Invernadero de San Luis Potosí, 2007 a 2014.* (p. 102). Universidad Autónoma de San Luis Potosí.

Ayuntamiento de San Luis Potosí 2015-2018. (2015). *Plan Municipal de Desarrollo 2015-2018*. http://sanluis.gob.mx/wp-content/uploads /2015/11/PMD-2015-2018.pdf

Banco de México. (2020). *SIE - Inflación*. Sistema de Información Económica. https://www.banxico.org.mx/tipcamb/main.do?page=inf&idioma=sp

Banerjee, A. V., & Duflo, E. (2011). *Poor economics: A radical rethinking of the way to fight global poverty*. PublicAffairs.

Barbero, S., & Pereno, A. (2013). Systemic energy grids: A qualitative approach to smart grids. *J Record*, *6*(4), 220–226.

Barnes, D. F., Krutilla, K., & Hyde, W. (2004). *The Urban Household Energy Transition Energy, Poverty, and the Environment in the Developing World*.

Barquero, V. (2016). *Livelihood Assessment for Rural Delicias Chihuahua as means to develop a Community Energy Model* [University of Arizona]. http://hdl.handle.net/10150/621141

Bartl, M. (2010). The Affordability of Energy: How Much Protection for the Vulnerable Consumers? *Journal of Consumer Policy*, *33*(3), 225–245. https://doi.org/10.1007/s10603-009-9122-9

Bazilian, M., Rogner, H., Howells, M., Hermann, S., Arent, D., Gielen, D., Steduto, P., Mueller, A., Komor, P., Tol, R. S. J., & Yumkella, K. K. (2011). Considering the energy, water and food nexus: Towards an integrated modelling approach. *Energy Policy*, *39*(12), 7896–7906. https://doi.org/10.1016/j.enpol.2011.09.039

Bermudez-Contreras, M. T. (2009). Renewable Energy Powered Desalination in Baja California Sur, Mexico. *Desalination*, *220*, 431–440.

Bhagat, A., Kshirsagar, N., Khodke, P., Dongre, K., & Ali, S. (2016). Penalty Parameter Selection for Hierarchical Data Stream Clustering. *Procedia Computer Science*, *79*(December), 24–31. https://doi.org/10.1016/j.procs.2016.03.005

Bouzarovski, S. (2011). Energy Poverty in the EU: A Review of the Evidence. *Luettavissa:* http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.593.7020&rep=rep1&type=pdf

Bouzarovski, S. (2018). *Energy Poverty: (Dis)Assembling Europe's Infrastructural Divide*. Springer Nature.

Bouzarovski, S., & Petrova, S. (2015). A global perspective on domestic energy deprivation: Overcoming the energy poverty-fuel poverty binary. *Energy Research and Social Science*, *10*, 31–40. https://doi.org/10.1016/j.erss.2015.06.007

Bouzarovski, S., & Thomson, H. (2018). Energy Vulnerability in the Grain of the City: Toward Neighbourhood Typologies of Material Deprivation. *Annals of the American Association of Geographers*, *108*(3), 695–717. https://doi.org/10.1080/24694452.2017.1373624

Buendía Oliva, M. (2019). *Diseño y Evaluación del Club de Educación Ambiental y Sustentabilidad como Estrategia para la Apropiación de Ecotecnias en la escuela Francisco González Bocanegra de la delegación la Pila San Luis Potosí, SLP* [Doctorate Thesis]. Universidad Autónoma de San Luis Potosí.

CENACE. (2018). *Diagramas Unifilares del Sistema Eléctrico Nacional 2018-2023*. https://www.cenace.gob.mx/Docs/MercadoOperacion/ModGralPlaneacion/Mod%20Gral%20Planeación%202018-2023%20Diagramas%20Unifilares%20RNT%20y%20RGD%20del%20MEM.pdf

Cervantes, P., & Barradas, M. V. L. (2010). Ajustes de escalas de sensación térmica para Xalapa, Veracruz, México. *Investigación y Ciencia*, *48*.

CFE. (2020, April 13). *Consulta Tu Tarifa—Tarifa 01*. Comisión Federal de Electricidad. https://app.cfe.mx/Aplicaciones/CCFE/Tarifas/TarifasCRECasa/Tarifas/Tarifa1.aspx

Cisneros Vidales, A. A. (2018). *Building Sustainable Urban Metabolism through Resilience Strategies in La Pila, San Luis Potosí, Mexico* (p. 250).

COESPO - Consejo Estatal de Población. (2020). *Estimaciones de indicadores socioeconómicos para la delegación de La Pila*. COESPO.

Comisión Federal de Electricidad. (2013). *Modelo de Contrato de Suministro de Energía Eléctrica en Baja Tensión*. https://www.cfe.mx/inversionistas/Documents/modelos_contratos/Modelodecontratosdesuministroe_e_dof28nov2013.pdf

Comisión Federal de Electricidad. (2015). *Costos y Parámetros de Referencia para la Formulación de Proyectos de Inversión en el Sector Eléctrico (COPAR Generación 2015).*

RES/142/2017, § Diario Oficial de la Federación (07.03.2017).

Acuerdo Num A/XXXX/2019, (2019). http://187.191.71.192/expedientes/23159

Comisión Reguladora de Energía. (2020). *Consulta de precios vigentes de gas LP mediante planta de distribución reportados por los permisionarios—Localidad La Pila, S.L.P.* http://www.cre.gob.mx/ConsultaPrecios/GasLP/PlantaDistribucion.html?idiom=es

Comunicación del Senado de la República. (2020, February 5). *Demanda Senado condonar a escuelas adeudos por servicio eléctrico*. Senado de La República - Coordinación de Comunicación Social. http://comunicacion.senado.gob.mx/index.php/informacion/boletines/47434-demanda-senado-condonar-a-escuelas-adeudos-por-servicio-electrico.html

CONEVAL. (2020). *Líneas de pobreza por ingresos—InfoPobreza*. Consejo Nacional Para Evaluación de La Política Social. http://sistemas.coneval.org.mx/InfoPobreza/Pages/wfrLineaBienestar?pAnioInicio=2016&pTipoIndicador=0

Cota, A. D., & Foster, R. E. (2010). Chapter 3—Photovoltaics for Rural Development in Latin America: A Quarter Century of Lessons Learned. In *Solar Collectors and Panels, Theory and Applications*. Seyo Publishing.

