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GOING SOLAR: MOTIVATORS, BARRIERS, AND ENABLERS TO RESIDENTIAL PHOTOVOLTAIC SYSTEM ADOPTION IN MEXICO

TESINA

QUE PARA OBTENER EL TÍTULO DE
LICENCIADO EN POLÍTICAS PÚBLICAS

PRESENTA

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Abstract

Mexico's lag in the adoption of renewable energy sources compared to other countries in Latin America and the Caribbean, coupled with the depletion of its oil and gas reserves, has raised concerns about its dependence on fossil fuels. To address this issue, the goal of this research is to provide policy recommendations to promote the adoption of residential photovoltaic systems. By identifying the main motivators, barriers, and enablers of adoption, this research can offer insights into the factors that can help Mexico transition to renewable energy sources.

To address the research question **to what degree are the most prevalent motivators, barriers, and enablers of the adoption of residential photovoltaic systems present in Mexico?** this piece of research uses an in-house-designed survey to gather data on motivators, barriers, and enablers of residential photovoltaic system adoption. Logit regression, cross-validation of opinions using a randomized survey experiment, ranking of responses, and spatial regression were used to analyze the obtained survey responses. Additionally, administrative, and geographic information system data were utilized to establish correlations between solar irradiance and energy consumption.

The findings of this study are I) people does display environmental interest to install photovoltaic systems, II) there is not a statistically significant effect on reducing the cost of the electricity bill, III) the main barriers are acquisition cost, information issues on both technical and acquisition aspects of photovoltaic systems, lack of financial aid, and the potential adopter is not the owner of the house. Based on the findings, the policy measures that recommended to increasing adoption rates of residential photovoltaic systems are a combination of reflecting the true price of energy, providing subsidies for acquiring solar panels, and offering high-quality advice on the adoption. All the previous measures focusing primarily in highly irradiance zones of the country. By addressing the barriers and leveraging the enablers, Mexico can accelerate the adoption of photovoltaic systems and move towards a more sustainable energy future

Acronym	Definition
CENAPRED	Centro Nacional de Prevención de Desastres. (National Center for Disaster Prevention)
CFE	Central Federal de Electricidad. (Federal Power Central). CFE is the Mexico´s main utility.
CNH	Comisión Nacional de Hidrocarburos (National Hydrocarbons Comission)
CONABIO	Comisión Nacional de Biodiversidad. (National Biodiversity Comision)
CRE	Comisión Reguladora de Energía (Mexico´s Independent System Operator)
ENSOLRES	Encuesta sobre adopción de paneles solares en hogares mexicanos. (Survey on photovoltaic solar panel adoption in Mexican households.)
GHI	Global Horizontal Irradiance
INEGI	Instituto Nacional de Estadistica y Geografía. (National Institute of Statistics and Geography)
MBE	Motivators, Barriers, and Enablers.
NDC	Nationally Determined Contribution
SAT	Servicio de Administración Tributaria (Internal Revenue System of Mexico)
SEMARNAT	Secretaría de Medio Ambiente y Recursos Naturales (Ministry of Environment and Natural Resources)
SHCP	Secretaría de Hacienda y Credito Público (Ministry of treasury and public credit)

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1. Introduction

1.1 The Issue: Addressing Mexico's Reliance on Fossil Fuels

Mexico's energy landscape has long been dominated by fossil fuels, with oil and gas accounting for 73.3% of the country's total energy generation (see Table 1). The country's heavy reliance on oil and gas for energy generation has become a challenge for the country in terms of both environmental sustainability and long-term energy security. As reserves continue to decrease (see Figures 1 and 2), Mexico faces the task of transitioning to a more sustainable and diversified energy mix.

However, compared to other countries in the Latin America and the Caribbean (LAC) region, Mexico's adoption of renewable energy sources has been stagnant. Currently, only 19.4% of Mexico's energy needs are met by renewables, a figure that pales in comparison to the LAC region's overall renewable electricity generation of 58.3% (see Table 1). The urgent need to bridge this gap and align with global sustainability goals requires an "energy transition" (Gatto, 2022), which needs to be priority for policymakers in Mexico.

Considering the situation described, it is crucial for Mexico to undertake a purposeful and well-planned transition towards an economy that is less dependent on fossil fuels. This transition is driven not only by environmental concerns but also by the pressing reality of diminishing oil and gas reserves. The declining trend in reserves, as illustrated by Figures 1 and 2, underscores the urgency of shifting towards alternative and sustainable energy sources. To achieve this objective, it is essential to adopt a comprehensive approach that involves strong policy interventions and meticulous planning to ensure a sustainable and equitable energy transition that aligns with Mexico's economic and environmental objectives.

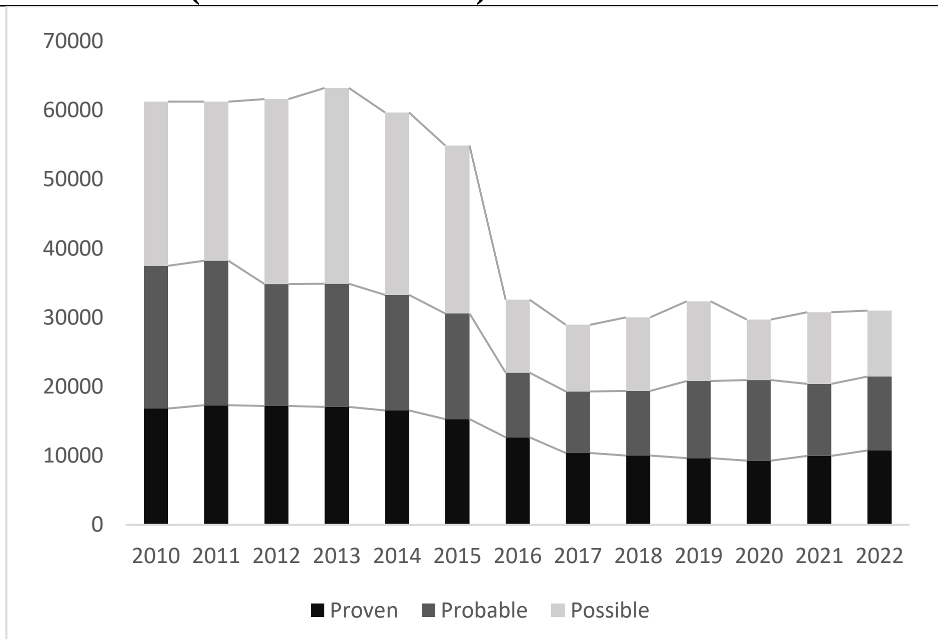
Table 1. Energy matrix in Mexico and LAC 2020

	Fossil fuels			**Nuclear**	**Renewables**			
	Gas	Coal	Oil		Wind	Hydro	Solar	Other
Mexico	63.4% 217823	2.6% 9079	9.9% 34095	3.2% 10864	5.7% 19701	7.8% 26817	3.9% 13528	2% 6833

LAC	28.8% 449469	4.3% 66309	5.9% 92438	2.3% 35624	6.6% 102238	44.3% 690481	2.3% 35658	5.1% 79386

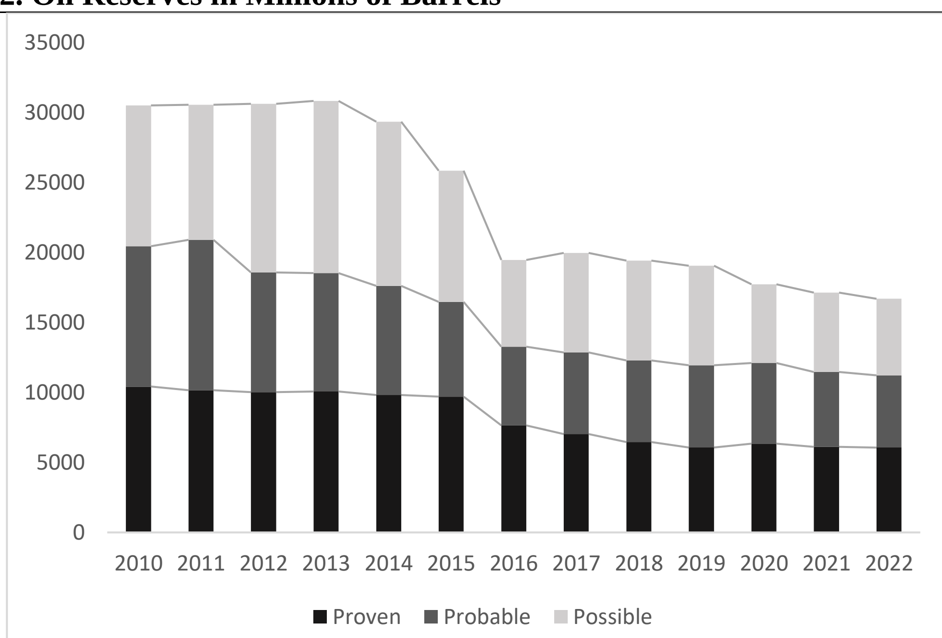
Source: own elaboration with information from International Energy Agency (IEA), quantities in GWh.

Figure 1. Gas reserves (Billions of cubic feet)



Source: own elaboration with information from CNH.

Figure 2. Oil Reserves in Millions of Barrels



Source: own elaboration with information from CNH.

Reducing Mexico's dependence on fossil fuels is a critical priority for the country, driven in part by its international commitments to reduce greenhouse gas emissions. As outlined in its Nationally Determined Contribution (NDC), Mexico has pledged to generate 40 GW of clean energy capacity and reduce emissions by 35% by 2030, compared to a baseline of 991 MtCO2e 8 (SEMARNAT, 2022). Mexico´s NDC commitments are aligned with global efforts to limit the temperature increase to 1.5°C above pre-industrial levels and limit the impacts of climate change (IPCC, 2018).

Achieving those targets will require a significant shift away from the burning of fossil fuels towards renewable energy sources. However, given that Mexico currently relies heavily on hydrocarbons for its energy needs, this transition presents a significant challenge. Mexico will need to make substantial investments in renewable energy infrastructure and develop supportive policy frameworks that incentivize the adoption of clean energy.

Table 2. Final energy consumption by source (petajoules)

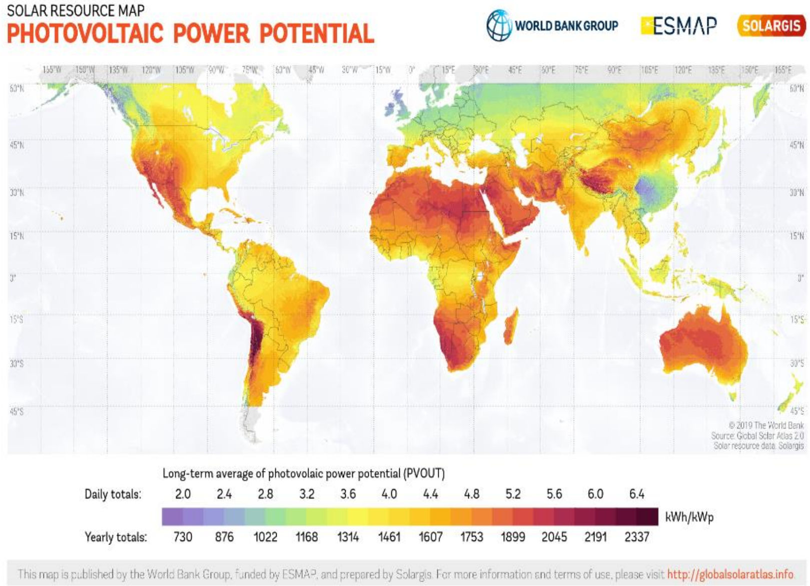
Year	2017	2018	2019	2020
Total energy consumption	5363	5284	4761	4383
Coal	237	187	122	21
Renewables	311	317	298	387
Solar	**11**	**13**	**14**	**16**
Coke total	206	180	174	161
Hydrocarbon	2938	3016	2595	2322
Dry gas	735	583	549	476
Electricity	936	1001	1023	1016

Source: own elaboration with information from Dirección General de Planeación e Información Energéticas, Sistema de Información Energética, SENER. Partial sum may not coincide due to rounding.

