SHEDDING LIGHT ON THE UNEQUAL DISTRIBUTION

OF RESIDENTIAL SOLAR PV ADOPTION IN LAC

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Cataloging-in-Publication data provided by the
Inter-American Development Bank
Felipe Herrera Library
Shedding light on the unequal distribution of residential solar PV adoption in Latin America and the Caribbean / Jesus Enrique Chueca Montuenga, Mariana Weiss, Rogelio Celaya, Pauline Ravillard, Mauricio Tolmasquim, Michelle Hallack.
p. cm. — (IDB Monograph ; 886)
Includes bibliographic references.
1. Photovoltaic power systems-Latin America. 2. Solar energy policy-Latin America. 3. Distributed generation of electric power-Latin America. 4. Dwellings-Energy consumption-Latin America. I. Chueca Montuenga, Enrique. II. Weiss, Mariana. III. Celaya, Rogelio. IV. Ravillard, Pauline. V. Tolmasquim, Mauricio Tiomno. VI. Hallack, Michelle, 1983- VII. Inter-American Development Bank. Energy Division. VIII. Series.
IDB-MG-886

JEL codes: O33; L94; L52; D63

Keywords: Solar Energy, Solar generation, Rooftop Solar, PV, Energy transition, Residential Adoption, Self-Generation, Geospatial, Inequality, Economic Development

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December 2020

1. Special thanks go to our colleagues contributed their technical inputs to this report, including David Lopez Soto, Maria Eugenia Sanin, Tomas Serebrisky, Boris Ortega, Alfonso Delgadillo. The document also benefited from the blinded peer review process.