CRE. (2017). *Certificados de Energías Limpias — CEL*. Retrieved from https://www.gob.mx/cms/uploads/attachment/file/246668/CELs.pdf

Décimo Octavo Tribunal Colegiado en Materia Administrativa del Primer Circuito. (2018). *Tesis Aislada I.18o.A.85 A (10a.)*. Semanario Judicial de la Federación. http://juristadelfuturo.org/wp-content/uploads/2018/05/Tesis-aisladas-11-05-18.pdf

Deng, R., Chang, N. L., Ouyang, Z., & Chong, C. M. (2019). A techno-economic review of silicon photovoltaic module recycling. *Renewable and Sustainable Energy Reviews*, *109*(January), 532–550. https://doi.org/10.1016/j.rser.2019.04.020

Denholm, P., Margolis, R., Palmintier, B., Barrows, C., Ibanez, E., Bird, L., Zuboy, J., & National Renewable Energy Laboratory. (2014). Methods for Analyzing the Benefits and Costs of Distributed Photovoltaic Generation to the U.S. Electric Utility System. *NREL Technical Report*, *September*.

Díaz Acosta, F., Alberto Cortés Cáceres El Colegio de México Agustín Escobar Latapí, F., Graciela Freyermuth Enciso, M., Ángel Rivera Dommaro, J., María Teruel Belismelis, G., del Rosario Cárdenas Elizalde, M., Nahmad Sittón, S., & Scott Andretta, J. (2006). *Metodología para la medición multidimensional de la pobreza en México. Consejo Nacional de Evaluación de la Política de Desarrollo Social*. https://coneval.org.mx/InformesPublicaciones/InformesPublicaciones/Documents/Metodologia-medicion-multidimensional-3er-edicion.pdf

Dobbins, A., & Pie, S. (2016). Member State level regulation related to energy poverty and vulnerable consumers. In *Energy Poverty Handbook* (p. 33). European Commission.

EU Energy Poverty Observatory. (2020). *Policies & Measures*. Policies and Measures - EU Energy Poverty Observatory. https://www.energypoverty.eu/policies-measures

European Commission. (2019, May 22). *Energy poverty* [Text]. Energy - European Commission. https://ec.europa.eu/energy/topics/markets-and-consumers/energy-consumer-rights/energy-poverty_en

Fell, M. J. (2017). Energy services: A conceptual review. *Energy Research and Social Science*, *27*, 129–140. https://doi.org/10.1016/j.erss.2017.02.010

Florman, M., Facada, M. J., & Klinger-Vidra, R. (2016). A critical evaluation of social impact assessment methodologies and a call to measure economic and social impact holistically through the External Rate of Return platform. In *LSE Enterprise Working Paper* (Vol. 1602).

Fthenakis, V. M., Chul Kim, H., & Alsema, E. (2008). Emissions from Photovoltaic Life Cycles. *Environmental Science & Technology*.

García Ochoa, R., & Graizbord Ed, B. (2016). Privation of energy services in Mexican households: An alternative measure of energy poverty. *Energy Research and Social Science*, *18*, 36–49. https://doi.org/10.1016/j.erss.2016.04.014

García, R. (2014). *Pobreza energética en América Latina*. Comisión Económica para América Latina y el Caribe, Naciones Unidas (2014) [Documento de Proyecto]. 1–36.

García-Ochoa, R., & Graizbord, B. (2016). Spatial characterization of fuel poverty in Mexico. An analysis at the subnational scale. *Economía, Sociedad y Territorio*, *xvi*, 289–337. http://www.scielo.org.mx/pdf/est/v16n51/2448-6183-est-16-51-00289.pdf

Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy*, *36*(3), 399–417. https://doi.org/10.1016/j.respol.2007.01.003

Geilfus, F. (2008). *80 Tools for Participatory Development*. IICA. http://repiica.iica.int/docs/B1013I/B1013I.pdf

Gomes, C. A. (2018). Pobreza Energética: Uma Nova Espécie de Pobreza? *Revista ESMAT*, *10*(15), 211. https://doi.org/10.34060/reesmat.v10i15.239

González, T. (2019, April 24). *Termoeléctrica de Villa de Reyes indiferente con los ciudadanos y el medio ambiente*. Revistas de Análisis Político Buzos. https://buzos.com.mx/index.php/nota/index/1616

González-Eguino, M. (2015). Energy poverty: An overview. *Renewable and Sustainable Energy Reviews*, *47*, 377–385. https://doi.org/10.1016/j.rser.2015.03.013

Granados Rojas, F. (2019). *Avances en la Generación Distribuida*. Webinar Generación Distribuida, Canal Conuee. https://www.youtube.com/watch?v=16Ex7d-d-QI&t=945s

Großmann, A., Lehr, U., Lutz, C., Mönning, A., & Kleissl, S. (2016). *Planning Policy Impact Assessments and Choosing the Right Methods: Manual for Development Practitioners*. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

Gündel, S., Hancock, J., &, & Anderson, S. (2001). *Scaling-up Strategies for Research in Natural Resources Management: A comparative review*. 1–65. https://assets.publishing.service.gov.uk/media/57a08d6be5274a27b2001839/R7865rev.pdf

Healy, J. D. (2004). *Fuel Poverty and Health: A Pan European Analysis*. Ashgate Publishing Ltd.