1.2 A potential solution: going solar.

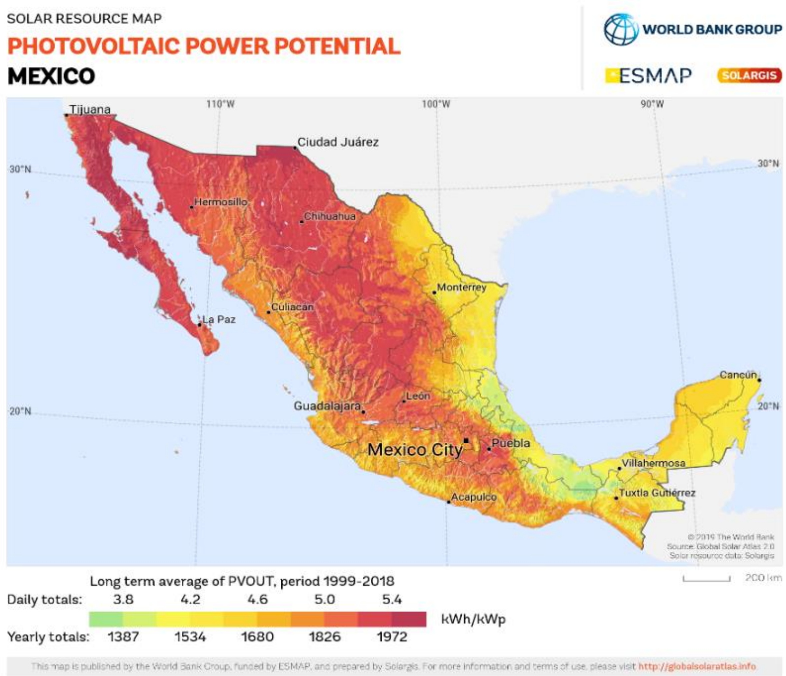
The utilization of solar energy represents a promising avenue for addressing Mexico's reliance on fossil fuels. Given its substantial solar energy potential, which surpasses that of numerous other nations, Mexico possesses a unique opportunity to tap into this resource. As illustrated in Figures 3 and 4, the country's solar energy potential is abundant. Expanding renewable energy capacity by means of solar power has the potential to markedly decrease Mexico's dependence on fossil fuels.

Figure 3. Photovoltaic power potential in the world.[1]



Source: ESMAP. 2020. Global Photovoltaic Power Potential by Country. Washington, DC: World Bank.

Figure 4. Photovoltaic power potential in Mexico



Source: ESMAP. 2020. Global Photovoltaic Power Potential by Country. Washington, DC: World Bank.

[1] Photovoltaic Power Potential refers to the theoretical potential of long-term energy availability of solar resources, combining the physical variable of Global Horizontal Irradiance (World Bank, 2020)

Moreover, the cost of photovoltaic systems has significantly decreased, particularly in the residential sector. The utility-scale levelized cost of energy, which includes the cost of building and operating a plant, has dropped from 359 USD per MWH in 2009 to 60 USD in 2023, with a historical minimum of 36 USD in 2021 (Lazard, 2023). This trend towards cheaper technologies is expected to continue in the following years (Wolak, 2021).

Solar resources can provide enough energy to meet global consumption of electricityif its widely adopted (Prentiss, 2015), as a matter of fact, it would be needed only 0.02% of the earth´s surface if solar cells could capture all the energy available (Prentiss, 2015). These figures demonstrate the enormous potential of solar energy as a source of clean, reliable, and renewable energy. However, it is necessary to ensure that sufficient storage capacity can be achieved, and that investment in solar energy is cost-effective.

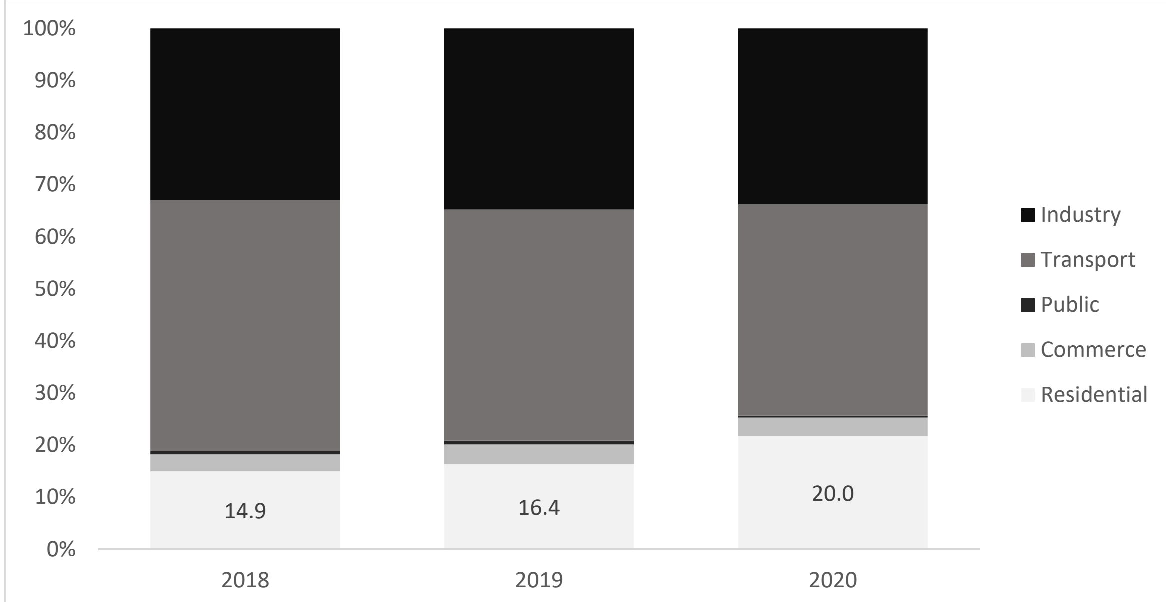
In summary, Mexico has an opportunity to increase its renewable energy mix by incentivizing solar energy sources. Even though prices have been declining over time, but adoption is almost negligible, the objective of this study is to understand the drivers of photovoltaic system adoption in Mexican households.

This study uses a quantitative approach to understand the drivers of adoption in the residential sector. The main tool used is a self-reported survey. The objective of the survey is to classify the responses on either Motivator (the reason to adopt), Barrier (a reason that difficult or makes impossible to adopt) and Enabler (something that help overcome a barrier).

1.3 A general description of the research project.

The primary objective of this research project is promoting the comprehension of the drivers of adoption of residential photovoltaic systems in Mexico by identifying its main drivers. The study focuses on the residential sector because, on the one hand, this sector is a significant contributor to Mexico's final energy consumption, accounting for approximately 20% (Figure 5). Therefore, implementing policies to reduce energy consumption in this sector could have a significant impact. On the other hand, while the industrial and transportation sectors may be more energy intensive, widespread adoption of residential photovoltaic systems is currently unfeasible in these sectors. Additionally, certain industries, such as "hard-to-abate" sectors, face challenges in fully transitioning to solar energy due to their inherent process intensity (Willige, 2022).

Figure 5. final energy consumption by sector in Mexico



Source: own elaboration with information from Dirección General de Planeación e Información Energéticas, Sistema de Información Energética, SENER.

As noted in Table 3, almost every house is connected to the grid and lack access to alternative energy resources. The trend is valid for both dense and thinly populated places, which indicates a national trend. Although Table 3 does not identify the specific alternative energy sources being utilized, it is reasonable to assume that residential photovoltaic systems may be among them, but not be the only alternative energy source. As a result, the potential for greater adoption of residential photovoltaic systems may be even more significant than the table suggests.

Table 3. Electricity sources in Mexican households

	Inhabited private dwellings		15000 and more inhabitants		Less than 15000 inhabitants	
	Absolute	%	Absolute	%	Absolute	%
It has an electricity connection	32875974	99.1	25943843	99.5	6932131	97.9
Public Grid Power Only	32737991	99.6	25872333	99.7	6865658	99.0
Only power from an alternative source	**67466**	**0.2**	**20713**	**0.1**	**46753**	**0.7**
Public electricity grid connection and alternative source	**70517**	**0.2**	**50797**	**0.2**	**19720**	**0.3**

They do not have electricity	286174	0.9	135326	0.5	150848	2.1
Source: own elaboration with data from Encuesta Nacional de Consumo de Energéticos en Viviendas Particulares (ENCEVI-INEGI) 2018						

My interest in the adoption of photovoltaic systems in residential areas is also driven by the distributed energy paradigm. This paradigm emphasizes the generation of electricity from various sources, including households and industrial plants, as opposed to relying solely on large centralized solar parks. "Distributed Energy Resources" is the term used to describe electric power generation sources with limited capacity that are directly connected to a distribution system rather than the bulk power transmission system (Funsho Akorede, Hizam, & Pouresmaeil, 2009).

According to Funsho Akorede, Hizam, and Pouresmaeil (2009), distributed generation through photovoltaic systems offers significant advantages compared with a centralized generation, including higher energy efficiency, reduced greenhouse gas emissions, minimized health risks, and conservation of resources for other uses than a centralized grid. These benefits make photovoltaic systems an attractive option for sustainable energy generation, with the potential to improve energy efficiency, lower emissions, improve health outcomes, and conserve resources.

However, there are associated risks, such as grid imbalances or contingencies resulting from excess electricity exported from residential photovoltaic systems to the grid (Shrivastava, Dumar Saini, & Pandit, 2020). Consumers may prefer to dispatch their own storage resources to reduce their bills rather than reducing the cost of a broader system, which shrinks the benefits of distributed generation (Zakeri, Gissey, & Dodds, 2021), this implies that energy self-consumption may offer greater benefits than exporting electricity to the grid (Sweco Energuide AB, 2019).

Given that the residential sector is relevant to reduce emissions, it is feasible to adopt solar energy as a fuel, there does exist a decreasing cost trend and most of the households in Mexico only use the grid directly as their electricity source, there is a substantial opportunity to accelerate the transition to distributed generation and greener supply of energy in Mexico. However, there is a lack of understanding regarding crucial characteristics of Mexican households and homes, including the motivators behind the adoption of solar panels, the obstacles encountered during the adoption process, and the enabling factors. Therefore, the research project aims to address the following research question:

To what degree are the most prevalent motivators, barriers, and enablers of the adoption of residential photovoltaic systems present in Mexico?

The study consists of the following sections: literature review, research design, data analysis, findings, and policy recommendations. The literature review establishes a theoretical framework and lists motivators, barriers, and enablers (MBEs) related to residential photovoltaic system adoption. The research design explains the approach and data collection techniques used, including the ENSOLRES 2022/2023 survey. The data analysis employs logit regression, spatial regression, and cross-validation. The findings indicate that financial and informational barriers are significant, while ownership of the house, awareness of financial aid, and residing in a highly irradiance zone drive adoption. The study suggests that environmental motivators exist. The policy recommendations propose a mix of financial incentives, increased awareness, gradual reduction of electricity subsidies, and targeted interventions in high-irradiance zones to enhance photovoltaic system uptake, addressing the identified barriers, enablers, and motivators.

2. The review of the literature

The main objective of this section is to derive a theoretical framework that takes into consideration various factors that affect the decision-making process of households in the adoption of residential photovoltaic systems. This includes identifying and analyzing the different theoretical frameworks that may be used to conceptualize and explain the decision-making process, and examining the various factors that affect household decisions to adopt photovoltaic systems. By providing a thorough examination of these factors, this literature review seeks to contribute to a more complete understanding of what drives or hinders the adoption of residential photovoltaic systems.

This literature review is structured into two main sections. The first section is devoted to the establishment of an integrated theoretical framework on the adoption of residential photovoltaic systems. This framework is based on a synthesis of the diffusion of innovations theory, the planned behavior theory, and the value-belief-norm theory. The aim is to provide a comprehensive and coherent model that accounts for the different factors that influence the decision-making process of households when considering the adoption of photovoltaic systems. The second section focuses on the identification and analysis of the motivators, barriers, and enablers (MBEs) that have been identified in previous studies. The purpose is to provide an 14 overview of the most relevant and common MBEs reported in the literature, and to identify potential gaps in the existing research.

2.1 Theoretical framework.

This research project is based on a theoretical framework that synthesizes three different behavioral decision theories: the diffusion of innovations theory, the planned behavior theory, and the value-belief-norm theory and it is based primarily on the work of Wolske, Stern and Dietz (2017). The purpose of this synthesis is to explore the implications of each theory to establish a common understanding of their unique characteristics. The result is an integrative theoretical framework that combines the three theories into a unified model, providing a comprehensive and coherent approach to understanding the complex and multifaceted decision-making process of households when considering the adoption of photovoltaic systems.

I will begin with a definition of Motivators, Barriers, and Enablers (MBEs). A Motivator, as used in this context, refers to a compelling reason that propels an individual towards the adoption of a residential photovoltaic system within their home. On the other hand, a Barrier is an impediment or an unfavorable circumstance that inhibits or renders the adoption of a residential photovoltaic system impractical. Lastly, an Enabler denotes a condition that is beyond the control of the adopter but serves to alleviate or eradicate the barriers to the adoption of a residential photovoltaic system.

Despite the empirical evidence on the factors that influence the decision to adopt solar panels, the theoretical underpinnings of such findings were until recently underdeveloped. The decision-making process behind the adoption or rejection of residential solar systems had not been subject to systematic study, with research instead focusing on the characteristics of consumers who had already installed residential solar systems and their environment (Wolske, Stern, & Dietz, 2017). This cognitive process is complex and influenced by various individual and environmental factors.

In the following subsections, I will provide an in-depth description of the three theoretical frameworks that have been synthesized to form the foundation of this research project on the adoption of residential photovoltaic systems. These theories are the diffusion of innovations theory, the planned behavior theory, and the value-belief-norm theory. By examining the assumptions and implications of each theory, we can gain a comprehensive understanding of 15 the decision-making process of households when considering the adoption of photovoltaic systems. This will enable us to develop a unified model that incorporates the strengths of each theory and provides a more complete and coherent approach to understanding the complex and multifaceted cognitive process that underlies the adoption or rejection of residential solar systems.