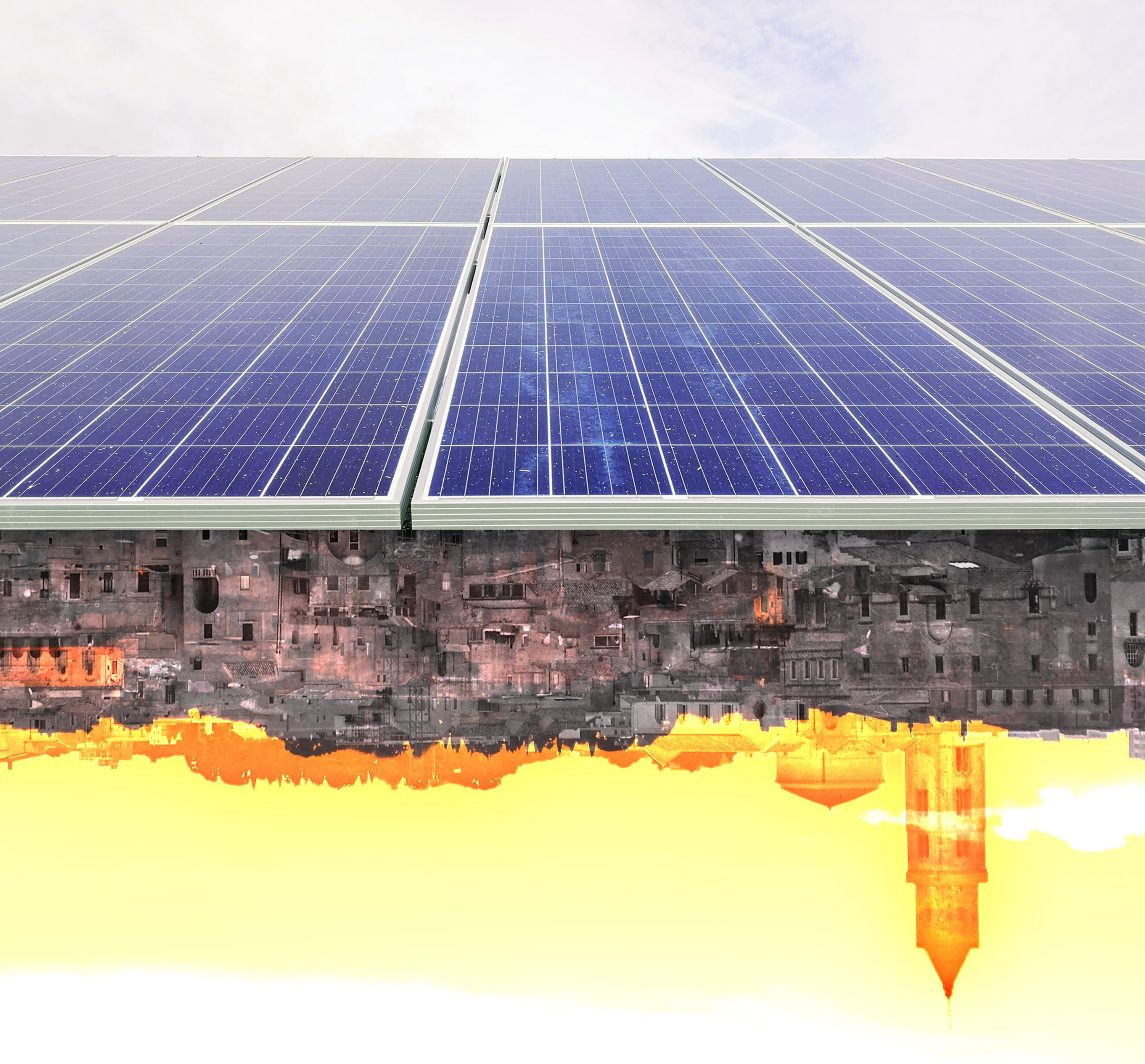


TABLE OF CONTENTS

List of Figures

List of Tables

List of Boxes

List of Acronyms

CEPAL /ECLAC: Economic Commission for Latin America and the Caribbean
ZIP: Código de Endereçamento Postal (“Postal Addressing Code”)
DG: Distributed generation
EE: Energy efficiency
FiT /FiP: Feed-in tariffs/premium
GIZ: Deutsche Gesellschaft für Internationale Zusammenarbeit (“German Development Fund”)
GW: Gigawatt
GWh: Gigawatt hour
IDB/IADB: Interamerican Development Bank
IRENA: International Renewable Energy Agency
IEA: International Energy Agency
KFW: Kreditanstalt für Wiederaufbau (“Credit Institute for Reconstruction”)
KW: Kilowatt
KWh: Kilowatt hour
LAC: Latin America and the Caribbean
MW: Megawatt
MWh: Megawatt hour
NB: Net billing
NDC / INDC: Nationally determined contributions
NM: Net metering
PVDG: Solar photovoltaic distributed generation
PV: Photovoltaic

INTRODUCTION

Historically, consumers have been price takers and have hence been receiving low or no attention in the design and implementation of electricity markets. However, new technologies associated with distributed energy resources (DER) have created opportunities for empowering consumers and allowing them to play an important role in electricity markets. Among the different DER options, on-grid solar photovoltaic distributed generation (PVDG) adoption has been experiencing exponential growth worldwide. Consequently, we have observed a paradigm shift, transforming consumers into prosumers[2] (a mix of the words "producer" and "consumer").

This global trend of PVDG adoption holds true in LAC countries as well. Solar energy is one of the fastest-growing energy sources in the region due to a critical cost reduction of the technology during the last decade, its high solar radiation levels, and adopted policies. PVDG has many benefits: it is a clean energy, it generates jobs, it avoids some of the grid costs and it may promote democratization of the sector, empowering consumers and increasing competitiveness (Hallack et al., 2020).

Recognizing the potential of solar photovoltaic generation in LAC, governments have implemented policies and programs that foster the use of this resource, increasing its participation within national electricity matrices[3.] These policies and programs aim to promote the use of solar power both in the centralized power generation system and through distributed generation (DG), including initiatives aimed at households (e.g., Honduras, Guyana, Costa Rica and Mexico), public buildings (e.g., Chile, Bolivia, Guyana, and Paraguay) and industry (e.g., Mexico, Ecuador, the Dominican Republic, and Bolivia) (Mejdalani et al., 2018).

In order to allow consumers to benefit from all the advantages of PVDG, policy and regulation have focused on promoting its adoption. This has been an important starting point for adoption of these new technologies. Many recent studies have analyzed the potential results of PVDG incentive policies and the economic viability of PVDG systems in the residential sector in LAC countries[4].

The massive adoption of distributed technologies can revolutionize the energy sector and help Latin American and Caribbean countries face historical challenges, such as access, quality and affordability. However, in order to have the full benefit of the new technologies and to avoid potential disruptions that they may cause, policy makers and regulators should avoid distortions, especially when adoption starts to become relevant to the sector (Hallack et al., 2020). In order to avoid distortions, it is important to understand who the adopters under the current institutional framework are. This understanding can contribute to improve and redesign policies, avoiding distortions[5] .

2. In this case, the term prosumer refers to a consumer that also produces his or her own energy.

3. Vazquez M. and Hallack M. (2018) discusses the role of regulatory learning in the process of adaptation of rules to incorporate new technologies. The discussion is applied to the PV solar adoption in Brazil.

4. In terms of feasibility of household PVDG systems and their relationship to policy adjustments, Holdermann et al. (2014), Lacchini & Rüther (2015), and Vale et al. (2017) dissert about the Brazilian case; López et al. (2016) and Léon-Vargas et al. (2019) the Colombian case, and Coria et al. (2019) the Argentinian case. Other papers give an overview of PVDG incentive policies achievements and barriers, as well as simulate scenarios of PVDG penetration in the residential sector, such as Campos et al. (2016) for Chile, Hancevic et al. (2017) for Mexico, Miranda et al. (2015) and Garlet et al. (2019) for Brazil.

5. Some examples, of papers discussing policies that could help democratize the use of the technology are

In this context, it is of the utmost importance to analyze the possible distributional consequences of the current policies and regulation. If unmitigated, these policies can increase disparities between those who can adopt and those who cannot. Metaphorically, the adoption inequality challenges need to be understood and addressed through policies and regulation to enable PVDG to bring light to everyone, without leaving any group in the shadows. The purpose of this study is to shed some light on these challenges, in order to urge LAC policymakers and regulators to continue promoting solar adoption while avoiding its potential 'shadows'.