Hernandez-Escobedo, Q., Ramirez-Jimenez, A., Dorador-Gonzalez, J. M., Perea-Moreno, M. A., & Perea-Moreno, A. J. (2020). Sustainable solar energy in Mexican universities. Case study: The National School of Higher Studies Juriquilla (UNAM). *Sustainability (Switzerland)*, *12*(8), 1–22. https://doi.org/10.3390/SU12083123

Hesselman, M., Varo, A., & Laakso, S. (2019). *The Right to Energy in the European Union*. ENGAGER European Energy Poverty, Policy Brief No.2. https://ssrn.com/abstract=3466803

Höhne, N. et al, & United Nations Environment Programme (UNEP). (2017). Renewable energy and energy efficiency in developing countries: Contributions to reducing global emissions. In *Terje Kronen (Ministry of Climate and Environment)* (Vol. 2, p. 76). http://wedocs.unep.org/bitstream/handle/20.500.11822/10027/1_gigaton_coalition_report_2016.pdf?sequence=1&isAllowed=y%0Ahttp://edgar.jrc.ec.europa.eu/news_docs/onegigatonreport_2016.pdf%0Ahttps://wedocs.unep.org/bitstream/handle/20.500.11822/22149/1_Gigat

Howell, R., Sauer, H., & Coad, W. (2005). *Principles of heating, ventilating and air conditioning: A textbook with design data based on the 2005 ASHRAE handbook Fundamentals.*

IEA. (2019). *Renewables 2019*. International Energy Agency. https://www.iea.org/reports/renewables-2019

INEGI. (2010). *Perfil sociodemográfico Estados Unidos Mexicanos. Censo de Población y Vivienda 2010*. INEGI.

INFONAVIT. (2020). *Manual Explicativo de la Vivienda Ecológica 2020—Versión 2.0—Hipoteca Verde*. INFONAVIT. https://portalmx.infonavit.org.mx/wps/wcm/connect/518d3446-9974-4451-ba1c-c48bdf94189c/Manual_Explicativo_Vivienda_Ecologica_Mayo2020.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE-518d3446-9974-4451-ba1c-c48bdf94189c-n7LNCOJ

Iniciativa Climática de México. (2017). *Análisis de Costo Beneficio del Programa Bono Solar Fase 1*. Iniciativa Climática de México. http://www.iniciativaclimatica.org/wp-content/uploads/2018/04/Bono-Solar-ICM.pdf

Instituto Nacional de Estadística y Geografía (INEGI). (2013). *Encuesta Nacional de Gastos de los Hogares*. https://www.inegi.org.mx/programas/engasto/2013/

Instituto Nacional de Estadística y Geografía (INEGI). (2018). *Encuesta Nacional de Ingreso y Gasto de los Hogares*. https://www.inegi.org.mx/programas/engasto/2013/

IPCC. (2018). Summary for Policymakers SPM. *Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change,* 32–32. https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf

Jenkins, K., McCauley, D., Heffron, R., Stephan, H., & Rehner, R. (2016). Energy justice: A conceptual review. *Energy Research and Social Science*, *11*, 174–182. https://doi.org/10.1016/j.erss.2015.10.004

Jiménez, M. (2020). *Generación Distribuida Colectiva en México—Análisis tecno-económico para nuevos modelos de negocio*. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

Jimenez-Garcia, J. A., Calderon-Nepamuceno, D. M., Duran-Garcia, M. D., & Torres-Tovar, R. (2018). Exergetic and Thermoeconomic Analysis of the Villa De Reyes Steam Power Plant Operating on Partial Load. *Revista de Ingeniería Eléctrica*, *2*(7), 1–13.

Kodinariya, T. M., & Makwana, P. R. (2013). Review on determining number of Cluster in K-Means Clustering. *International Journal of Advance Research in Computer Science and Management Studies*, *1*(6).

Lok-Dessalline, R. (1999). Review of Poverty Concepts and Indicators. *PNUD*, 21. http://kambing.ui.ac.id/onnopurbo/library/library-ref-ind/ref-ind-1/application/poverty-reduction/Poverty/Review_of_Poverty_Concepts.pdf

Lune, H., & Berg, B. L. (2017). *Qualitative Research Methods for the Social Sciences* (9th ed., p. 240). Pearson Education Limited.

Manfren, M., Caputo, P., & Costa, G. (2011). Paradigm shift in urban energy systems through distributed generation: Methods and models. *Applied Energy*, *88*(4), 1032–1048. https://doi.org/10.1016/j.apenergy.2010.10.018

Max-Neef, M. (1992). Development and human needs. *Real-Life Economics*, 197–214. https://doi.org/10.4324/9781315258003-14

Meadows, D. H. (2009). *Thinking in Systems*. Diana Wright Sustainability Institute, Ed.

Medellín Milán, P. (2002, July 11). Impacto Ambiental de una Termoeléctrica. *Pulso*, 2–5. http://ambiental.uaslp.mx/dpcs/PMM-AP020711.pdf

Montejano Villaseñor, R. A. (2016). *Infancia en cautiverio: Situación de niñas/os que se encuentran en prisión. Estudio de caso en el Centro de Reinserción Social de San Luis Potosí, La Pila.* [Master Thesis]. Universidad Autónoma de San Luis Potosí.

Moon, B. (2018). A Study of Solar PV Potential to Ensure Reliable Supply of Affordable Electricity in Favelas, Rio de Janeiro, Brazil. [Master Thesis]. Universidad Autónoma de San Luis Potosí & Cologne University of Applied Sciences.