2.1.1 Diffusion of Innovations

The concept of diffusion, as postulated by Rogers, Singhal, and Quinlan (2019), pertains to the process through which an innovation is communicated to members of a social system over time. According to Rogers, Singhal, and Quinlan (2019), an innovation denotes any idea, object, or process that is perceived as new by an individual or any other unit of analysis that claims to have acquired it. The diffusion of innovation theory contends that solar panels, as self-generating technologies, can serve as innovations that permeate the community through a social system that disseminates benefits through active or passive means. As explained by Wolske, Stern, and Dietz (2017), the adoption process is composed of five stages, specifically knowledge, persuasion, decision, implementation, and confirmation:

I) In the knowledge stage, individuals become cognizant of the existence of the innovation.

II) In the persuasion stage, they acquire information regarding the innovation from the attitudes of other members of the social system, either actively or passively.

III) In the decision stage, individuals decide whether to adopt the innovation or not.

IV) In the implementation stage, they take the necessary measures to implement the innovation.

V) Finally, in the confirmation stage, individuals make a judgment on whether to persist in using the innovation, expand its use, or discontinue using it entirely.

The adoption of novel technologies or innovations is often depicted as a process that follows a curve that comprises four distinct adopter groups (Rogers E. , 1983). The foremost category of adopters is designated as the "Early adopters". These individuals tend to exhibit the lowest levels of risk aversion and the highest levels of optimism towards novel technologies. They typically exhibit a keen interest in exploring new products and are willing to undertake a certain degree of risk in doing so (Rogers E. , 1983). The second adopter group is known as the "Early majority". These individuals also tend to adopt the product at an early stage; however, they usually display lower risk aversion levels than the average consumer and share the optimistic outlook of the early adopters (Rogers E. , 1983). The third group of adopters is the "Late majority". This category of adopters tends to be more cautious and manifests an average level of risk aversion (Rogers E. , 1983). They may not necessarily be optimistic about innovation; however, they will ultimately adopt new technologies when they become widely accepted and the benefits are evident. The final group of adopters is referred to as the "Laggards". These are the last people to embrace innovations and may do so hesitantly, either due to high risk aversion or because the new technology has become the new status quo (Rogers E. , 1983). These classifications are relevant since, in countries like Mexico, with a low penetration of photovoltaic systems, although residential solar systems are no longer "new" in the strict sense of the word, may be new in the social system, in terms of Rogers, Singhal, and Quinlan (2019). Studies such as the one carried out by Labay & Kinnear (1981) find that *early adopters* tend to perceive solar thermal systems as low risk and complex compared to the other three types of *adopters*. This theory is useful to understand adoption behavior in the self-disposition diagram (as shown in figure 6), because people would be driven to its own taste for innovation.

2.1.2 Theory of planned behavior

The theory of planned behavior (TPB) takes a rational approach to the process of adopting solar panels. It assumes that the decision to adopt or not adopt solar panels is influenced by a person's attitudes, subjective social norms, and perceived behavioral control (Ajzen, 1991). TPB is a long-standing theory used in various fields such as psychology, sociology, and marketing to explain and predict human behavior. The process of adoption is divided into three stages (Wolske, Stern, & Dietz, 2017): Attitudes about Behavior, Subjective Social Norms, and Assessment of Ability to Perform the Behavior.

Attitudes about Behavior

In the first stage of the TPB, individuals assess their own perception of the benefits and costs of adopting solar panels (Wolske, Stern, & Dietz, 2017). The perceived benefits include environmental benefits, financial savings, and energy independence. The perceived costs include the initial installation cost, maintenance costs, and inconvenience. Individuals also consider how their decision to adopt or reject solar panels will be socially perceived by their family, friends, and neighbors.

Subjective Social Norms

The second stage of the TPB involves assessing the perceived social norms about adopting solar panels. Social norms refer to the beliefs of individuals about what others think they should or should not do (Wolske, Stern, & Dietz, 2017). In the context of adopting solar panels, social norms can be either descriptive or injunctive. Descriptive norms refer to what most people do, while injunctive norms refer to what people should do. Individuals who perceive that others in their social network approve of solar panel adoption are more likely to adopt solar panels themselves (Wolske, Stern, & Dietz, 2017).

Assessment of Ability to Perform the Behavior

The third stage of the TPB involves assessing the individual's perceived ability to perform the behavior. This includes assessing the individual's knowledge and skills to adopt solar panels, as well as their access to resources, such as financing, technical expertise, and installation services (Wolske, Stern, & Dietz, 2017).

Overall, the TPB postulate that the decision to adopt or reject solar panels is a rational process that involves weighing the perceived benefits and costs of adoption, considering the perceived social norms about solar panel adoption, and assessing the individual's perceived ability to adopt solar panels (Wolske, Stern, & Dietz, 2017). The TPB is a widely used theory in predicting and explaining human behavior and has been applied in various contexts such as health behavior, consumer behavior, and environmental behavior.

Empirical Evidence

Empirical studies have examined the applicability of the TPB in predicting the adoption of solar panels. A survey of 200 homeowners by Korcaj, Hahnel, and Spada (2015) found evidence of rational calculations guiding the decision to install solar panels. The authors identified the following benefits and costs of adopting photovoltaic systems: collective benefits such as reduced pollution and individual benefits such as financial or network independence, as well as the risk of loss to investment.

The authors concluded that attitudes towards adopting solar panels are highly dependent on individual gains and social context. In other words, the decision to adopt solar panels is not exclusively driven by either individual benefits or social norms, but rather a combination of both. The conclusion of their study is that attitudes are highly dependent on individual gains and social context. That is, this theory helps to conclude that social norms matter but also do perceive material benefits.

2.1.3 Value-Belief-Norm theory

The Value-Belief-Norm theory (VBN) is a theory that explains the adoption of photovoltaic solar panels based on individuals' perception of the environmental benefits associated with the technology. According to this theory, individuals' personal norms for environmental responsibility influence their decision to adopt solar panels (Wolske, Stern, & Dietz, 2017). The

VBN theory suggests that the adoption process involves a cognitive process that consists of a sequence of steps, whereby social or environmental values influence specific beliefs regarding ecological vision, the consequences of action, and personal responsibility. These beliefs, in turn, lead to the formation of specific personal norms and intentions, which ultimately culminate in observable behavior, namely, the adoption of solar panels (Wolske, Stern, & Dietz, 2017).

The study by Jager (2006) investigated the underlying factors that prompted the adoption of photovoltaic solar panels in Groningen, the Netherlands. The research findings indicate that the principal impetus behind investment in this technology was a desire to promote a more ecologically sustainable environment. Similarly, Haas, Ornetzeder, Hametner, Wroblewski, and Hübner (1999) conducted an in-depth analysis of the Austrian 200 kWp-photovoltaic-rooftop program and concluded that concerns pertaining to environmental conservation and the utilization of solar energy as a substitute for nuclear energy are the predominant reasons for investing in photovoltaic systems.

The VBN theory's focus on personal norms for environmental responsibility provides insight into the underlying factors that influence individuals' decision to adopt photovoltaic solar panels. The theory suggests that individuals' perceptions of the environmental benefits of solar panels are crucial in motivating them to adopt this technology. Moreover, the TPB theory highlights the importance of intentions as a determinant of behavior, suggesting that individuals' motivations play a vital role in shaping their decision to adopt solar panels.

The findings of Jager (2006) and Haas et al. (1999) support the VBN theory's premise that concerns pertaining to environmental conservation and the utilization of solar energy as a substitute for nuclear energy are critical factors in motivating individuals to adopt photovoltaic systems. These studies suggest that individuals' perceptions of the environmental benefits of solar panels are instrumental in shaping their attitudes and intentions towards adopting this technology.

In conclusion, the VBN theory and the TPB theory provide a theoretical framework for understanding the factors that influence individuals' decision to adopt photovoltaic solar panels. The VBN theory emphasizes the importance of personal norms for environmental responsibility, while the TPB theory highlights the significance of intentions as a determinant of behavior. Empirical evidence supports the premise that concerns pertaining to environmental conservation and the utilization of solar energy as a substitute for nuclear energy are critical factors in motivating individuals to adopt photovoltaic systems.

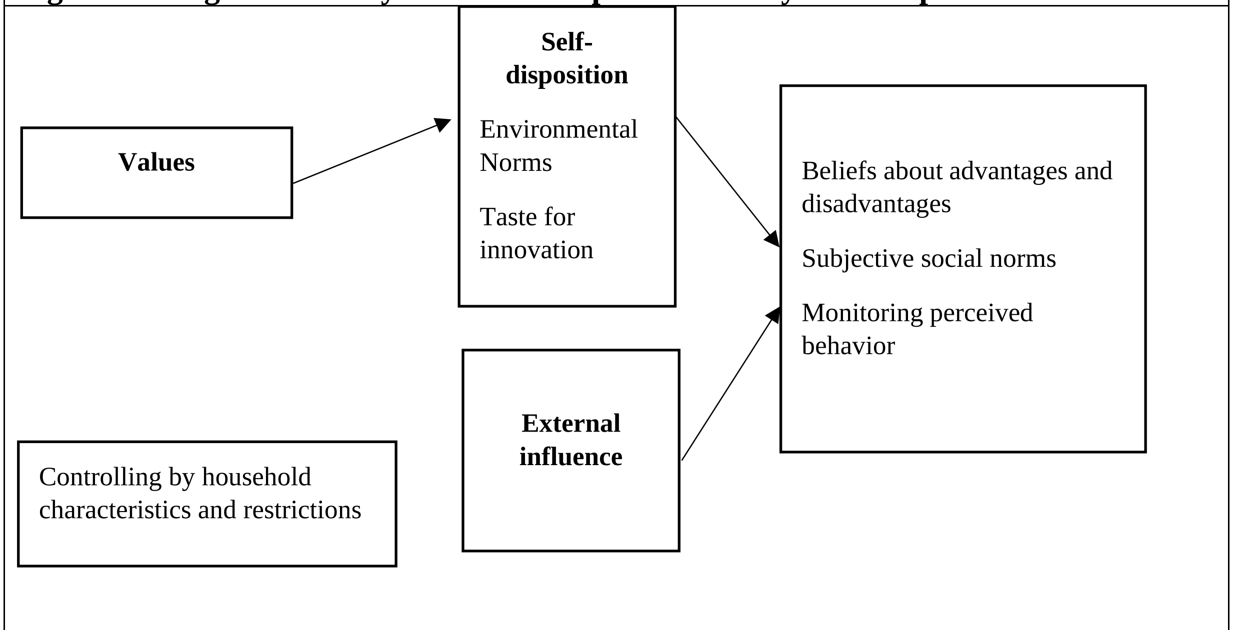
2.1.4 An integrative theory of residential photovoltaic system adoption

Wolske, Stern, and Dietz (2017) proposed an integrative theory that synthesizes the social and psychological factors that influence the decision-making process for residential photovoltaic system adoption. Their theory draws upon the previously discussed value-belief-norm theory, the theory of planned behavior, and the diffusion of innovation theory.

By combining these theories, the authors aimed to provide a comprehensive understanding of the complex factors that contribute to the likelihood of a household adopting a photovoltaic system. The integrative theory of residential photovoltaic system adoption postulate that the decision-making process involves a series of stages, including awareness, consideration, decision, installation, and use. The theory suggests that these stages are influenced by a range of factors, including individual attitudes, social norms, perceived behavioral control, perceived value, and the characteristics of the photovoltaic system itself. By utilizing an integrated framework, the theory offers a more holistic understanding of the multifaceted decision-making process involved in residential photovoltaic system adoption.

The following diagram, as presented by Wolske, Stern, and Dietz (2017), illustrates the various factors that influence an individual's decision to adopt residential photovoltaic systems. Values are the primary determinant of individual perceptions regarding solar panels, and these values are influenced by the value-belief-norm theory. According to this theory, an individual's values are shaped by their context, which comprises of cultural, social, and personal factors. In turn, an individual's values inform their beliefs, which are shaped by both external factors and personal dispositions.

Figure 6. Integrative theory of residential photovoltaic system adoption.



Integrative theory on adoption of photovoltaic residential solar systems in the residential sector. Source: own elaboration based on Wolske, Stern, & Dietz (2017)

Beliefs and attitudes specific to solar panels are informed by perceptions of advantages and disadvantages, subjective social norms, and perceived behavioral control. Perceptions of advantages and disadvantages are the rational assessments of the costs and benefits associated with a particular course of action. Individuals are likely to adopt photovoltaic systems if they believe that the benefits outweigh the costs. Therefore, an individual's perception of the advantages and disadvantages of photovoltaic systems plays a significant role in the adoption decision.

Subjective social norms refer to social pressures to conform to certain behaviors. Individuals are likely to adopt photovoltaic systems if they believe that other people in their social network expect them to do so. On the other hand, if an individual perceives that their social network does not support photovoltaic system adoption, they may be less likely to adopt the system. Therefore, subjective social norms influence an individual's decision-making process.