There are already some intuitions and estimations in LAC about inequalities in adoption, as identified by Miranda et al. (2015) and Rosa et al. (2020). Both studies discuss this issue in Brazil, where the residential sector's PVDG uptake is impacted by socioeconomic factors, such as income, electricity consumption, availability of rooftops, load curve, capital cost, and financing instruments. In addition, the authors found evidence of unequal diffusion patterns in southern Brazil. Internationally, the literature has also shown evidence of unequal adoption. For instance, Lukanov and Krieger (2019) showed evidence that socioeconomic variables are the determinants for disparities in solar uptakes and dissemination in California.

To contribute to this discussion, this paper analyzes several characteristics of PVDG adopters in the three LAC countries with the highest adoption of PV generation according to IRENA (2020): Brazil, Chile and Mexico. This analysis aims to better understand the PVDG early-adopter profile in the residential sector according to socio-economic variables, and also other adoption incentives, such as network effect and variables that impact project viability, such as tariffs. We test the hypothesis that the adoption of PVDG is not equally distributed, and more precisely that socio-economic variables are an important explanatory variable in the adoption rate. Proof of the hypothesis would indicate that the benefit of the current policy and regulatory framework does impact all citizens evenly.

In order to test our hypothesis, we determined the most relevant factors and characteristics of PVDG's early adopters based on a literature review of other countries' experiences and applied a multilevel regression model to validate their statistical importance. This model aims to illustrate what early adopters look like. Therefore, it includes factors related to the viability of the investment in the project (electricity tariff, PVDG system capacity, and solar radiation) and socioeconomic and neighborhood factors (income per capita, years of education, rural and urban regions, solar inequality, distance from the closest neighbor with PVDG, his/her time of adoption and installed capacity), which we will further explain in other sections of this paper. Our goal is to see how these variables impact adoption of PVDG over time in Brazil, Chile and Mexico. In cases where we lack information about individual adopters, we analyze the spatial concentration[6].

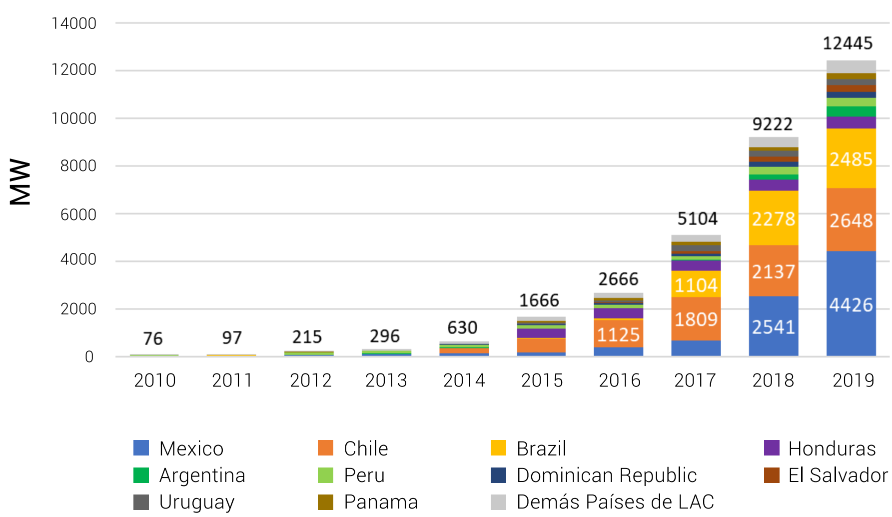
In order to contribute to the discussion about the risks of PVDG adoption inequality in LAC, after this introduction, we set the context of DG policies, focusing on Brazil, Chile, and Mexico, and we summarize the discussion in the literature about why the policy and regulatory framework may impact heterogeneously the different users. We also discuss why we should avoid regulatory and policy distortion during the acceleration of PVDG adoption. In the fourth section, we present the data based on our analysis, followed by the main result. In the last section, we present our final remarks.

6. For further discussion about spatial concentration, the literature concentrates the discussion about the potential of urban and rural areas. While Miranda et al. (2015) indicates that there is technological feasibility for urban and rural areas in Brazil, Campos et al. (2016) and Rosa et al. (2020) reinforce that the most significant potential of on-grid PVDG is in urban areas. It is also aligned with Campos et al. (2016) finds for Chile, which shows that metropolitan cities could satisfy 83% of their annual electricity demand with PVDG systems.

1.EVOLUTION OF SOLAR PHOTOVOLTAIC DISTRIBUTED GENERATION IN LAC

In 2019, 22[7] of 26 LAC countries already had initiatives that foster solar energy. Similarly, 17 of 26 LAC countries already had PVDG regulation or incentive programs in place (Mejdalani, 2018). As a result, in one decade, LAC moved from a total solar photovoltaic installed capacity of 0.8GW in 2010 to 12.5 GW in 2019 (Figure 2). In LAC, solar photovoltaic energy production has spread the most in Brazil, Chile, and Mexico. These countries reached, respectively, 4.4 GW, 2.6 GW and 2.5 GW of installed capacity in centralized solar photovoltaic power plants in 2019 (Figure 1).