Muñoz, G. E. (2018). NAMA de Vivienda Nueva: Un análisis cualitativo. *Vivienda y Comunidades Sustentables*, *3* (January - July 2018). https://doi.org/10.32870/rvcs.v0i3.29

Mycoo, M., McGregor, D., & Simon, D. (2006). *The peri-urban interface: Approaches to sustainable natural resource use*. London: Routledge, https://doi.org/10.4324/9781849775878

Niu, S., Jia, Y., Wang, W., He, R., Hu, L., & Liu, Y. (2013). Electricity consumption and human development level: A comparative analysis based on panel data for 50 countries. *International Journal of Electrical Power and Energy Systems*, *53*(1), 338–347. https://doi.org/10.1016/j.ijepes.2013.05.024

Nordhaus, T., Devi, S., & Trembath, A. (2016). *Energy for Human Development*. Breakthrough Institute.

OECD/IEA. (2010). *Energy Poverty: How to make modern energy access universal?* OECD/IEA. https://www.undp.org/content/undp/en/home/librarypage/environment-energy/sustainable_energy/energy_poverty_howtomakemodernenergyaccessuniversal.html

Omic, E., & Halb, J. (2019). *Energy Poverty in Europe: How Energy Efficiency and Renewables Can Help*. Council of Europe Development Bank.

OSINERGMIN. (2019). *Tarifas Residenciales en Latinoamérica—4to Trimestre 2018*. https://observatorio.osinergmin.gob.pe/tarifas-electricas-residenciales-latinoamerica

Ostrom, E. (2011). *El gobierno de los bienes comunes. La evolución de las instituciones de acción colectiva* (2nd ed.). Fondo de Cultura Económica.

Oxford Poverty and Human Development Initiative. (2018). *Global Multidimensional Poverty Index 2018: The Most Detailed Picture to Date of the World's Poorest People*. University of Oxford, UK. http://www.ophi.org.uk/wp-content/uploads/B47_Global_MPI_2017.pdf

Pereira, M. G., Freitas, M. A. V., & da Silva, N. F. (2010). Rural electrification and energy poverty: Empirical evidences from Brazil. *Renewable and Sustainable Energy Reviews*, *14*(4), 1229–1240. https://doi.org/10.1016/j.rser.2009.12.013

Pérez Cueva, A., Gómez Lopera, F., & Tornero, J. (2006). Ciudad y confort ambiental: Estado de la cuestión y aportaciones recientes. *Cuadernos de Geografía*, *80*, 147–182.

Petrova, S. (2018). Encountering energy precarity: Geographies of fuel poverty among young adults in the UK. *Transactions of the Institute of British Geographers*, *43*(1), 17–30. https://doi.org/10.1111/tran.12196

Ley Federal de Protección al Consumidor, § Diario Oficial de la Federación (09.04.2012).

Plan Nacional de Desarrollo 2019-2024, § Diario Oficial de la Federación (12.07.2019).

Riutort Isern, S. (2016). *Energía para la Democracia: La Cooperativa Som Energía como Laboratorio Social*. Fuhem Social, Los Libros de la Catarata.

Rivera Vásquez, J. E. (2014). *Análisis Climático de la Ciudad de San Luis Potosí para la Determinación de Variables de Confort Térmico en Edificaciones* (p. 158).

Roberts, J., Bodman, F., & Rybski, R. (2014). *Community Power: Model Legal Frameworks for citizen-owned Renewable Energy*. ClientEarth.

Rockström, J., Steffen, W., Noone, K., Persson, Asa, Chapin, F. S., Lambin, E. F., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., De Wit, C. A., Hughes, T., Van Der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., … Foley, J. A. (2009). A safe operating space for humanity. *Nature*, *461*(7263), 472–475. https://doi.org/10.1038/461472a

Rodrigues, T. P., & Gonçalves, S. (2018). *Pobreza energética: Evidências para famílias da área rural do Brasil*. https://www.researchgate.net/publication/326491983_Pobreza_energetica_evidencias_para_familias_da_area_rural_do_Brasil

Rzedowski, J. (2006). *Vegetación de México* (First Digital Edition). Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. https://www.biodiversidad.gob.mx/publicaciones/librosDig/pdf/VegetacionMx_Cont.pdf

Sampaio, P. G. V., & González, M. O. A. (2017). Photovoltaic solar energy: Conceptual framework. *Renewable and Sustainable Energy Reviews*, *74*(December 2016), 590–601. https://doi.org/10.1016/j.rser.2017.02.081

Saviuc, I., Peremans, H., Van Passel, S., & Milis, K. (2019). Economic Performance of using batteries in European residential microgrids under the net-metering scheme. *Energies*, *12*(1). https://doi.org/10.3390/en12010165

Secretaría de Energía. (2017). *Beneficios de la Generación Limpia Distribuida y la Eficiencia Energética en México*. http://www.gob.mx/sener/documentos/beneficios-de-la-generacion-limpia-distribuida-y-la-eficiencia-energetica-en-mexico

Programa de Desarrollo del Sistema Eléctrico Nacional, (2018). Secretaría de Energía. https://www.gob.mx/sener/acciones-y-programas/programa-de-desarrollo-del-sistema-electrico-nacional-33462

Sen, A. (1983). Poor, Relatively Speaking. *Oxford Economic Papers*, *35*(2), 153–169. https://www.jstor.org/stable/2662642

Lineamientos que establecen los criterios para el otorgamiento de Certificados de Energías Limpias y los requisitos para su adquisición, § Diario Oficial de la Federación (31.10.2014).

Políticas y Estrategias para la Electrificación de Comunidades Rurales y Zonas Urbanas Marginadas, § Diario Oficial de la Federación (29.03.2017).

Política Pública para Promover la Generación Distribuida en México, (2018). Secretaría de Energía, 12.11.2018. https://www.gob.mx/sener/documentos/politica-publica-para-promover-la-generacion-distribuida-en-mexico

Smets, A., Jäger, K., Isabella, O., Van Swaaij, R. A. C. M. M., & Zeman, M. (2016). *Solar Energy—The physics and engineering of photovoltaic conversion, technologies and systems*.