Perceived behavioral control involves introspection concerning an individual's ability to successfully perform a given behavior. If an individual believes that they have the necessary skills and resources to install and use a photovoltaic system, they are more likely to adopt the system. Conversely, if an individual believes that they lack the necessary skills and resources, they may be less likely to adopt the system. Perceived behavioral control plays a crucial role in an individual's decision to adopt photovoltaic systems.

In conclusion, Wolske, Stern, and Dietz's (2017) integrated framework provides a more comprehensive understanding of the social and psychological factors that drive residential photovoltaic system adoption, than one individual framework in isolation. The framework emphasizes the critical role of values, external influences, personal dispositions, and beliefs specific to solar panels in shaping the decision-making process. Moreover, the framework highlights the importance of rational assessments of advantages and disadvantages, subjective social norms, and perceived behavioral control in determining the final decision.

2.2 Drivers of residential photovoltaic system adoption.

The integrative theory provides significant insights that could be instrumental in guiding policies and interventions intended to foster the widespread uptake of residential photovoltaic systems. This section is subdivided into three subsections, each dedicated to elucidating one of the drivers of residential photovoltaic system adoption. Specifically, I will discuss the motivators, barriers, and enablers identified in the literature, as well as the policies that have been implemented to promote adoption. The section culminates with a summary of the key findings presented in Table 4.

2.2.1 Motivators

One of the most straightforward drivers of adoption is the desire to lower the electricity bill or to generate income by supplying electricity to the grid. To increase household microgeneration, the United Kingdom introduced a program in its 2009 renewable energy strategy (Balcombe, Rigby, & Azapagic, 2013). According to Balcombe, Rigby, and Azapgic (2014), the main reasons households participated in the program were to become more self-sufficient and to mitigate potential increases in energy prices. The program evaluation revealed that grid independence and price stability were the primary motivators for adopting microgeneration technologies (Balcombe, Rigby, & Azapgic, 2014).

In contrast to the previously mentioned motivators, the evaluation of the UK's microgeneration strategy revealed that while environmental considerations were present, they were not a significant driver (Balcombe, Rigby, & Azapagic, 2013). According to citizens' reports, they were unwilling to bear higher costs for the sake of environmental benefits (Balcombe, Rigby, & Azapagic, 2013). Similar findings of environmental concerns being a weak motivator were reported in another study. Schelly (2014) conducted 48 interviews with early adopters of solar panels in Wisconsin to determine the factors influencing their adoption of residential photovoltaic systems. She found that the desire to help the environment was not a determinant among the participants of her study.

Despite some evidence suggesting that environmental concerns may not be a significant motivator for the adoption of residential photovoltaic systems, the research in this area is not consistent. Palm (2018) conducted a qualitative study in Sweden, interviewing sixty-three individuals between 2008 and 2016 to investigate the factors driving adoption. In her findings, Palm (2018) concludes that environmental concerns were a decisive and consistent motivator over time. However, she also identifies a range of other motivators, including a desire to test modern technology, technical interests, increased comfort or convenience, cost efficiency, protection against high future costs, security in continuity of service, symbolic reasons, and energy self-sufficiency.

Regarding motivators, it is important to note that the motivators for adoption of photovoltaic systems are not uniform and vary depending on country-specific circumstances and the stage of technology development. Additionally, government policies may play a role in promoting adoption in some cases, while individual motivation may drive adoption in others. These findings highlight the need for tailored policies that address the diverse range of motivators for residential photovoltaic system adoption.

2.2.2 Barriers

The adoption of solar panels in residential settings may be hindered by various factors, including financial barriers. Palm's (2018) study identified several barriers to the adoption of residential photovoltaic systems, including administrative burdens, information asymmetry, financial constraints, aesthetics, impact on infrastructure, difficulty finding objective experts, conflicting opinions, technical defects, low compatibility, and limited scale. Among these, financial constraints were consistently found to be the most significant barrier, as confirmed by

Chatthaworn et al. (2018) and Balcombe et al. (2013). Specifically, Balcombe et al. (2013) noted that the upfront cost of installation was the primary reason for the lack of adoption of residential solar systems. These findings indicate that addressing financial barriers is crucial for the successful adoption of solar panels in the residential sector.

The obstacles concerning the generation of distributed systems also apply to the acceptance of residential photovoltaic systems. However, in my empirical project, I won't delve into analyzing these barriers. Nevertheless, I'll explain this obstacle to highlight its policy implications. It's worth noting that as policy makers haven't yet tackled this matter, it isn't considered significant for a household decision-maker.

Distributed generation refers to electric power generation within distribution networks or on the customer side of the network (Ackermann, Andersson, & Söder, 2001). This represents a novel approach to the electricity industry that modifies the generation of electricity on the grid from centralized plants to multiple units directly connected to the network (El-Khattam & Salama, 2004). The policy barriers to distributed generation technologies identified by Carley (2009) are as follows:

- Absence of national procedures for standard interconnection.
- System operators must receive approval from multiple stakeholders.
- Utilities lack experience with distributed operation.
- High associated fees for interconnection to the central grid.
- Distributed generation systems may not recover payback due to a standardized tariff scheme.

In conclusion, the adoption of residential photovoltaic systems can be impeded by various barriers in the residential sector. While the barriers related to distributed generation can indirectly affect the adoption of residential photovoltaic systems, they are not the focus of this study as it does not address system operators or grid capacity building. Nonetheless, there are policy-relevant barriers such as upfront costs, property ownership, and lack of information that require attention from policymakers.

2.2.3 Enablers

Enablers, which are factors that promote the adoption of residential solar systems, are a key component of the integrative theory and are situated in the external influence and household characteristics section. Schelly (2014) highlights that personal, home or any other kind of events occurring within the household, such as retirement or home renovations, can significantly impact the decision to adopt residential solar systems. Enablers can be categorized into two types: time-bounded and contextual. Time-bounded enablers refer to events that occur within a defined period, as mentioned by Schelly (2014). In contrast, contextual enablers encompass conditions both inside and outside the household that can help to overcome barriers and facilitate adoption. While barriers and enablers both play crucial roles in the adoption of residential solar systems, it is important to note that enablers can help to mitigate the impact of barriers and promote adoption, particularly those barriers that are policy relevant, such as upfront costs, property ownership, and lack of information.

The first enabler considered for residential photovoltaic system adoption is referred to as the “peer effect.” This refers to the direct or indirect influence of other households to encourage the adoption of photovoltaic systems. From the perspective of an outside adopter, being viewed as an “example to others” is a simple way to understand the concept of a peer (Palm & Tengvard, 2011). The peer effect, also known as the network effect, serves as an enabler against information asymmetry issues. For instance, individuals who interact with neighbors that have already adopted residential photovoltaic systems and feel confident in their decisions are more likely to adopt the technology themselves (Scheller et al., 2022). Moreover, it can be inferred that stronger spatial and affinity relationships facilitate the adoption of photovoltaic systems (Wolske, Gillingham, & Schultz, 2020).

In a review of the literature, Scheller et al. (2020) found that there exist major influence dynamics based on networks of stakeholders, and the perceived closeness and likeability of stakeholders indicate a higher level of influence. The study concludes that trust is the most important characteristic for peer influence to happen (Scheller, Doser, Sloot, McKeena, & Bruckner, 2020). The peer effect is boosted by the adopter´s characteristics. Cho, Shaygan, and

Daim (2019) performed a geospatial data analysis and found a correlation between education, income level, and the number of residential photovoltaic system adopters in the state.

The second enabler of residential photovoltaic system adoption is the condition of house ownership. Specifically, when the decision maker owns the house, they are more likely to adopt the system due to the absence of economic losses in case of moving houses (Balcombe, Rigby, & Azapgic, 2014). Additionally, renting a house may hinder the adoption process, even if it is economically viable, due to the negotiation process with the landlord (Balcombe, Rigby, & Azapgic, 2014).

Finally, the adoption decision is related to age. Being younger increases the intention to adopt, but being older makes it easier to achieve adoption due to available economic means (Balcombe, Rigby, & Azapagic, 2013). In other words, those who want to install solar panels might not have the money or property to do so, whereas those who have the money or property to do so do, do not want to install a photovoltaic system.

In conclusion, the adoption of residential solar systems is influenced by various enablers, which are factors that promote adoption. Enablers are categorized into two types: time-bounded and contextual. Time-bounded enablers refer to events that occur within a defined period, such as retirement or home renovations. On the other hand, contextual enablers encompass conditions both inside and outside the household that can help to overcome barriers and facilitate adoption. Enablers, particularly the peer effect and house ownership, can help to mitigate the impact of barriers and promote adoption, particularly those barriers that are policy relevant, such as upfront costs, property ownership, and lack of information.

Overall, understanding the enablers of residential solar system adoption can help policymakers and stakeholders develop effective strategies to promote adoption and overcome barriers. Peer influence and house ownership are particularly important enablers that can facilitate adoption, while age can also play a role in the decision-making process.

Finally, it is essential to take into consideration that motivators, barriers, and enablers are context-specific, rather than present to the same degree everywhere, all the time. In a study conducted in Ontario, Canada, and Bavaria, Germany, by Adepetu et al. (2018), the authors used an agent-based modeling approach to understand residential photovoltaic system adoption behaviors. They discovered that there *is no homogeneous behavior associated with adoption in both locations*. For example, by lowering the prices of residential photovoltaic systems, adoption in Ontario may increase, but increasing the price of electricity in Bavaria may have a greater impact (Adepetu, Alyousef, Keshav, & de Meer, 2018).

This study highlights that a one-size-fits-all approach to policy design will be meaningless. To increase adoption of photovoltaic systems requires adapting policies to specific citizens' needs, motivations, and behaviors. To design a Mexico-fit policy, it is first important to understand what Mexico needs and not assume that there will be the same MBEs present to the same degree as in other countries.

2.2.4 Conclusion

The extant literature exhibits geographical and cultural biases, resulting in gaps in the findings. Most studies predominantly focus on settings in the Global North, which risks neglecting systematic differences in country-specific motivators, barriers, and enablers of the adoption of residential photovoltaic (PV) systems. By only considering a small variation of contexts potentially important MBEs are left out from studies. For instance, in the case of Mexico, the country exhibits unique characteristics such as "energy populism," a phenomenon where the government distorts energy prices, thereby influencing households' perceptions and expectations about their actual energy consumption (Hancevic, Cont, & Navajas, 2016). Such contextual nuances may not be applicable to settings such as the UK or Germany, which are commonly examined in the existing literature. By examining cases beyond Europe or the United States, there exists potential to identify substantial differences in motivations, barriers, and enablers for residential PV adoption. For example, variations in home ownership arrangements or residency characteristics may create previously unidentified barriers in certain settings, warranting further investigation.

This review of the literature aimed to set the theoretical background for the rest of the study. By providing a review of the three main theories that explain adoption and its integrative theory, I can set the design of the instrument I will use to collect data. The objective of reviewing what has been found to be potential drivers of adoption of photovoltaic systems is to evaluate whether and to what degree they are present in the Mexican residential sector.

Table 4. summary of MBE of residential photovoltaic system adoption in residential sector		
Motivators	**Barriers**	**Enablers**
• Test modern technology and technical interests. • Protection against high future costs and saving cost (Financial incentives). • Security in continuity of service. • Symbolic reasons as protecting the environment. • Energy self-sufficiency. • Perceived reliability of the public electricity supply. • Peer effect: showing to others the benefits of the system, showing to others oneself as a leader.	• Finance, investment cost and long time to recover the investment. • Aesthetics and impact on the residence. • Low compatibility with existing infrastructure. • It takes place on a small scale.	• Knowledge of similar technologies. • Homeownership • Consider being leaders, or an example for others. • Network effect: diffusion of information (reduction of information disparities due other´s experiences with adoption).
Source: own elaboration.		

3. Research design

3.1 Scope of the study

To study what factors, affect the adoption of residential photovoltaic systems in the Mexican residential sector, I conducted an online survey and supplemented it with administrative records from multiple agencies. The focus of this research project is on descriptive research, which aims to provide a comprehensive overview of the current state of motivators, barriers, and enablers for residential photovoltaic system adoption in Mexico. The primary objective of this research is to identify the factors that drive the adoption of photovoltaic systems among households in Mexico. This includes examining the various motivators that prompt households to adopt solar energy and the barriers and enablers that can either facilitate or impede the adoption process. Through a detailed analysis of the available data, this research aims to shed light on the key factors that affect the adoption of solar energy systems in Mexico and provide insights into how these factors can be leveraged to promote greater adoption rates.

Based on the literature review, I have identified various quantitative methods that can be used to study the adoption of residential photovoltaic systems in Mexico. These methods include discrete choice analysis and regression analysis. In order to ensure a rigorous approach, I will use a deductive approach that is grounded in the integrative theory of residential photovoltaic system adoption.

In terms of the household spectrum, I will not divide it by stage of adoption, but instead, take a comprehensive view of the motivators, barriers, and enablers to adoption. To provide a more nuanced understanding, I will make comparisons between different states and households. This will allow me to identify any variations in the factors that influence the adoption of residential photovoltaic systems and provide insights into how these factors may vary across different households.