Figure 1. Solar Photovoltaic Installed Capacity in LAC Countries

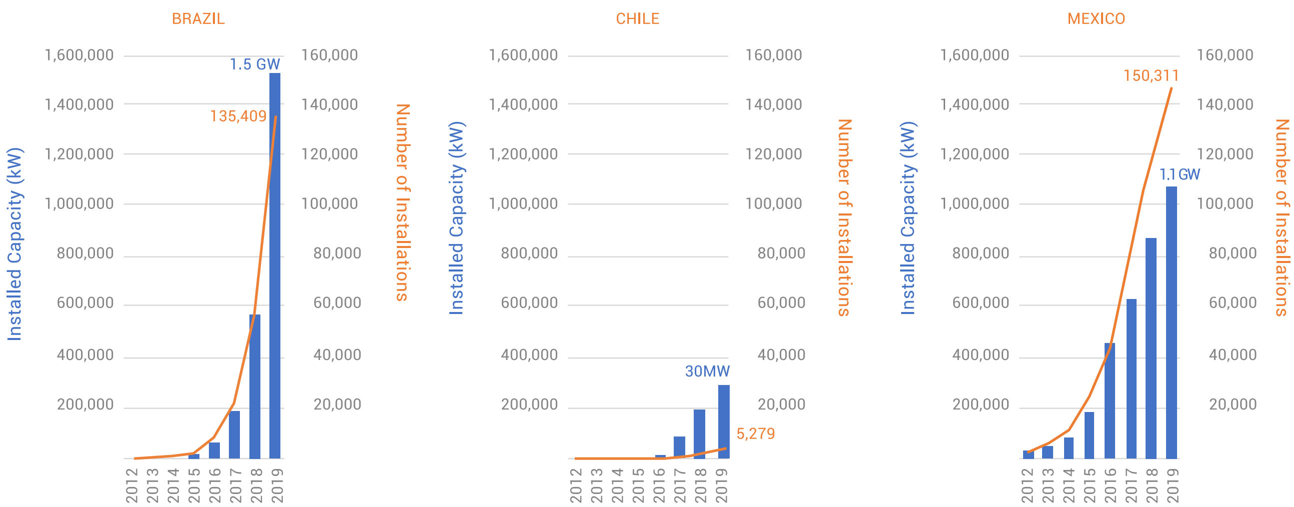


Source: Authors' elaboration based on data from IRENA (2020).

These same countries also have been experiencing an exponential increase in rooftop PV solar (Figure 2). By the end of 2019, Brazil held around 1.5 GW of installed capacity, distributed evenly by 135,000 PVDG solar installations, resulting in systems with an average size of 11.1 KW. During the same time, Mexico had around 1,1GW of PVDG. The PVDG projects in Mexico were, on average, smaller than in Brazil – around 7.33 kW per project. Overall, there exists a smaller concentration of PVDG projects in Mexico. In Chile, the technology represents a tiny installed capacity, though the Chilean PVDG policy is as old as the Brazilian one. There was around 30 MW of installed capacity in Chile at the end of 2019. Chile had a higher concentration of PVDG projects than the other countries; each Chilean PVDG project has on average 56.8 kW.

7. According to our research, LAC countries currently with solar energy programs were: Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, Guatemala, Guyana, Haiti, Honduras, Mexico, Nicaragua, Paraguay, Peru, Suriname and Uruguay. The details are available in Annex A1.

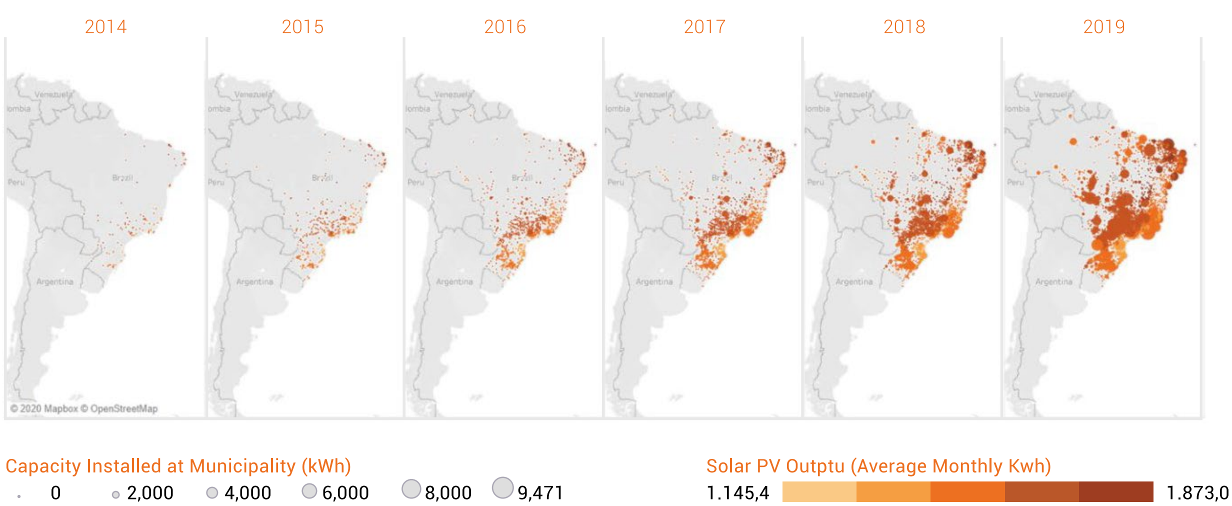
Figure 2. Exponential Adoption of Residential PV Solar in LAC: Brazil, Chile and Mexico



Source: Own elaboration based on data from IRENA (2020).