SolarGis & World Bank Group. (2019). *La Pila—Global Solar Atlas*. https://globalsolaratlas.info/detail?c=22.034093,-100.868225,11&s=22.034,-100.867833&m=site&pv=small,180,24,1

Theumer, S., Rivero, M. del C., Flores, J., Ebel, W., Kraft, G., Neuhauss, W., Beele, A., & Stöcklein, A. (2014). *NAMA Apoyada para Vivienda Existente en México*. CONAVI and SEMARNAT.

Townsend, P. (1987). Deprivation. *Journal of Social Policy*, *16*(2), 125–146. https://doi.org/10.1017/S0047279400020341

Ulsrud, K., Winther, T., Palit, D., Rohracher, H., & Sandgren, J. (2011). The Solar Transitions research on solar mini-grids in India: Learning from local cases of innovative socio-technical systems. *Energy for Sustainable Development*, *15*(3), 293–303. https://doi.org/10.1016/j.esd.2011.06.004

UNDP (2018). *Pobreza Energética: Análisis de Experiencias Internacionales y Aprendizajes para Chile*. United Nations Development Programme.

United Nations. (2011, July 25). *'The Implications of Energy Poverty are Enormous,' Says Secretary-General, Urging All to 'Join the Dots' between Energy, Food, Water, Climate Security, Development | Meetings Coverage and Press Releases*. https://www.un.org/press/en/2011/sgsm13755.doc.htm

United Nations. (2016). *Goal 7—Sustainable Development Knowledge Platform*. Sustainable Development Goals Knowledge Platform. https://sustainabledevelopment.un.org/sdg7

United Nations. (2019). *The Sustainable Development Goals Report 2019*. https://www.un-ilibrary.org/content/publication/55eb9109-en

Verbong, G., & Geels, F. (2007). The Ongoing Energy Transition: Lessons from a Socio-Technical, Multi-Level Analysis of the Dutch Electricity System (1960–2004). *Energy Policy*, *35*, 1025–1037. https://doi.org/10.1016/j.enpol.2006.02.010

Vezzoli, C., Ceschin, F., Osanjo, L., M'Rithaa, M. K., Moalosi, R., Nakazibwe, V., & Diehl, J. C. (2018). Distributed/Decentralised Renewable Energy Systems. In C. Vezzoli, F. Ceschin, L. Osanjo, M. K. M'Rithaa, R. Moalosi, V. Nakazibwe, & J. C. Diehl (Eds.), *Designing Sustainable Energy for All: Sustainable Product-Service System Design Applied to Distributed Renewable Energy* (pp. 23–39). Springer International Publishing. https://doi.org/10.1007/978-3-319-70223-0_2

Vezzoli, C., Delfino, E., & Ambole, L. (2014). System Design for Sustainable Energy for all: A new challenging role for design to foster sustainable development. *FORMakademisk Journal*, *7*(3), 1–27.

Villa y Caña, P., & Morales, A. (2020, May 21). *Empresas de energía renovable tienen derecho a recurrir a instancias judiciales: SENER*. El Universal.

https://www.eluniversal.com.mx/nacion/empresas-de-energia-renovable-tienen-derecho-recurrir-instancias-judiciales-sener

Villalobos, C., Chávez, C., & Uribe, A. (2019). Energy poverty measures and the identification of the energy poor: A comparison between the utilitarian and multidimensional approaches in Chile. In *Discussion Papers—Ibero-America Institute for Economic Research* (No. 4955139817; Issue 243, pp. 0–35).

World Energy Council. (2006). *América Latina—Pobreza Energética, Alternativas de Alívio* (p. 71). World Energy Council.

Yin, R. K. (2018). *Case Study Research: Design and Methods* (6th edition). SAGE.

Yishu, L. (2019). A photovoltaic ecosystem: Improving atmospheric environment and fighting regional poverty. *Technological Forecasting and Social Change*, *140*(November 2018), 69–79. https://doi.org/10.1016/j.techfore.2018.12.002

Appendix A – Spreadsheets of the EP Assessment

Energy Services in La Pila 1 = exists; 0 = does not exist							
ELS	Et	WH	Refri	FC	Any deprivation?	How many deprivations?	Group
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	0	0	1	0	Yes	3	Extreme Energy Poor
1,0	1	1	0	1	Yes	1	Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	0	1	1	1	Yes	1	Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	0	1	Yes	1	Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	0	Yes	1	Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	0	1	1	1	Yes	1	Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	0	1	0	1	Yes	2	Strong Energy Poor
0,8	1	1	1	1	Yes	1	Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	0	1	Yes	1	Energy Poor
0,4	1	1	1	1	Yes	1	Energy Poor
0,8	0	0	0	0	Yes	5	Extreme Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor
1,0	1	1	0	1	Yes	1	Energy Poor
1,0	1	1	1	1	No	0	Non Energy Poor