3.2 Hypothesis

It is expected that multiple factors will affect the intention of households to adopt solar panels in the residential sector. The first hypothesis is that savings is not a prominent motivator for photovoltaic adoption in Mexico. While found as important motivator in other contexts, the distortion in electricity prices within the country, may not incentivize households to adopt residential solar systems as a cost-saving measure. As Hancevic, Núñez, and Rosellón (2019) report, households currently only pay around 46% of the actual cost of energy, which includes generation, transmission, and distribution costs. To test this hypothesis, an assessment of the significance of prices will be conducted to determine whether a reduction in cost is a statistically significant variable. Such an evaluation would provide valuable insight into the potential impact of price reduction on the adoption rate of residential solar systems.

The second hypothesis to be tested is that, despite recent reductions in the cost of acquiring residential photovoltaic systems, low-income levels in Mexico may remain a significant barrier to adoption. It is therefore anticipated that the price of residential photovoltaic systems will continue to be a significant obstacle for Mexicans seeking to adopt this technology. poverty levels in Mexico may constitute a significant barrier to adoption, despite the sharp decrease in the cost of residential photovoltaic systems.

A third hypothesis to be tested is the potential negative correlation between solar irradiance and energy consumption. This relationship is significant for policy design as interventions may be targeted towards areas with higher energy consumption and higher irradiance levels. If a negative correlation is established, it would be necessary to focus on places with higher irradiance for the intervention. Studying irradiance is important because Mexico receives, on average, more solar irradiance than other countries studied in the literature, which may drive adoption due to the efficiency of residential photovoltaic systems.

A fourth hypothesis is related to home ownership and housing stock. Whereas renting has been identified as barrier and homeownership as enabler to photovoltaic adoption elsewhere, the specificities of properties in Mexico are likely to impact decision-making regarding adopting solar panels. The design of housing in Mexico presents difficulties for solar panel installation, especially in facilities such as "Vecindades" in Mexico City where neighborhood councils have the right to deny certain modifications to the house, creating a distortion in homeowner preferences.

The different hypothesis point to difference in the degree to which motivators, barriers and enablers are present in different contexts. Country-specific factors impact the drivers of residential photovoltaic adoption. Therefore, there "one-size-fits-all" policy for promoting residential photovoltaic systems.

3.3 Methodology

To determine to what degree the drivers that influence the adoption of residential solar systems in are present in Mexico, I utilized a quantitative approach that involved the integration of different data sources and analytical techniques. This section provides a thorough explanation of the methodology used, which encompasses the sources of data, the data collection procedures, and the analytical tools employed in the analysis. The purpose of this detailed explanation is to offer a better comprehension of the research process and the methods employed to produce the findings and conclusions presented in this study.

3.3.1 Sources of data

In this section, I outline the sources of data utilized for investigating the motivators, barriers, and enablers to the adoption of residential solar systems in the Mexican residential sector. The data was derived from diverse sources including an in-house-designed survey, administrative data from CFE (Comisión Federal de Electricidad), and geographic information system data. The use of multiple data sources was necessitated by the absence of a single comprehensive source of information, and since the econometric techniques employed required the use of different types of data. A description of each data source is provided in the following subsections, thereby providing a comprehensive overview of the data collection process undertaken in this research.

3.3.1.1 ENSOLRES 2022/2023

The present study relies on the ENSOLRES 2022/2023 survey as its primary data source. The ENSOLRES survey was developed in-house and conducted online between November 2022 and February 2023. The survey targeted Mexican homeowners and collected a range of information on household characteristics, electricity consumption patterns, motivators, barriers, and enablers that may influence the adoption of residential photovoltaic systems. The section on electricity consumption included information on both electric appliances and the last electricity bill, while the household characteristics section gathered data on variables such as the number of household members. The motivators section indirectly collected information on factors that may drive adoption, while the barriers section directly asked respondents to identify the main obstacles they may face when considering the installation of photovoltaic systems. The enablers section focused on household and house characteristics, as well as the respondents' awareness of government assistance for residential photovoltaic system adoption. A detailed list of the survey questions used in ENSOLRES for this study can be found in Appendix 1.

The decision to use an online survey as the primary data collection method was informed by two factors. Firstly, previous studies on residential photovoltaic system adoption have employed online surveys, and secondly, online surveys offer a convenient means to gather data from geographically dispersed locations and have been established in the literature as a valid recruitment method (Evans & Mathur, 2005). However, it should be noted that the representativeness of such an online survey can be limited. Due to the way the survey was conducted, and participants recruited, certain states may be overrepresented, as detailed in Table 5. The dataset for this study comprises a total of 296 observations, distributed across various states.

Table 5. State sample of ENSOLRES 2022/2023

State	N	%	State	N	%
Aguascalientes:	94	31.8	Morelos	6	2.0
Baja California:	4	1.4	Nayarit	1	0.3
Baja California Sur:	2	0.7	Nuevo León	4	1.4
Campeche:	0	0.0	Oaxaca	3	1.0
Chiapas:	6	2.0	Puebla	8	2.7
Chihuahua:	2	0.7	Queretaro	3	1.0
Mexico City:	59	19.9	Quintana Roo	1	0.3
Coahuila	6	2.0	San Luis Potosí	0	0.0
Colima	9	3.0	Sinaloa	1	0.3
Durango	6	2.0	Sonora	3	1.0
Estado de México	33	11.1	Tabasco	4	1.4
Guanajuato	6	2.0	Tamaulipas	2	2
Guerrero	1	0.3	Tlaxcala	0	0.0

Hidalgo	7	2.4	Veracruz	6	2.0
Jalisco	9	3.0	Yucatán	4	1.4
Michoacán	5	1.7	Zacatecas	1	0.3
N	296				
Source: own elaboration.					

3.3.1.2 Administrative data

After conducting a transparency trial against the Mexican utility CFE, I was able to obtain data on monthly user tariffs at the municipality level for the years 2018 to 2022. The database includes tariff groups 1, 1A, 1B, 1C, 1D, 1E, 1F, and DAC. A DAC tariff is applied only to homes that consume a high and intensive level of electricity, or due to specific home characteristics that necessitate this level of consumption, as defined by the Comisión Federal de Electricidad (2023).

3.3.1.2 Geographic Information System data

I use a variety of GIS data sources, mainly from Mexican government agencies.[2] The main limitation of the information is that the variables irsmun10gw, gvul10mun, and gwemmun10gw are outdated but can be used as proxies. I am using 2019 as the baseline year due to global horizontal irradiance availability and CFE administrative data. Table 6 describes the variables used:

Table 6. GIS data used in the study

Data type	Name	Source	Description	Attribute used
Vector	teminmungw	CENAPRED	The map shows the extreme minimum temperature by municipality.	T_MINEXT. Num. Extreme minimum temperature by municipality.
	seqesc05gw	CENAPRED	The map shows the degree of danger due to drought by municipality in Mexico. It is based on ran deficit duration. It's a 10-point categorical variable ranging from moderate to critical.	SEQUIA. Char. Drought hazard classification by municipality.

[2] Most of the information is accessible in the following link: http://www.conabio.gob.mx/informacion/gis/ (last accessed on January 29, 2023).

	marmun10gw	CONABIO	Marginalization index in 2010. It is a summary of deficiencies suffered by the population because of lack of access to education, inadequate housing, perception of insufficient monetary income and others. Built with information of CONAPO.	IND_MAR Marginalization index by municipality, 2010.
	irsmun10gw	CONABIO	The social backward index is a measure that orders municipalities from highest to lowest degree of social backwardness. Considers: education lag, access to health services, access to basic quality services and spaces in home, and assets at home. It is calculated using a Principal Component Analysis.	IRS2010. Num. Social backwardness index by municipality.
	gvul10mungw	CENAPRED	The social vulnerability index associated with disasters indicate municipalities which have greater susceptibility to suffer disasters from the impact of different type of phenomena. Do not include perception of risk.	VULNERA. Char. Social vulnerability index 2010.
	emmun10gw	Percentage of employed population. CONABIO.	Using information from INEGI, indicate population aged 12 and over that had a job.	BY_ASA10. Char. Percentage of the salaried population by municipality, 2010.
Raster	GHI	SOLARGIS, World Bank	Indicates the Global Horizontal Irradiance.	GHI, 2019.
Source: own elaboration.				

3.3.2 Data analysis techniques

In this section I describe the econometric techniques to analyze the data. This is a general description of how each analysis work and why it is used.

3.3.2.1 Logit regression

To understand the role different motivators, play in the decision to adopt photovoltaic systems, I use a discrete choice model in which I define $P_i = \frac{e_i^{\beta x}}{\Sigma e_j^{\beta x}}$ as the probability that respondent chooses alternative i, where: $i \in \{consider\ installing, do\ not\ consider\ installing\}$ or $i \in \{have\ installed\ a\ system, have\ not\ installed\ a\ system\}$. The interest is to identify direction and significance of β parameters, which are motivators for residential photovoltaic system adoption.

3.3.2.2 Ranking device

The ranking device used in this study for assessing barriers involves presenting a list of potential barriers to the adoption of residential photovoltaic systems and asking respondents to rank them in order of importance. This method allows for a clear understanding of which barriers are most significant to respondents, as well as the relative importance of different barriers.

By using a ranking device, the study can identify the most pressing barriers faced by homeowners in Mexico when considering the adoption of residential photovoltaic systems. This information can be used to inform policies and interventions aimed at addressing these barriers and promoting the adoption of renewable energy systems.

Furthermore, the use of a ranking device allows for a standardized approach to assessing barriers, ensuring that all respondents are presented with the same list of potential barriers and asked to rank them in the same order. This reduces the potential for response bias and ensures that the data collected is reliable and valid.

3.3.2.3 Randomized survey

This methodology was used to cross validate opinions between respondents. There was a base question that was randomly modified for every respondent by adding for example a qualifier “many” or “a little”.

3.3.2.4 Spatial regression analysis

To address policy design regarding where to focus the potential intervention, I use a spatially corrected regression analysis. I use DAC percentage as a dependent variable and global horizontal irradiance as an explanatory variable, and I control for covariates in various model specifications.

4 Results and analysis

This section provides an analysis of the data collected from the ENSOLRES 2022/2023 survey and other data. The results are presented in the following sequence: first, with the examination of the motivators, then elaborating on the barriers, and finally, enablers to adoption. My results show I) that people have environmental interest, are not motivated by reducing the electricity bill, II) financial, information and ownership barriers are the main issues that people face during the adoption process and III) people would adopt if there were financial incentives, reduction of information barriers and photovoltaic systems were placed in a highly irradiance zone (due efficiency of solar panels).

4.1 Motivators

4.1.1 Heating, cooling and expected savings.

I use a logit model to test whether there exists motivation from temperature and expected savings to install residential photovoltaic system controlling for the number of appliances in a household. In Table 9, the results of the regression are shown. Both CDM and total appliances are significant at the 5% level. This means that as the number of appliances increases (indirectly implying a higher level of electricity consumption), people are more likely to plan to install a residential photovoltaic system. I introduce the irradiance variable because in the engineering literature is relevant to the efficiency of the panels to be placed in highly irradiance zones, as can produce more energy (Amer Chaaban, 2011), I hypothesize that there exist spatial dependence between irradiance and high energy consumption. A description of variables used is given below:

Table 7: definitions of variables to motivators.

Variable	Description
Install	1 for install, 0 for not planning to install. This is the dependent variable
CDM	Months with low temperatures. (The average of two proxies for the number of months the household used appliances to heat the house.)

HDM	heating degree months. (The average of two proxies for the months in which the household used appliances to cool the house.)
ExpectSav	Perceived percentage of savings to the bill, divided by the expected cost of installing.
TotAppliances	The sum of individual appliances (Total appliances).
Source: own elaboration.	

Table 8. Logit regression of plan to install against different covariates.				
Number of observations: 237		Log likelihood: -134.74		
Variable	Coefficient	Standard Error	z	P>|z|
Dependent variable: Install				
HDM	0.08116	0.1198	0.68	0.498
CDM	0.53718	0.2713	1.98	0.048
ExpectSav	-12.08604	22.7471	-0.53	0.595
TotAppliances	0.06093	0.0298	2.04	0.041
Constant	-3.64335	0.9527	-3.82	0.0
Source: own elaboration.				

As hypothesized before, expected savings are not found to be a motivator, its P-value is 0.595, which is not significantly different from a zero coefficient. The relevance of this finding lies in the potential distortion that exist due the highly subsidized tariffs in Mexico. This situation potentially contributes to the low uptake of photovoltaic systems, because if energy prices are distorted and low, little savings are to be had from investing in solar panels in Mexico. It is easy to illustrate with a simple calculation: savings of 200 Mexican pesos bimonthly (which is not an unreasonable energy bill), would pay off an investment of 55000 Mexican pesos (not an unreasonable price for a photovoltaic system) in 550 months. Considering that the maximum lifetime of a photovoltaic system is usually estimated to be 30 years (360 months), only considering the monetary benefits would by far not offsets the cost. Now if the price would reflect the true cost (in this example around 400 pesos), it would only take 275 months, to recoup the cost of the investment.