Contrary to expectations, the PVDG have not been presenting a bigger concentration in regions with higher irradiation levels in these LAC countries. Early adopters of PVDG systems in these three LAC countries tend to be in large metropolises (Figures 3, 4 and 5). Therefore, we see that the distribution of the patterns of PV expansion follow the population density of the area where it is been installed, rather than the natural resource endowment of the area where PV solar is installed, pointing to an imitation style diffusion of other technologies in the country.

Figure 3. Spatial Dispersion and Expansion of PVDG in Brazil



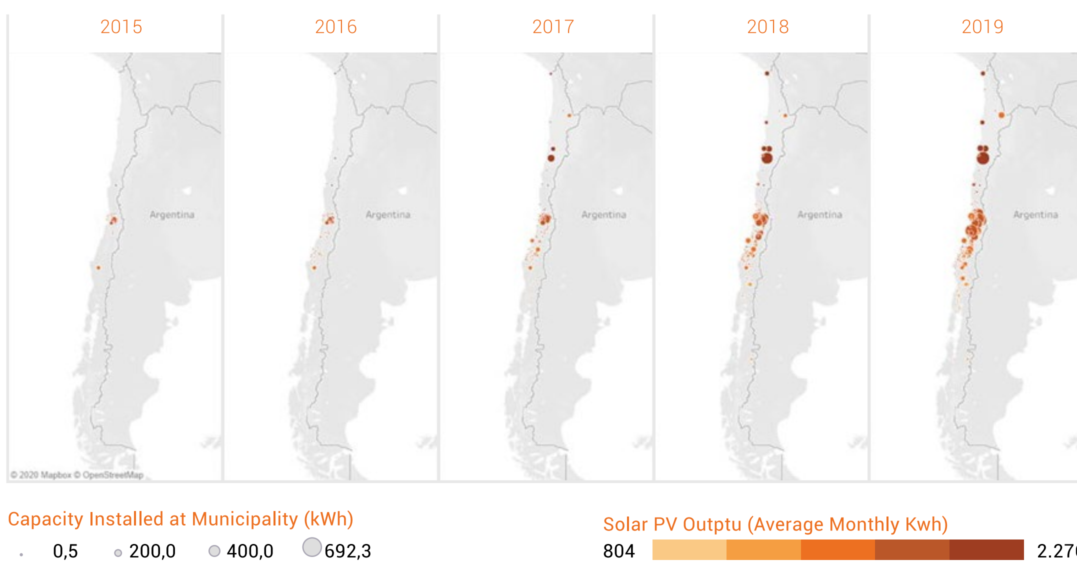
Source: IDB elaboration based on ANEEL data.

In Brazil, for example, the PV output range is generally homogeneous, with the maximum PV potential output being in the state of Bahía in the northeast region at 1776 kWh/kWp, and the minimum in the state of Paraná in the southern region at 1217 kWh/kWp. However, the spatial distribution is generally concentrated on the shores to the south and southeast of the country but dispersed across different locations and municipalities. At the end of 2019, the biggest concentration of installed capacity in Brazil was located in the cities of Santa Cruz do

Sul (South Region – Rio Grande do Sul State), Goiânia (Central-West Region – Goiás State), Cascavel (South Region – Paraná State) and Brasilia (Central-West Region – Federal District). However, these cities only tally up to represent 2.86 percent of the total installed capacity, showing a more disperse set of installations across different municipalities in the country when looking at it from the municipal aggregate level. When looking at the state level, Minas Gerais (Southeast Region), Rio Grande do Sul (South Region), São Paulo (Southeast Region) and Paraná (South Region) represent 56.51 percent of the installed capacity.

When we examine Chile's progression in PVDG penetration, we can observe the world's largest variance of solar potential across the regions in a country. The Atacama region has the greatest potential for generating solar energy on the planet, with 2,292 kWh/kWp a year, while the Magallanes and Antarctica Region in the south of Chile present the lowest[8]. The difference between the two regions expand over 1500 kWh per kW installed per year and it carries with it the intrinsic difference in the cost recovery time for any solar project. This significant difference of solar power potential between the Chilean regions is also the result of the concentration of facilities. For example, the III Region of Atacama, due to its high solar irradiance levels, in November 2019 registered 1,812 projects that together have an installed capacity of 1,715.33 kW. Although Atacama is the region with the largest number of facilities, the XVIII Metropolitan Region is the second by number of facilities with 1,294 and the first by installed capacity, with a total power of 10,674.93 kW. In contrast, the region with the lowest number of installations is the XI Region of Aysén, with only 10 registered installations and an installed capacity of 76.6 kW at the end of 2019. This would follow a fall in the number of installations as the solar irradiation diminished in the southern region, where we can find no installations. This would point to the natural solar endowment of each region to be one of the drivers of adoption since we see no adoption as we move to lesser irradiation regions. This fact is included in the forthcoming analysis.