Income (monthly)	Electricity			Gas			Total spent in energy	
	expenditure	% of income	% of Energy burden	expenditure	% on income	% of Energy Burden	Expenditure	%
7.499,66 MXN	100,00 MXN	1%	50%	100,00 MXN	1%	50%	200,00 MXN	3%
5.260,00 MXN	200,00 MXN	4%	59%	140,00 MXN	3%	41%	340,00 MXN	6%
2.010,00 MXN	435,00 MXN	22%	48%	480,00 MXN	24%	52%	915,00 MXN	46%
4.400,00 MXN	150,00 MXN	3%	60%	100,00 MXN	3%	40%	250,00 MXN	6%
3.591,66 MXN	100,00 MXN	3%	35%	183,33 MXN	4%	65%	283,33 MXN	8%
6.343,67 MXN	122,00 MXN	2%	33%	250,00 MXN	4%	67%	372,00 MXN	6%
8.808,33 MXN	175,00 MXN	2%	64%	100,00 MXN	1%	36%	275,00 MXN	3%
4.966,67 MXN	100,00 MXN	2%	40%	150,00 MXN	3%	60%	250,00 MXN	5%
7.125,00 MXN	200,00 MXN	3%	26%	560,00 MXN	8%	74%	760,00 MXN	11%
9.817,67 MXN	1.900,00 MXN	19%	64%	1.050,00 MXN	11%	36%	2.950,00 MXN	30%
7.731,67 MXN	150,00 MXN	2%	28%	390,00 MXN	5%	72%	540,00 MXN	7%
7.440,00 MXN	90,00 MXN	1%	47%	100,00 MXN	1%	53%	190,00 MXN	3%
2.780,00 MXN	100,00 MXN	4%	30%	230,00 MXN	8%	70%	330,00 MXN	12%
5.176,67 MXN	90,00 MXN	2%	52%	83,33 MXN	2%	48%	173,33 MXN	3%
10.331,67 MXN	115,00 MXN	1%	13%	800,00 MXN	8%	87%	915,00 MXN	9%
5.170,00 MXN	60,00 MXN	1%	24%	186,67 MXN	4%	76%	246,67 MXN	5%
7.170,00 MXN	40,00 MXN	1%	13%	270,00 MXN	4%	87%	310,00 MXN	4%
6.094,33 MXN	75,00 MXN	1%	12%	556,00 MXN	9%	88%	631,00 MXN	10%
6.550,00 MXN	750,00 MXN	11%	88%	100,00 MXN	2%	12%	850,00 MXN	13%
3.700,00 MXN	100,00 MXN	3%	50%	100,00 MXN	3%	50%	200,00 MXN	5%
5.150,00 MXN	75,00 MXN	1%	20%	300,00 MXN	6%	80%	375,00 MXN	7%
5.700,00 MXN	300,00 MXN	5%	27%	800,00 MXN	14%	73%	1.100,00 MXN	19%
4.355,00 MXN	80,00 MXN	2%	35%	150,00 MXN	3%	65%	230,00 MXN	5%
5.545,00 MXN	85,00 MXN	2%	41%	120,00 MXN	2%	59%	205,00 MXN	4%
10.216,67 MXN	150,00 MXN	1%	33%	300,00 MXN	3%	67%	450,00 MXN	4%

Appendix B – Social impact's qualitative and scoring matrixes

Social Impacts Matrix (Benefits - 1 - low, 2 - medium and 3 - high)		Individual Application	
Dimension	Identified aspect	GC	GC + Batt
Energy Poverty		**1,3**	**1,8**
	Use of firewood to cook and heat water	1	1
	Absence of economic goods, mainly refrigerators.	1	1
	Seasonal energy poverty in summer due to higher supply interruptions	1	3
	Strong deprivation of energy services that depend on applicances connected to electricity	2	2
Dimensions influencing on energy poverty		**2,0**	**2,8**
Energy Precarity		2,0	2,5
Policy	No special protection to low income population and recognition of energy poor	3	3
Political decisions	Supporting oil and thermoelectrics and raising energy tariffs	3	3
	Managerial decisions concerning interruptions on energy supply	1	3
Local solutions	Parents pay energy bills of schools	1	1
Energy vulnerabilities		**2,5**	**2,8**
Access	Interruptions on the supply	1	3
	Part of the delegation do not have access to energy.	-	-
Affordability	Increase in energy consumption is desirable to human development/desirable rebound effect	3	3
	Exposition to raise in energy tariffs	3	3
	Energy burdens to LP families are higher than the state average	3	3
	Low-income	2	2
	Sudden dropout of tariff subsidy scheme	3	3
Energy Security		**1,5**	**3,0**
	Thermoelectric is pollutant, depends on oil and its makert variations and ist exposed to water scarcity	2	3
	Interruptions on the supply - the grid is not 100% reliable	1	3
Energy Justice		**2,0**	**3,0**
	Seasonal energy poverty in summer	1	3
	No special protection to energy poor people regarding disconnections and tariffs.	3	3

Social Impacts Matrix (Benefits - 1 - low, 2 - medium and 3 - high)		Public Schools	
Dimension	Identified aspect	GC	GC + Batt
Energy Poverty		**1,3**	**1,3**
	Use of firewood to cook and heat water	1	1
	Absence of economic goods, mainly refrigerators.	1	1
	Seasonal energy poverty in summer due to higher supply interruptions	1	1
	Strong deprivation of energy services that depend on applicances connected to electricity	2	2
Dimensions influencing on energy poverty		**2,0**	**2,1**
Energy Precarity		2,0	2,8
Policy	No special protection to low income population and recognition of energy poor	1	3
Political decisions	Supporting oil and thermoelectrics and raising energy tariffs	3	3
	Managerial decisions concerning interruptions on energy supply	1	2
Local solutions	Parents pay energy bills of schools	3	3
Energy vulnerabilities		**2,3**	**2,5**
Access	Interruptions on the supply	1	2
	Part of the delegation do not have access to energy.	-	-
Affordability	Increase in energy consumption is desirable to human development/desirable rebound effect	3	3
	Exposition to raise in energy tariffs	3	3
	Energy burdens to LP families are higher than the state average	3	3
	Low-income	1	2
	Sudden dropout of tariff subsidy scheme	3	2
Energy Security		**1,5**	**2,0**
	Thermoelectric is pollutant, depends on oil and its makert variations and ist exposed to water scarcity	2	3
	Interruptions on the supply - the grid is not 100% reliable	1	1
Energy Justice		**2,0**	**1,5**
	Seasonal energy poverty in summer	1	1
	No special protection to energy poor people regarding disconnections and tariffs.	3	2