Now I compare the previous model with a cross validated result from ENSOLRES 2022/2023. The assignment of every variation of the question was randomized (in bold I emphasize what was shown different to each respondent). In the following tables I present the responses from questions about savings and energy consumption.

Table 9. Perception of savings after adoption of a residential solar system.			
Question	**Degree of agreement**	**N**	**%**
Acquiring a residential photovoltaic system will allow me save **nothing** in electricity bill	Totally disagree	59	54.1
	Partially disagree	15	13.8
	Neither agree, nor disagree	8	7.3
	Partially agree	10	9.2
	Totally agree	17	15.6
	N	109	
Acquiring a residential photovoltaic system will allow me to save **a lot** in electricity bill	Totally disagree	11	12.8
	Partially disagree	4	4.7
	Neither agree, nor disagree	6	7.0
	Partially agree	23	26.7
	Totally agree	42	48.8
	N:	86	
Total N: 195			
Source: own elaboration.			

The previous question shows that respondents believe that they will save on the electricity bill. The responses to the first variation of the question show that more than a half of the respondents think that they will at least save something on their electricity bill if they were to adopt solar panels. A portion of 15.6% of respondents believe they would not save anything, potentially due to the current energy tariff they pay or a rebound effect: adopters anticipate that acquiring a photovoltaic system would be offset by greater energy use, thus the changes in behavior resulting in no net change.

The responses to the second variation of the question show similar results. Most of the respondents thinks that they will save a lot on their electricity bills (partially agree plus totally agree sums up to 45.5%). There is a similar percentage of people that think they will not save a lot and people that think will not save nothing (17.5% in the former, 15.6% in the latter).

One of the possible explanations of why people responded they will not save on their electricity bills after installing solar panels comes from behavioral changes. This is an improvement in energy efficiency or lower costs of electricity can lead to the same or even more consumption of energy. This effect is known as the rebound effect (Gillingham, Rapson, & Wagner, 2015). To inquire about this issue, I asked whether people believe that they would use, more, less or the same amount of energy after installing solar panels.

Table 10. perception of energy consumption after installing residential solar systems.			
Question	**Degree of agreement**	**N**	**%**
If I install residential photovoltaic systems, I will consume **less** electricity	Totally disagree	17	20.7
	Partially disagree	8	9.8
	Neither agree, nor disagree	36	43.9
	Partially agree	11	13.4
	Totally agree	10	12.2
N		82	
If I install residential photovoltaic systems, I will consume **the same** level of electricity	Totally disagree	11	15.1
	Partially disagree	5	6.8
	Neither agree, nor disagree	4	5.5
	Partially agree	18	24.7
	Totally agree	35	47.9
N		73	
If I install residential photovoltaic systems, I will consume more electricity	Totally disagree	28	37.8
	Partially disagree	14	18.9
	Neither agree, nor disagree	9	12.2
	Partially agree	7	9.5
	Totally agree	16	21.6
N		74	
Total N		229	
Source: own elaboration.			

The responses to the first variation of the question are concentrated on the neither agree, not disagree answer (43.9%). The second and third variation of the question have very similar percentage in the totally agree option to the neither agree nor disagree of the first variation (47.9% in the former, 43.9% in the latter). This means that, irrespective of how the question is posed, almost half of respondents believe that adopting photovoltaic systems will not change their levels of energy consumption. There are two possible explanations of this result: either people believe that will use energy more intensively (rebound effect) or will keep consuming the same at lower cost. As a conclusion, there does not exist a clear interest on either consume more electricity (at the same prices) or consume the same electricity (at lower prices).

4.1.2 Environmental disposition and self-perceived norms.

To determine personal values and self-perceived norms, I provided respondents with a series of randomized variations of claims and asked them to indicate their level of agreement or disagreement with each on a 5-point scale. In the following tables, the results of this exercise.

Every table is divided in the following way: I) the randomly selected question; II) the level of agreement chosen; and III) the number of people who chose that level of agreement. IV) the percentage of people that choose that answer of all respondents to that variation of the question.

Table 11. Self-perceived norm: environment preservation			
Question	**Degree of agreement**	**N**	**%**
I can help preserve the environment	Totally disagree	4	3.8
	Partially disagree	2	1.9
	Neither agree, nor disagree	4	3.8
	Partially agree	33	31.1
	Totally agree	63	59.4
N		106	
I can help **little** to preserve the environment	Totally disagree	11	13.3
	Partially disagree	8	9.6
	Neither agree, nor disagree	10	12.0
	Partially agree	21	25.3
	Totally agree	33	39.8
N		83	
I can help **a lot** to preserve the environment	Totally disagree	7	6.5
	Partially disagree	6	5.6
	Neither agree, nor disagree	8	7.5
	Partially agree	28	26.2
	Totally agree	58	54.2
N		107	
Total N		296	
Source: own elaboration.			

Most survey participants expressed a sense of personal responsibility in preserving the environment. Specifically, in the first module, the combined percentage of respondents who partially and totally agreed with this notion was 82.7%. The second module revealed a decline in such responses by 17.6%, indicating that fewer participants believed their ability to make a difference was limited. In contrast, the percentage of participants who answered partially and totally agree when asked if they can help a lot was 80.4%, which is comparable to the percentage of positive responses obtained in the first module. This suggests that individuals in the first module perceived themselves as capable of making a significant contribution towards environmental preservation, even in the absence of an explicit prompt to do so.

In summary, it can be inferred that the surveyed individuals generally consider themselves capable of contributing towards environmental preservation efforts. Notably, most participants believe they can do more than little, indicating a potential willingness to take more proactive steps towards environmental conservation.

Table 12. Self-perceived norm: individual action for preserving the environment			
Question	**Degree of agreement**	**N**	**%**
With individual actions I can help reduce climate change	Totally disagree	6	6.4
	Partially disagree	3	3.2
	Neither agree, nor disagree	8	8.5
	Partially agree	27	28.7
	Totally agree	50	53.2
N		94	
With individual action I can help a **little** reduce climate change	Totally disagree	10	9.3
	Partially disagree	8	7.5
	Neither agree, nor disagree	8	7.5
	Partially agree	23	21.5
	Totally agree	58	54.2
N		107	
With individual action I can help **a lot** to reduce climate change	Totally disagree	9	9.5
	Partially disagree	2	2.1
	Neither agree, nor disagree	8	8.4
	Partially agree	22	23.2
	Totally agree	54	56.8
N		95	
Total N		296	
Source: own elaboration.			

The following section of questions delves into the issue of whether respondents believe that their individual actions can help reduce climate change. This issue is significant as climate change can be perceived as a global problem that individuals have little power to influence, rather than an issue that requires both local and individual action as well as collective efforts.

The initial variation of the question, which omits the qualifier "little" or "lot," demonstrates a similar level of agreement as the previous question regarding environmental protection. Specifically, 81.9% of respondents either totally or partially agree with the statement that they can help reduce climate change through individual actions. In the second variation of the question, which adds the qualifier "a little," the rate of agreement with the question diminishes, but not to the same extent as the environment protection question. The combined responses of partially agreeing and totally agreeing equate to 75.7%. Lastly, 80% of respondents believe they can help a lot, which is a similar rate of agreement to the first variation of the question that lacks any qualifiers.

Based on the preceding analysis, it can be argued that respondents perceive themselves as capable of taking action to address climate change. This series of questions yields a very similar rate of responses as the environment protection questions. Taken together, these responses suggest that people view themselves as agents that can help protect the planet. However, this does not necessarily indicate that they will regard acquiring residential photovoltaic systems as the optimal means of environmental protection. Instead, it may mean that they will take other types of actions motivated by environmental concerns. Furthermore, the present analysis does not permit the conclusion that environmental concerns are the sole driver behind the decision to adopt photovoltaic systems. Nonetheless, the responses do establish that environmental considerations hold a presence among the respondents.

Table 13. Perception about residential photovoltaic systems impact on preserving the environment.

Question	Degree of agreement	N	%
Installing a residential solar system helps **nothing** preserve the environment	Totally disagree	39	41.9
	Partially disagree	6	6.5
	Neither agree, nor disagree	8	8.6
	Partially agree	10	10.8
	Totally agree	30	32.3
N		93	
Installing a residential solar system helps **a lot** to preserve the environment	Totally disagree	8	8.2
	Partially disagree	1	1.0
	Neither agree, nor disagree	4	4.1
	Partially agree	21	21.4
	Totally agree	64	65.3
N		98	
Total N		191	
Source: own elaboration.			

Table 13, when considered jointly with the previous questions, provides evidence that respondents believe that acquiring residential photovoltaic systems can help protect the environment. When the question was asked in a negative form, i.e., whether installing residential solar systems helps "nothing" to preserve the environment, a dual extreme distribution was observed: 41.9% of respondents totally disagreed and 32.3% totally agreed, the reason I consider this distribution may be derived from is the fact (as I explain in the barriers section), that there does exist information issues, then, people may be not well informed not only about technical issues of the systems but also other benefits that come from installing them. When both types of agreement and disagreement were considered, 43.1% and 48.4% of responses were observed, respectively, indicating a relatively similar percentage of responses in both categories, albeit with a slightly higher percentage of respondents disagreeing with the claim.

However, a different view emerged when the second variation of the question, which included the qualifier "a lot," was used. In response to this question, 86.7% of respondents believed that installing residential photovoltaic systems can help a lot to protect the environment. The most popular response was "totally agreed," accounting for 65.3% of responses.

Taking all of this into consideration, I argue that:

I. Respondents perceive themselves as agents capable of protecting the environment and reducing climate change.
II. Respondents endorse a norm towards taking action to protect the environment and reduce climate change exists.
III. Respondents consider residential photovoltaic systems to contribute towards protecting the environment.

In conclusion, within the framework of the integrative theory of residential photovoltaic system adoption, this evidence suggests an environmental motivation for adopting residential photovoltaic systems is present among ENSOLRES respondents. Thus, a favorable opinion towards residential photovoltaic system adoption exists as a means of protecting the environment.

4.1.3 Independence from the grid.

One of the motivators of residential photovoltaic system adoption that some authors claim is relevant is grid independence. This means that the house generates the electricity that the household consume.

To investigate the issue, two queries were presented to the respondents. Firstly, they were asked to express their opinion on the significance of attaining independence from the state-owned electricity provider, CFE. Secondly, they were requested to indicate their level of concern about electricity outages. This method was employed because individuals are more likely to adopt residential photovoltaic systems and invest in batteries when they hold a high level of concern about electricity supply outages.

Table 14. Perception about shortages.			
Question	**Degree of agreement**	**N**	**%**
I am worried about outages	Totally disagree	17	18.7
	Partially disagree	10	11.0
	Neither agree, nor disagree	11	12.1
	Partially agree	21	23.1
	Totally agree	32	35.2
N		91	
I am **not really** worried about outages	Totally disagree	26	24.5
	Partially disagree	13	12.3
	Neither agree, nor disagree	25	23.6
	Partially agree	25	23.6
	Totally agree	17	16.0
N		86	
I am worried **a lot** about outages	Totally disagree	16	16.2
	Partially disagree	14	14.1
	Neither agree, nor disagree	13	13.1
	Partially agree	30	30.3
	Totally agree	26	26.3
N		99	
Total N		276	
Source: own elaboration.			

In both first and third variations of the question more than a half of people declare that they are worried about outages (either partially or totally agreeing). This potentially comes from problems with the stability of the Mexican energy grid. Temporary power cuts are not a common issue in diverse parts of Mexico (see for example Terreros (2023) and Sáenz Guzmán (2021)). In the variation of the question little worried responses are distributed in a way that no firm conclusions can be made. The indirect approach to independence from the grid, offers an indication that avoiding shortages is something that respondents are interested in. Reliability of energy supply might therefore be a motivator for residential photovoltaic system adoption.

Table 15. Independence from the grid			
Question	Degree of agreement	N	%
Being independent from the CFE grid is important to me	Totally disagree	3	4.4
	Partially disagree	5	7.4
	Neither agree, nor disagree	22	32.4
	Partially agree	21	30.9
	Totally agree	17	25.0
	Totally disagree	19	20.9

Being independent from the CFE grid is **not important** to me	Partially disagree	14	15.4
	Neither agree, nor disagree	29	31.9
	Partially agree	18	19.8
	Totally agree	11	12.1
Being independent from the CFE grid is **some** important to me	Totally disagree	7	9.9
	Partially disagree	4	5.6
	Neither agree, nor disagree	21	29.6
	Partially agree	18	25.4
	Totally agree	21	29.6
Being independent from the CFE grid is **very** important to me	Totally disagree	1	1.6
	Partially disagree	7	11.5
	Neither agree, nor disagree	18	29.5
	Partially agree	20	32.8
	Totally agree	15	24.6
Source: own elaboration.			

Employing a more straightforward approach, the empirical analysis reveals evidence that underscores the significance of people's preference for independence from the grid. The first variation of the question, incorporating a control, suggests that 32.4% of the respondents exhibit no preference between being connected or disconnected from the grid, while 55.9% indicate that they value their autonomy from the grid. The second variation of the question presents a similar degree of indifference, but fewer respondents express a desire to be independent from the grid (36.3%, comprising the sum of totally and partially disagree), and a greater proportion state that they do not consider independence from the grid to be important (31.9%). What can be inferred is that people do not care about being connected to the public grid if it shows a reliable behavior (this can be concluded combining these responses with the previous question (about outages)).