Figure 4. Spatial Dispersion and Expansion of PVDG in Chile



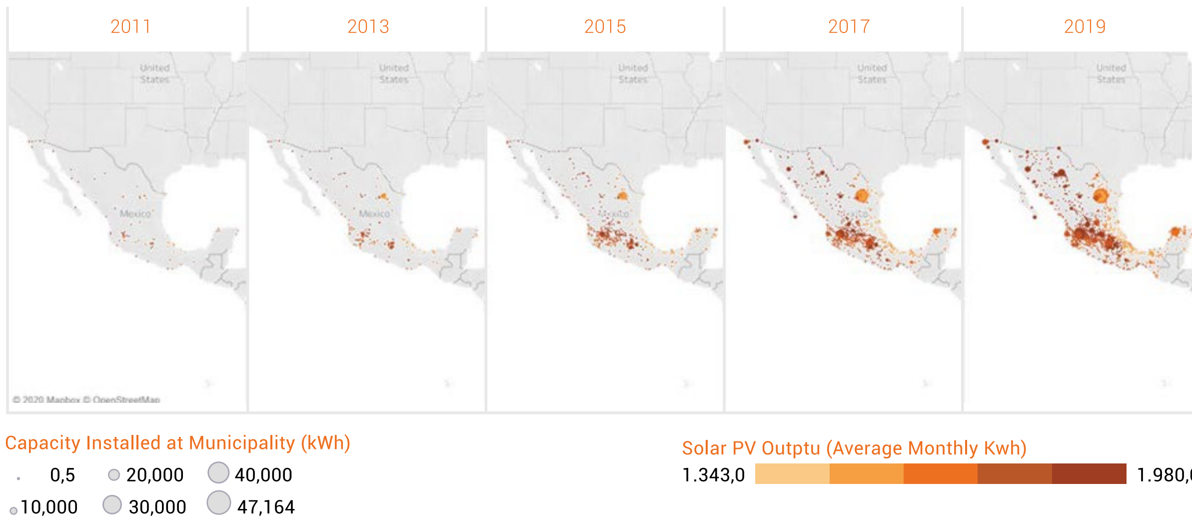
Source: IDB elaboration based on CNE data

In Mexico (Figure 6), we see that the PVDG has been developing in big metropolises and cities with high solar radiation raster. In 2019, the spatial distribution was heavily concentrated in a few areas in Mexico. On a state level, the states of Nuevo León, Jalisco and Mexico City

8. There is no solar radiation data for the southern region of Chile.

represented 61.9 per cent of the total capacity installed in the country. Due to the size and prolific municipal boundaries in Mexico, looking at the state level might offer a better overview of how significant the concentration of capacity is in Mexico. The municipalities of San Pedro Garza García, Huixquilucan, Monterrey, Naucalpan de Juárez and Guadalajara represented 43% of the total capacity of the country as of 2017, despite having been later arrivers to DG adoption (Figure 6).

Figure 5. Spatial Dispersion and Expansion of PVDG in Mexico



Source: IDB elaboration based on CFE data

Observing the maps of these LAC countries, we can see that there are disparities in PVDG development, and its implementation did not begin necessarily in regions with the highest solar power potential of each country. The PVDG systems are mainly concentrated in metropolises, which seems to indicate that socioeconomic factors are a stronger driver than solar power potential. Therefore, we will discuss briefly the types of policies that foster the adoption of solar photovoltaic distributed generation and which types have been used in LAC, especially in Brazil, Chile and Mexico.

1.1. Types of Policies of Photovoltaic Distributed Generation in LAC

The primary justifications for using policies and incentives to foster PVDG are to increase energy supply diversity, improve grid reliability, and reduce power generation's environmental impact. PVDG increases prosumers' independence and assures them that the energy generated and consumed comes from a 100% clean energy source. More widespread adoption of PVDG also implies a decrease in electricity demand from the grid, which translates into a reduction in the need to dispatch available power plants, and the possibility of investment deferment in new power plants and grid network expansion. In addition, if PVDG avoids the construction of fossil fuel plants or displaces fossil fuel utility scale plants, it possibly leads the energy sector to a lower level of emissions. Moreover, the more electricity demand from the grid falls and can be satisfied by decentralized power units, the more electricity losses due to transportation between generator and consumer are reduced. Therefore, PVDG can create substantial positive externalities that benefit society, such as emission reduction, increased energy efficiency and security, and other positive economic and health effects.

As PVDG is a "new" technology, sectoral policies and incentives can play a significant role in its market consolidation. Like any other non-established technology, PVDG still needs to overcome a series of adoption barriers to achieve higher market shares. These barriers include the lack of information on the part of consumers and producers, as well as the need for financial instruments, components, and specialized services related to PVDG technologies. Therefore, PVDG policies and regulation must coevolve with technological development (Vazquez & Hallack, 2018). As LAC moves into a time of more accessible DG equipment and higher numbers of PVDG installed within the region's grids policies and regulation need to evolve.

Most of the region's countries have adopted or are in the process of adopting some form of PVDG policy, but they present different regulatory schemes. Many LAC countries have also been implementing financing policies (Annex A2) and fiscal policies (Annex A3) to foster PVDG adoption. However, one of the most critical components of regulating PVDG is determining the grid's energy compensation mechanism. The compensation and limitations will, for most consumers, be a key factor in evaluating the cost-benefit of investing in an installation and the revenue they might generate from it over time. Prolonged recovery time from the investment can deter consumers from paying the high upfront cost of many PVDG installations and introduce costly financial uncertainties over the financed period.