Social Impacts Matrix (Benefits - 1 - low, 2 - medium and 3 - high)		Community Ownership	
Dimension	Identified aspect	GC	GC + Batt
Energy Poverty		**1,3**	**1,8**
	Use of firewood to cook and heat water	1	1
	Absence of economic goods, mainly refrigerators.	1	1
	Seasonal energy poverty in summer due to higher supply interruptions	1	3
	Strong deprivation of energy services that depend on applicances connected to electricity	2	2
Dimensions influencing on energy poverty		**2,3**	**2,8**
Energy Precarity		2,5	2,5
Policy	No special protection to low income population and recognition of energy poor	3	3
Political decisions	Supporting oil and thermoelectrics and raising energy tariffs	3	3
	Managerial decisions concerning interruptions on energy supply	3	3
Local solutions	Parents pay energy bills of schools	1	1
Energy vulnerabilities		**2,5**	**2,8**
Access	Interruptions on the supply	1	3
	Part of the delegation do not have access to energy.	-	-
Affordability	Increase in energy consumption is desirable to human development/desirable rebound effect	3	3
	Exposition to raise in energy tariffs	3	3
	Energy burdens to LP families are higher than the state average	3	3
	Low-income	2	2
	Sudden dropout of tariff subsidy scheme	3	3
Energy Security		**1,5**	**3,0**
	Thermoelectric is pollutant, depends on oil and its makert variations and ist exposed to water scarcity	2	3
	Interruptions on the supply - the grid is not 100% reliable	1	3
Energy Justice		**2,0**	**3,0**
	Seasonal energy poverty in summer	1	3
	No special protection to energy poor people regarding disconnections and tariffs.	3	3

Descriptive Matrix of Expected Positive Impact		Individual Application	
	Identified aspect	GC	GC + Batt
Energy Poverty			
	Use of firewood to cook and heat water	Low and indirect impact due to: (1) culturally, these appliances rely on LPG and not on electricity. New appliances would need to be acquired. (2) providing free electricity helps on affording LPG to these uses.	Same as the GC scenario. The use of batteries may guarantee secure energy to electric goods and avoid the use of firewood when the grid is off, if they are bought by households.
	Absence of economic goods, mainly refrigerators.	Low and indirect impact, assuming that financial savings provided by the system are applied to buy home appliances.	
	Seasonal energy poverty in summer due to higher supply interruptions	Low impact, the system shuts down in cases of interruption on the grid. In high penetration, PV feeds the grid with energy and can help avoiding interruptions.	High impact. The batteries supply energy to the house in case of black-outs and brown-outs.
	Strong deprivation of energy services that depend on appliances connected to electricity	GC provide affordable energy, a requierement to the the functioning of such home appliances.	Same as GC, with an aditional fact that batteries provide secure energy to the energy services delivery.
Dimensions influencing on energy poverty			
Energy Precarity			
Policy	No special protection to low income population and recognition of energy poor	Electricity self-production diminishes the dependancy on the energy market and energy disconnections	
Political decisions	Decision of supporting oil and thermoelectrics,raising energy tariffs	Electricity self-production make its users independent of paid energy	
Political decisions	Managerial decisions concerning interruptions on energy supply	Users would still be exposed to energy interruptions.	Batteries provide energy to the house in case of interruptions.
Local solutions	Parents pay energy bills of schools	There is an impact considering financial savings provided by PV, but the situation would still exist.	

<table>
<tr><th colspan="2">Energy vulnerabilities</th><th></th><th></th></tr>
<tr><td rowspan="2">Access</td><td>Interruptions on the supply.</td><td>No impacts, GC is grid-dependent.</td><td>Give the user protection against grid instabilities.</td></tr>
<tr><td>Part of the delegation do not have access to energy.</td><td colspan="2">No impacts, GC is grid-dependent.</td></tr>
<tr><td rowspan="5">Affordability</td><td>Increase in energy consumption is desirable to human development/desirable rebound effect</td><td colspan="2">It can contribute to a raise in energy consumption since it provides costless energy</td></tr>
<tr><td>Exposition to raise in energy tariffs</td><td colspan="2">High impact, since user will produce its own energy.</td></tr>
<tr><td>Energy burdens to LP families are higher than the state average</td><td colspan="2">High impact, since families won't spend their income on electricity and will diminish their energy burdens.</td></tr>
<tr><td>Low-income</td><td colspan="2">Potential impact due to the savings that are provided and possibility of generating extra income with CELs and selling the surplus.</td></tr>
<tr><td>Sudden dropout of tariff subsidy scheme</td><td colspan="2">Gives users protection against it, since he/she will produce its own energy.</td></tr>
<tr><th colspan="2">Energy Security</th><th colspan="2"></th></tr>
<tr><td rowspan="2"></td><td>Thermoelectric is pollutant, depends on oil and its makert variations and is exposed to water scarcity</td><td colspan="2">It has potential impact if PV has a high penetration on the community.</td></tr>
<tr><td>Interruptions on the supply - the grid is not 100% reliable</td><td>No impacts, GC is grid-dependent.</td><td>Give the user protection against grid instabilities.</td></tr>
<tr><th colspan="2">Energy Justice</th><th colspan="2"></th></tr>
<tr><td rowspan="2"></td><td>Seasonal energy poverty in summer</td><td>Low impact, the system shuts down in cases of interruption on the grid. With a high penetration, PV feeds the grid with energy and can help avoiding interruptions.</td><td>High impact. The batteries supply energy to the house in case of black-outs and brown-outs.</td></tr>
<tr><td>No special protection to energy poor people regarding disconnections and tariffs.</td><td colspan="2">Electricity self-production lowers the dependancy on the energy market and energy disconnections</td></tr>
</table>