4.2 Barriers

I am using direct approach to understanding the barriers that may prevent individuals from adopting residential photovoltaic systems. To gather data on these barriers, the survey prompted respondents to rank their top three reasons for not acquiring a residential photovoltaic system. This approach allows me to directly capture the perceived obstacles that people may face when considering the adoption of this technology. The results of the survey are then reported in table 16, which presents the frequency with which each barrier was selected by respondents:

Table 16. Barriers	
Reason	**Percentage**
Expensive or out of budget	54.4
Not enough information to decide installing residential photovoltaic systems, or providers are inaccessible or not reliable.	40.5
The household does not have its own resources or does not have third-party financing	25.0
The household is not the owner of the house	19.9
Requires purchasing battery to store energy	13.2
The structure of the house makes it impossible to install esidential photovoltaic systems	10.5
Approval required from third parties	9.8
Installing Residential photovoltaic systems would make the appearance of the property less attractive	1.7
Other	6.8
N:	296
Source: own elaboration.	

As hypothesized, funding is the main reason for not acquiring residential photovoltaic systems, 54.4% of respondents mentioned the expensiveness of photovoltaic systems and 25% of respondents mentioned not having own sources/third-party funding among the three barriers they consider most significant. One reason that was not hypothesized but resulted being an important barrier is lack of information, either about residential photovoltaic systems itself or inaccessibility of providers: 40.5% of respondents mentioned not counting on sufficient information as main barrier to adopting photovoltaic systems. Another relevant reason was house ownership, almost 20% of respondents expressed that this was an important barrier.

To delve deeper into the issue of costs, I inquired about the expenditure of installing residential solar systems throughout a randomization of variations of questions. I asked them to what extent acquiring solar panel represents a major or minor investment for their household.

Table 17. Expenditure of acquiring a residential photovoltaic system.			
Question	Degree of agreement	N	%
Acquiring a residential photovoltaic system would be an **insignificant** expenditure to my household	Totally disagree	26	44.1
	Partially disagree	14	23.7
	Neither agree, nor disagree	8	13.6
	Partially agree	8	13.6
	Totally agree	3	5.1
N		59	
Acquiring a residential photovoltaic system would be a **small** expenditure to my household	Totally disagree	15	20.0
	Partially disagree	21	28.0
	Neither agree, nor disagree	13	17.3
	Partially agree	13	17.3
	Totally agree	13	17.3
N		75	

Acquiring a residential photovoltaic system would be a **high** expenditure to my household	Totally disagree	17	22.7
	Partially disagree	8	10.7
	Neither agree, nor disagree	17	22.7
	Partially agree	19	25.3
	Totally agree	14	18.7
N		75	
Acquiring a residential photovoltaic system would be a **very significant** expenditure to my household	Totally disagree	4	4.6
	Partially disagree	11	12.6
	Neither agree, nor disagree	22	25.3
	Partially agree	32	36.8
	Totally agree	18	20.7
N		87	
Total N		296	
Source: own elaboration.			

In the first variation of the question, 67.8% of respondents stated that they disagree with the assertion that acquiring solar panels is an insignificant investment. Only 5.1% totally agree and 13.6% partially agree with the claim; 13.6% do not agree neither disagree. From these responses, I can conclude that respondents do not consider installing a residential photovoltaic system an insignificant investment. This is consistent with previously presented results.

The second variation of the question reduces the radicality of the claim. Now I asked whether installing residential photovoltaic systems is a small investment, this change increases the number of respondents that agree (34.6%) and reduces the number of people disagreeing (48%). Most respondents that stated that acquiring a photovoltaic system is not a small investment.

The next variation of the question shows similar levels (different direction but same meaning) of people answering that cost is a barrier. Respondents consider that acquiring a residential photovoltaic system is a high expenditure (44%) versus not being a high expenditure (33.7%). Here the percentage of respondents being indifferent to the claim increases (22.7%).

The last variation of the question uses a more radical claim. The percentage of people that consider installing a residential photovoltaic system would be a very significant expenditure to their household income is 57.5%, with 20.7% totally agreeing with the claim. In this variation, only 4.6% of respondents totally disagree with the claim.

The conclusion is that cost of installing rooftop residential solar systems is a major investment. Cost is one of the principal barriers among the respondents of the ENSOLRES survey. This is not surprising considering the still substantial costs of solar panels despite decreases in the recent past, particularly in the Mexican context of comparatively low wages. Besides costs, other barriers to the adoption of photovoltaic systems surfaced such as lack of information and lack of appropriate housing conditions and home ownership. The latter is addressed as enabler in the following.

4.3 Enablers

This section is devoted to inquiring about the current state of enablers to residential photovoltaic system adoption. I analyze four enablers that are part of the integrative theory: home-owning (characteristics of the house), perception about reliability of residential photovoltaic systems (norms), solar irradiance (perception of benefits), and external funding (external influence).

4.3.1 Ownership of the house

Home-owning is an important enabler as it allows households to make long-term investments in their homes, such as installing a photovoltaic system. Homeowners are more likely to invest in renewable energy technologies, as they are more likely to reap the benefits of the investment over the long term. Homeowners also have control over their property, which allows them to make decisions about the installation and maintenance of their photovoltaic systems. Therefore, policies that promote homeownership, such as mortgage programs, could indirectly incentivize the adoption of residential photovoltaic systems. I performed a logit regression to identify if ownership of the house (=1 if true) increases the probability of having a photovoltaic system (actual adoption).

Table 18. logit regression of actual installing against ownership of the house				
	Coefficient	Standard error	z	P>|z|
Ownership	2.34	1.028	2.28	0.023
Constant	-4.34	1.006	-4.32	0
N=296	Log likelihood: -85.0206			
Source: own elaboration.				

The marginal effect of having ownership on the house is given by the following:

Table 19. Conditional marginal effects at means of ownership of the house on actual installing				
	dy/dx	Delta-method Standard error	Z	P>|z|
Ownership	0.1486617	0.0444497	3.34	0.001
N=296	At: 0.7364865 (mean)			
Source: own elaboration.				

The previous results mean show that being the owner of the house have a statistically significant increase of probability of adoption, the marginal effect in the mean is around 15%. This means that if someone owns the house have a 15% more probability of adoption.

4.3.2 Reliability of residential photovoltaic systems

Perception of reliability is an important enabler because it affects consumer attitudes towards residential photovoltaic systems. If consumers perceive photovoltaic systems as reliable and efficient, they are more likely to invest in the technology. Perception of reliability is shaped by factors such as technical specifications, certification, and warranties of the technology. It is important for the government and the photovoltaic industry to ensure that consumers have access to reliable information about the technology and its benefits. This could be achieved through public awareness campaigns, information dissemination, and standardization of technical specifications.

Table 20. Reliability of residential photovoltaic systems.			
Question	Degree of agreement	N	%
Residential photovoltaic systems are a reliable source of energy	Totally disagree	9	9.1
	Partially disagree	9	9.1
	Neither agree, nor disagree	8	8.1

	Partially agree	29	29.3
	Totally agree	44	44.4
N		99	
Residential photovoltaic systems are **an unstable** source of energy	Totally disagree	32	33.7
	Partially disagree	19	20.0
	Neither agree, nor disagree	23	24.2
	Partially agree	17	17.9
	Totally agree	4	4.2
N		95	
Residential photovoltaic systems are **a very** reliable source of energy	Totally disagree	3	2.9
	Partially disagree	7	6.9
	Neither agree, nor disagree	24	23.5
	Partially agree	31	30.4
	Totally agree	37	36.3
N		102	
Total N		296	
Source: own elaboration.			

The previous results show that respondents trust the reliability of residential photovoltaic systems. In the first variation the 73.7% do consider that the systems are reliable, 53.7% disagree that are unstable and 66.7% consider are very reliable (which is close to the first variation).

4.3.3 Awareness of external funding

External funding, such as governmental aid, can also serve as an important enabler to the adoption of residential photovoltaic systems. The high upfront costs associated with the installation of photovoltaic systems can be a significant barrier to adoption for many households, particularly those with lower incomes. External funding can reduce the financial burden of investing in photovoltaic systems and make the technology more accessible to a wider range of households. Financial incentives, such as subsidies, tax credits, and net metering policies, can also incentivize households to invest in photovoltaic systems. These policies can be targeted towards households with lower incomes, who may face greater financial barriers to adoption.

I found that there was very little awareness of existing financial incentives among the ENSOLRES respondents. Of all respondents, only 4.83% are aware of the availability external financial aid (such governmental help as “credito verde”-green credit- or private loans). Considering that cost was identified as major barrier to adopting photovoltaic systems, the lack of awareness of the availability of funding is highly problematic. Governments can directly subsidize photovoltaic adoption; however potential adopters will also need to know about such program to factor it into their decision-making.

4.3.4 Solar irradiance

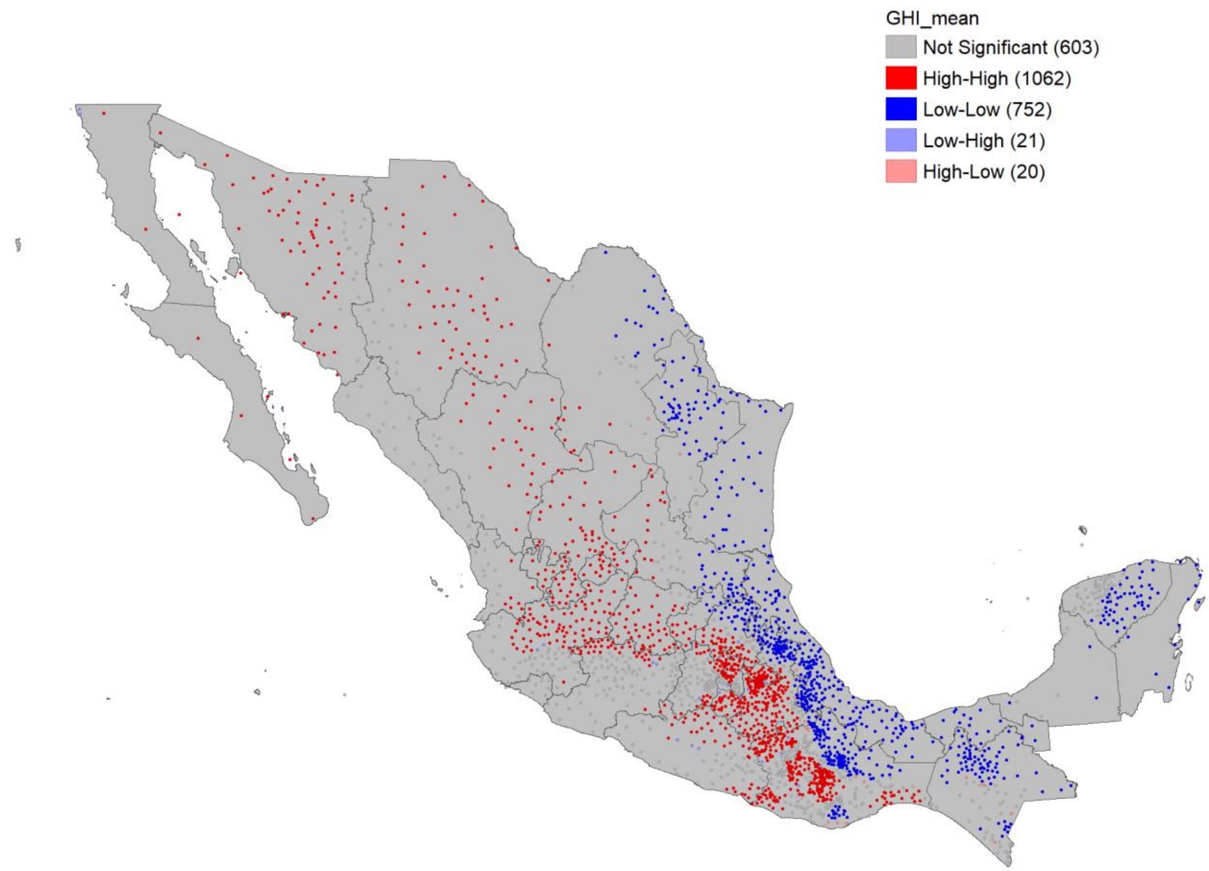
The efficiency of solar panel deployment is maximized when it concentrated in areas with high solar irradiance levels. This is because the amount of energy produced by a solar panel is affected positively to the irradiance level, holding every other parameter that would affect power generation constant, the higher the irradiance, the higher power generated (Pennsylvania State University, n.d.). Highly irradiance zones receive more direct sunlight than areas with lower irradiance, which means that solar panels installed in these areas can generate more electricity per unit of installed capacity.