PVDG policies in LAC have been inspired by practices from abroad, namely the United States and Europe. For example, there are no PVDG policies implementing a feed-in-tariff regulatory scheme, mainly due to Germany's experience with electricity demand disturbances and negative electricity prices due to overcapacity of PVDG. Consequently, in LAC, the most common PVDG policies consider net-metering (NM) or net-billing (NB) compensation schemes (Mejdalani et al., 2018). Table 1 provides a brief description of the different PVDG incentive mechanisms and their effect on PVDG adoption speed.

Both net-metering and net-billing compensation mechanisms refer to the amount of energy that prosumers consume, minus the amount of energy that is injected into the grid. If the result is positive, then the prosumer is a net buyer of energy. Conversely, when the result is negative, the prosumer is a net seller of energy for that specific period (that means that the prosumer injects more energy into the grid than he or she uses, i.e., the prosumer has a surplus of energy). The main difference between the two systems is how the excess is compensated – in energy units or monetary units. Some countries use cash credits (e.g., Panama, Honduras, Mexico, Chile, and the Dominican Republic), and others use energy credits (e.g., Guatemala, Brazil, Suriname, The Bahamas, and Uruguay). Likewise, the accumulation period varies per country, with some of them allowing up to five years of accumulation (e.g., Brazil), whereas others do not allow accumulation at all (e.g., Uruguay)[9].

The regulation of PVDG can also impose limitations for the installations' maximum size. It can bar large consumers from investing in these installations, using subsidies once they have already achieved scale gains. PVDG regulation can also differentiate among consumers (i.e., residential, commercial, and industrial). For example, PVDG programs have a special focus on households in Honduras, Guyana, Costa Rica, and Mexico, on public buildings in Chile, Bolivia, Guyana and Paraguay, and on industry in Mexico, Ecuador, Dominican Republic and Bolivia.

However, PVDG policies tend to concentrate on residential consumers. Governments design regulation for residential consumers to generate the lowest number of energy credits that can be used at another time (e.g., at night) or in the next billing cycle. However, there are cases where the commercial sector is the lead PVDG generator. For example, Haiti's dominant form of DG is mostly concentrated on commercial users, instead of the more common residential consumer. With this sectoral distribution, Haiti has just 26 energy generation locations connected to the grid, with sizes ranging from 50 KW to 800 KW.

9. Refer to Mejdalani et al. (2018) for a complete analysis of net-metering in the LAC region.

PVDG policies can have restrictions from a spatial perspective too. For instance, a policy could offer subsidized credit lines for consumers who live in areas with high radiation levels and low income levels. For example, in Brazil, a credit line (FNE Sol) was specially designed to finance small-scale distributed generation systems (by solar photovoltaic and other renewable sources) only for borrowers in the Brazilian Northeast region. However, it is possible that geographical limits could be imposed to reflect capacity limits of distribution networks. These technical limitations may restrict the entrance of late PVDG adopters (Pillai et al., 2017). Both policy and regulatory design and technical limitations pose a trade-off between democratization of PVDG and economic and technical efficiencies.

Table 1. Comparison of PVDG Incentives Mechanisms

Incentive Mechanism	Payoff	PVDG adoption speed
Instantaneous Self-Consumption (off-grid)	The adopter must consume all the energy at the exact moment when it was generated by the PVDG system. The generated energy cannot be injected into the grid or accumulated in credits for future consumption. One option is to invest in battery storage, but this would result in higher investment costs.	Slow adoption
Net-Metering (on-grid)	The energy generated by the PVDG system and the grid receives the same retail rate. The prosumer pays only for the electricity consumption that exceeds the generation. It usually is possible to accumulate the surplus of energy generated (and introduced into the grid) to use it in the future as energy credits. At the compensation, energy credits normally consider the relative cost of the tariff at the time they were generated in relation to the cost at the time when they will be used and deducted from the consumption of electricity.	Fast adoption
Net-Billing (on-grid)	It defines a specific regulated rate as payment for the energy generated by PVDG systems. This rate usually is different from the retail electricity rate (the price that the consumers pay for the electricity that comes from the grid), allowing for the ability to control incentives for self-generation separately. As PVDG rate decreases below the retail electricity rate, the incentive to adopt shrinks. There can also be a premium rate, which compensates surplus of PVDG electricity generated with a premium (for example, 1.15 kWh credits for each 1 kWh of generated surplus).	Medium-fast adoption, depending on PVDG electricity rate and premium rate
Buy all, sell all, (on-grid)	All generated electricity is sold to the grid at a specific determined rate, typically higher than the retail electricity rate. It usually has a limit of maximum installed capacity per prosumer.	Faster adoption

Source: Authors' elaboration, based on Mejdalani et al. (2018)

1.1.1. Brazilian Solar Photovoltaic Distributed Generation Policies

In Brazil, the solar photovoltaic distributed generation connected to the grid started to be an option for individual consumers in 2012. Through the Normative Resolution nº 482/2012, the Brazilian regulator (National Electric Energy Agency - ANEEL) implemented the net-metering (NM) mechanism to promote de-centralized renewable generation. In compensation for surplus energy injected into the grid by prosumers, the Brazilian DG system provides energy credits cumulative for up to five years from the moment it was sold back to the grid. The country accumulation period stands as one of the longest in the region.