Descriptive Matrix of Expected Positive Impact		Public Schools	
	Identified aspect	GC	GC + Batt
Energy Poverty			
	Use of firewood to cook and heat water	Low and indirect impact due to: (1) culturally, these appliances rely on LPG and not on electricity. New appliances would need to be acquired. (2) providing free electricity helps on affording LPG to these uses.	
	Absence of economic goods, mainly refrigerators.	Low and indirect impact, assuming that financial savings provided by the system are applied to buy home appliances.	
	Seasonal energy poverty in summer due to higher supply interruptions	Low impact, the system shuts down in cases of interruption on the grid. In high penetration, PV feeds the grid with energy and can help avoiding interruptions.	Low impact, batteries could only feed the school.
	Strong deprivation of energy services that depend on appliances connected to electricity	Potential impact. GC provide affordable energy, a requierement to the the functioning of such home appliances.	Same as GC, with an aditional fact that batteries provide secure energy to the energy services delivery.
Dimensions influencing on EP			
Energy Precarity			
Policy	No special protection to low income population and recognition of energy poor	Electricity self-production lows the dependancy on the energy market and energy disconnections. In this case, benefits goes to the school and households.	
Political decisions	Decision of supporting oil and thermoelectrics,raising energy tariffs	Electricity self-production make its users independent of paid energy	
Political decisions	Managerial decisions concerning interruptions on energy supply	Users would still be exposed to energy interruptions.	Batteries provide energy to the school in case of interruptions.
Local solutions	Parents pay energy bills of schools	The situation disappears, since the school is supllied with the PV system.	

Energy vulnerabilities			
Access	Interruptions on the supply.	No impacts, GC is grid-dependent.	Give the school protection against grid instabilities, but not the users.
	Part of the delegation do not have access to energy.	No impacts, GC is grid-dependent.	
Affordability	Increase in energy consumption is desirable to human development/desirable rebound effect	It can contribute to a raise in energy consumption since it provides costless energy	
	Exposition to raise in energy tariffs	High impact, since user will produce its own energy.	
	Energy burdens to LP families are higher than the state average	High impact, since families won't spend their income on electricity and will diminish their energy burdens.	
	Low-income	Potential impact due to the savings that are provided and possibility of generating extra income with CELs and selling the surplus.	
	Sudden dropout of tariff subsidy scheme	Gives users protection against it, since he/she will produce its own energy.	
Energy Security			
	Thermoelectric is pollutant, depends on oil and its makert variations and is exposed to water scarcity	It has potential impact if PV has a high penetration on the community.	
	Interruptions on the supply - the grid is not 100% reliable	No impacts, GC is grid-dependent.	Give the school protection against grid instabilities, but not the users.
Energy Justice			
	Seasonal energy poverty in summer	Low impact, the system shuts down in cases of interruption on the grid. In high penetration, PV feeds the grid with energy and can help avoiding interruptions.	Low impact, batteries could only feed the school.
	No special protection to energy poor people regarding disconnections and tariffs.	Electricity self-production lowers the dependancy on the energy market and energy disconnections	

Descriptive Matrix of Expected Positive Impact		Community Ownership	
	Identified aspect	GC	GC + Batt
Energy Poverty			
	Use of firewood to cook and heat water	Low and indirect impact due to: (1) culturally, these appliances rely on LPG and not on electricity. New appliances would need to be acquired. (2) providing free electricity helps on affording LPG to these uses.	Same as the GC scenario. The use of batteries may guarantee secure energy to electric goods and avoid the use of firewood when the grid is off, if they are bought by households.
	Absence of economic goods, mainly refrigerators.	Low and indirect impact, assuming that financial savings provided by the system are applied to buy home appliances.	
	Seasonal energy poverty in summer due to higher supply interruptions	Low impact, the system shuts down in cases of interruption on the grid. In high penetration, PV feeds the grid with energy and can help avoiding interruptions.	High impact. The batteries supply energy to the house in case of black-outs and brown-outs.
	Strong deprivation of energy services that depend on appliances connected to electricity	Potential impact. GC provide affordable energy, a requierement to the the functioning of such home appliances.	Same as GC, with an aditional fact that batteries provide secure energy to the energy services delivery.
Dimensions influencing on EP			
Energy Precarity			
Policy	No special protection to low income population and recognition of energy poor	Electricity self-production lows the dependancy on the energy market and energy disconnections	
Political decisions	Decision of supporting oil and thermoelectrics,raising energy tariffs	Electricity self-production make its users independent of paid energy	
	Managerial decisions concerning interruptions on energy supply	Users would still be exposed to energy interruptions.	Batteries provide energy to the house in case of interruptions.
Local solutions	Parents pay energy bills of schools	There is an impact considering financial savings provided by PV, but the situation would still exist.	

Energy vulnerabilities			
Access	Interruptions on the supply.	No impacts, GC is grid-dependent.	Give the user protection against grid instabilities.
	Part of the delegation do not have access to energy.	No impacts, GC is grid-dependent.	
Affordability	Increase in energy consumption is desirable to human development/desirable rebound effect	It can contribute to a raise in energy consumption since it provides costless energy	
	Exposition to raise in energy tariffs	High impact, since user will produce its own energy.	
	Energy burdens to LP families are higher than the state average	High impact, since families won't spend their income on electricity and will diminish their energy burdens.	
	Low-income	Potential impact due to the savings that are provided and possibility of generating extra income with CELs and selling the surplus.	
	Sudden dropout of tariff subsidy scheme	Gives users protection against it, since he/she will produce its own energy.	
Energy Security			
	Thermoelectric is pollutant, depends on oil and its makert variations and is exposed to water scarcity	It has potential impact if PV has a high penetration on the community.	
	Interruptions on the supply - the grid is not 100% reliable	No impacts, GC is grid-dependent.	Give the user protection against grid instabilities.
Energy Justice			
	Seasonal energy poverty in summer	Low impact, the system shuts down in cases of interruption on the grid. With a high penetration, PV feeds the grid with energy and can help avoiding interruptions.	High impact. The batteries supply energy to the house in case of black-outs and brown-outs.
	No special protection to energy poor people regarding disconnections and tariffs.	Electricity self-production lowers the dependancy on the energy market and energy disconnections	