The amount of energy generated by a solar panel is closely related to the cost-effectiveness of solar power generation. Solar panels that can generate more energy lead to lower costs per unit of electricity generated. Therefore, it is beneficial to focus on highly irradiance zones as they receive more direct sunlight, resulting in more electricity generated per unit of installed capacity and lower costs of electricity generated by solar panels.

In addition, the availability of direct sunlight is a crucial factor for the feasibility of solar power projects. If the irradiance levels are too low, the energy generated by solar panels may not be sufficient to meet the demand for electricity, leading to financial unviability. Thus, focusing on highly irradiance zones can increase the viability of solar power projects, which can promote the adoption of solar energy as a viable source of electricity.

Furthermore, solar panels require a substantial surface area to generate significant amounts of electricity. Focusing on highly irradiance zones can optimize the available land area and reduce the land use requirements of solar power generation. This is especially relevant in densely populated areas where land is limited. The following map shows the municipalities that posess highly irradiance (red), thus, the places in which focusing installing photovoltaic systems should take place:

Figure 7. GHI in Mexico, proposal of focus of adoption at municipality level.



Source: own elaboration.

I conducted a statistical analysis utilizing three distinct regression model specifications, all of which featured the percentage of the DAC tariff as the dependent variable and the Global Horizontal Irradiance (GHI) as the variable of interest. Two types of regression models were employed: classic regression and K-Nearest-Neighbors weight corrected errors (spatial regression). The outcomes from all three models indicated a significant and negative correlation between GHI and the percentage of the DAC tariff, with the effect sizes being similar across all models. These results suggest that as GHI increases, there is a reduction in the percentage of the DAC tariff. Furthermore, specification three consistently produced the same results in both the spatially corrected and classical regression models.

Table 21. Regression analysis of DAC percentage over GHI						
Variable	Model					
	Classic			Spatially corrected		
	1	2	3	1	2	3
Constant	161.232 (10.5115)	153.19 (10.4772)	111.356 (11.147)	159.67 (10.518)	151.67 (10.484)	111.356 (11.356)
GHI	**-0.063287 (0.00508)**	**-0.0587 (0.00508)**	**-0.07019 (0.0046)**	**-0.0626 (0.005)**	**-0.058 (0.005)**	**-0.07019 (0.004622)**
National weight		-33.843 (4.1994)			-33.63 (4.91)	
teminmungw			13.7519 (0.6897)			13.752 (0.6897)
irsmun10gw			-26.225 (2.9133)			-26.2256 (2.91334)
gvul10mung			-3.425 (1.2929)			-3.42565 (1.29289)
emmun10gw			1.46232e-05 (1.40876e-05)			1.46232e-05 (1.40876e-05)
marmun10gw			14.5384 (2.744)			14.5384 (2.74479)
seqesc05gw			4.62183 (0.45707)			4.62183 (0.457074)
F	155.104	102.709	147.188	151.64	100.711	147.188
Adjusted R^2	0.060148	0.078	0.299	0.0592	0.0769	0.299
N	2409					
Source: own elaboration.						

The previous results show a consistent effect of reducing high consumption of electricity in municipalities with high GHI. Furthermore, the GHI coefficient has relatively similar effect in all six models.

5. Policy recommendations

In this section I describe the policy recommendations to increase the uptake of residential photovoltaic systems. The policies can be implemented in any area of the country, but I consider that for initial stages it would be better to focus on highly irradiance zones, as found in the data, GHI is related to consumption, and as found in the literature, photovoltaic systems work better with more irradiance.

5.1 Financial incentives

The first policy recommendation is to provide financial incentives to acquire a photovoltaic system. Given that the main barrier identified is cost of the system, the proposed solution to overcome this barrier is to provide a subsidy, net metering, or tax credit. The provision of financial incentives could encourage more households to install photovoltaic systems by reducing initial cost associated with acquisition and installation cost.

The subsidy would offset the cost of acquiring the system, a net metering policy could allow households to receive money (or a credit for future electricity bills) for excess energy produced and fed back into the grid, finally, a tax credit offers similar benefits as a subsidy, but dependent on household income. The previous incentives may be targeted to households with lower income, as those households may face greater financial burdens in adopting PVSs.

In Mexico there are three agencies, at the national level of government that may implement these benefits:

- SAT can modify the rules regarding Mexico´s Law on Income Tax to allow the deduction of acquiring a photovoltaic system up to the median cost of the system.
- INFONAVIT provides a loan called “Hipoteca Verde” (Green Loan), to acquire ecotechnologies. This loan program could be expanded, rates lowered to near zero for acquiring a photovoltaic system to make it more attractive and greater awareness of the programs existence fostered.
- CRE and CFE can implement a net metering policies, which allow people that install photovoltaic systems to receive money for providing energy to the grid. Such policy change would allow users to receive a “positive” bill.

Given that availability of financing was not found to be an enabler and awareness among respondents was low, the government could work with financial institutions to increase access and availability to financing options such as low-interest loans or leasing programs. Low-interest loans could reduce the financial burden of purchasing and installing a photovoltaic system, while leasing programs could allow households to pay for the technology over time. This approach would make the technology more affordable and accessible to a wider range of households, particularly those with limited financial resources.

5.2 Progressive reduction of electricity subsidy

I found in the analysis that reduction of the electricity bill is not a statistically significant motivator among the respondents of the survey I conducted. I argue that this is due the current subsidy to electricity. This situation creates price distortions and overconsumption by energy end-users. Mexican electricity consumers do not bear the real costs of energy and are therefore not as incentivized to save energy or energy costs. I consider that progressively reducing the subsidy would eventually correct this inefficiency and market distortions. Considering the political costs, phasing out of subsidies should begin with consumers of higher tariffs and subsidies should be maintained for consumers in the lowest tariffs, who might have a harder time to cope with higher prices. Such a policy change would be the direct responsibility of the CRE, which is the agency responsible of adjusting and restructuring electricity tariffs, according to Chapter VI of the Law of Energy industry (Ley de la Industria Eléctrica) (Congreso de la Unión, 2014).

5.3 Awareness of aid to acquire photovoltaic systems.

According to the results of this study, the second most important barrier for adoption of photovoltaic systems was information issues. I recommend implementing campaigns to increase public awareness of benefits and technical aspects of photovoltaic systems, as well as the existence and availability of current governmental aid to acquire the systems. The dissemination of information to the public would also help demystify misconceptions about photovoltaic systems, which at present may discourage some households from adopting them. If the government is interested in removing barriers to the adoption of photovoltaic systems and motivating citizens to make the decision to do so providing reliable information is key.

This component can be implemented by multiple agencies at any level of government. At the national level, one possibility would be to amend the existing Law of Social Communication (Ley General de Comunicación Social). Its article 3 Bis, fraction V, subscript j, can be updated to read: "[Public Entities can disseminate, using campaigns of social communication, information regarding] Environmental protection **and green technologies**" (Congreso de la Unión, 2018).[3]

[3] Update: According to the resolution "Acción de Inconstitucionalidad 29/2023" of the Mexican Supreme Court this article is no longer in effect from May 31, 2023. A reform would be in the same direction of the now overturned disposition.

6. Conclusion

In this study I inquire on the Motivators, Barriers, and Enablers to photovoltaic system adoption in the Mexican residential sector. I used multiple strategies to analyze survey, GIS, and administrative data. I find that there are environmental motivators, informational and financial barriers, and some enablers such as home ownership to photovoltaic system adoption. However, I did not find one of the motivators, most prevalent in the existing literature, savings. I conjecture that this is related to the distorted prices of energy in Mexico. In conjunction my findings indicated that while some commonly mentioned motivators, barriers and enablers are present in Mexico, not all are or to the same degree. This strongly suggest that the drivers of the adoption of photovoltaic systems are context-dependent and influenced by factors that have been overlooked in existing studies, mostly focusing on the Global North.

Based on my findings, I propose a policy mix of three components to increase the adoption of photovoltaic systems. I argue that these policies should be first implemented in high-irradiance zones but can be implemented in any part of the country. The first component is to provide financial incentives in the form of subsidies, tax credits, or net metering policies offered by the government to make photovoltaic adoption more financially attractive and affordable. The second component is reduction of the energy consumption subsidy and price distortion. If energy prices approximated more their actual price, this would make renewable energy sources more competitive. Finally, I recommend increasing public awareness of photovoltaic systems and the availability of financing. An official communication campaign could educate and persuade potential adopters to become actual adopters.

In summary, by identifying motivators, barriers, and enablers of the adoption of photovoltaic systems present in Mexico and making policy recommendation based on the results obtained, this study provides a pathway to reducing residential electricity consumption based on fossil fuels and advancing towards the goal of net zero emissions in Mexico.

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Annex 1: ENSOLRES 2022/2023 questionnaire (Subset of questions used in this study)

Motivators	
Question	**Answers**
Select how many months you use per year: 1.Air conditioning in refrigeration mode 2. Air conditioning in heating mode 3. Ventilators 4. Electric heaters	<1> Not used or not applicable. <2> 1 <3> 2 <4> 3 <5> 4 <6> 5 <7> 6 <8> 7 <9> 8 <10> 9 <11> 10 <12> 11 <0> 12
Investing in a residential solar system would allow me to save {0} on the electricity bill	<1> Strongly disagree. <2> Somewhat disagree. <3> Neither agree nor disagree. <4> Something in agreement <5> Strongly agree
Installing a residential solar system helps {0} preserve the environment	<1> Strongly disagree. <2> Somewhat disagree. <3> Neither agree nor disagree. <4> Something in agreement <5> Strongly agree
If I install a residential solar system I would consume {0} amount of electricity.	<1> Strongly disagree. <2> Somewhat disagree. <3> Neither agree nor disagree. <4> Something in agreement <5> Strongly agree
I am worried {0} about energy shortages	<1> Strongly disagree. <2> Somewhat disagree. <3> Neither agree nor disagree. <4> Something in agreement <5> Strongly agree
Being able to disconnect from the CFE supply is {0} important for me	<1> Strongly disagree. <2> Somewhat disagree. <3> Neither agree nor disagree. <4> Something in agreement <5> Strongly agree
With Individuals actions I can contribute {0} to reducing climate change	<1> Strongly disagree. <2> Somewhat disagree. <3> Neither agree nor disagree. <4> Something in agreement <5> Strongly agree
Residential solar systems are a {0} stable source of energy	<1> Strongly disagree. <2> Somewhat disagree. <3> Neither agree nor disagree. <4> Something in agreement <5> Strongly agree
I can help {0} to preserve the environment	<1> Strongly disagree. <2> Somewhat disagree.

	<3> Neither agree nor disagree. <4> Something in agreement <5> Strongly agree
Barriers	
Question	**Answers**
What would be the reasons that would hinder or slow you from acquiring solar panels? If you think more than three options apply, just check the most important three.	<1> Are expensive or out of your budget. <2> It does not have its own resources or does not have third-party financing. <3> The structure of the house makes it impossible to place residential solar systems (e.g., does not support weight, house is uneven, not enough space) <4> He does not own the house either because it is rented, borrowed, etc. <5> Installation requires approval from other people (e.g., when living in a vertical apartment or condominium) <6> Requires purchasing battery to store energy. <7> You do not have sufficient information (about price, installation, operation, or place of sale) or the suppliers are not very accessible. <8> It would make the appearance of the property less attractive. <9> Other
Investing in residential solar systemswould be a {0} expense for my home	<1> Strongly disagree. <2> Somewhat disagree. <3> Neither agree nor disagree. <4> Something in agreement <5> Strongly agree
Enablers (Only the direct question)	
Question	**Answers**
Do you know of any government or private aid programs to finance the purchase and installation of solar panels?	<1> Yes <2> No
Is the program you know one of the following: Check all the corresponding options	<1> INFONAVIT Green Mortgage <2> FIDE <3> NAFIN CSolar <4> Other
Controlling by household characteristics	
Question	**Answers**
The dwelling in which you live is:	<1> Own without mortgage <2> Own with mortgage <3> Rented. <4> borrowed. <5> Other (e.g., ejidatario, in litigation, etc)
Do you plan to install a residential solar system this year, or next?	<1> This year <2> Next year <3> I am not considering installing

Annex 2: List of databases used for this study.
GIS Data:

- Available at http://www.conabio.gob.mx/informacion/gis/, the name of shapefiles are:
  - teminmungw: Minimum extreme temperature distribution by municipality (CENAPRED, 2012)
  - irsmun10gw: Level of social lag by municipality (CONABIO, 2010)
  - gvul10mung: Level of social vulnerability by municipality (CENAPRED, 2010)
  - emmun10gw: Employment in Mexico by municipality (CONABIO, 2010)
  - marmun10gw: Marginality at municipality level (CONABIO, 2010)
  - seqesc05gw: Drought level by municipality (CENAPRED, 2012)

ENSOLRES 2022/2023: not publicly available. Send email requests to the following website: https://sites.google.com/view/about-brandon-garcia/main.

CFE weights: raw data available at Plataforma Nacional de Transparencia with request number 330007722003662. For processed data relative to weights send email requests available on the website https://sites.google.com/view/about-brandon-garcia/main

For a clean database used for Table 20, which uses GIS data, and CFE weights, send email request to the website https://sites.google.com/view/about-brandon-garcia/main