The future prosumer needs to ask for permission to install and connect its PVDG system to the distribution network. This approval of the distribution company is necessary in order to secure safe and transparent energy production and accountability. The ANEEL established some limitations for new prosumers. After the implementation of the Normative Resolution nº 482/2012 by the Normative Resolutions nº 687/2015 and nº 786/2017, the maximum capacity per consumer allowed is 5 MW, but only in the case of installations up to 75 kW, and without shared generation the prosumer does not need to cover the costs of network reparation and adaptation. In addition, PVDG system capacity cannot surpass contracted demand of the consumer. If the consumer wishes to install a larger PVDG plant, he or she must request and contract a higher demand level. The Normative Resolution No. 482/2012 also introduces some restrictions to prevent a large solar plant from being divided into two or more smaller plants just to fit the limits of installed capacity defined for distributed generation and to take advantage of its incentives.

the distributor also seeks to assess whether a plant has not been divided into two or more smaller plants just to fit the installed capacity limits defined for distributed generation.

Normative Resolution nº 687/2015 also allowed three new modalities of PVDG: remote consumption and shared generation for consortiums, cooperatives, and condominiums. In the first modality, it is possible to have a PVDG system installed in a different place from the consumer unit, as long as both properties are owned by the user. In the second case, a group of users together in a consortium, cooperative or condominium can own a PVDG plant and deduct their part of electricity generated by the joint system from their electricity consumption.

The main policy responsible for the exponential increase of DG in Brazil was net-metering, implemented by the National Electric Energy Agency (ANEEL) in 2012 (Mejdalani, 2018). Two other programs supporting DG are the Distributed Generation Development Program for Energy (ProGD) and technical cooperation (TC), directed at both DG and EE. The former was created by the Ministry of Mines and Electricity to promote DG with the installation of PV solar panels. The main channels to provide funds are through the concession of subsidies and other financial alleviation policies, such as facilitating access to lower interest rate loans to reduce the up-front costs of installation. The latter, TC, is a partnership between the government and the IADB to improve the adoption of EE and DG in municipalities. While ProDG works alongside the TC, it specifically provides funding by fully financing the projects in most cases, for which it has an endowment of about $400,000 USD to engage not only in the public sector (as TC does), but also on household level DG installations and small firms' adopters of PV.

In the case of Brazil, Annex A.2 shows another main program: the Fund for Energy in Northeast (FEN). While ProDG covers the whole country, FEN has a regional character, focused exclusively on the northeast region of Brazil. It uses a blended mix of subsidies and financing to facilitate the adoption of solar energy generation alongside other sources like wind, biomass and small hydro plants. The budget of this project reaches $1 USD billion, which intends to promote solar and wind energy. Another initiative is the FNE Sol – the constitutional finan-

cing fund of the Northeast, designed especially for PVDG projects (commercial, industrial, rural and residential). The FNE Sol[10] started to be available for households of the Brazilian Northeast region at the end of 2018.

In general, Brazil has conducted a mix of subsidies and financing to promote renewable energy sources. Small scale renewables are more difficult to adopt and install due to their upfront cost for regular households or small firms. That is why the government is focusing on firms that have the expertise and willingness to develop projects and share information so that peers can replicate and expand the installation of PV generation elsewhere[11].

1.1.2. Chilean Solar Photovoltaic Distributed Generation Policies

Chile launched its distributed generation policy in 2012 with the objective of promoting renewable energies (mainly solar) and diversifying the country's energy matrix. Following the experience of other countries, Chile implemented net-billing to incentivize prosumers to sell their surplus to the system. This net-billing policy allows households to receive cash credits for the energy they sell, which is cashable in the next billing period. The accumulation period is one year, after which unclaimed credits will go to the community and the right of the seller over them is written off. The maximum capacity allowed for households is 2 MW, which must be approved by a licensed installation company.

In 2012, Chile passed the first law regulating distributed generation (DG), which went into effect in 2014. Law No. 20.571 gave users the right to install generation equipment for their own consumption and gives them the right to inject the energy generated by such equipment to the distribution network. After four years in implementation, in December 2018, Law 21.118 came as an updated version of the previous law. This law brought new changes. Chief among those changes is the increase to the authorized installed capacity limit from 100 to 300 kW. This increase seeks to integrate small and medium enterprises, as well as encourage community projects that were not contemplated in the previous version. Since Law 20.571 came into effect in 2014, the number of facilities registered with Superintendence of Electricity and Fuels (SEC) has increased exponentially; by October 2019, there were 5,191 connections distributed across all regions of the country.

Chile has two projects that indirectly support DG: Better Home and Program to Protect Family Assets (PPPF). Both these projects aim to improve household energy conditions by providing subsidies and financing to low-income families. Better Home considers only houses valued at a threshold of $21,640 or less (650 UF) and PPPF considers households that belong to the 60% poorest households. These designations allow the programs to better target those households where the policy can make the most difference vis-a-vis what would have been the adoption rate of DG had the policy not been implemented. The idea of these programs is to provide funds for PV solar panels, solar water heaters and other EE initiatives (e.g. house insulation) to qualified households.

10. https://www.bnb.gov.br/fne-sol/pessoa-fisica

11. For discussion about details of Brazilian policies, especially concerning the goal of adaptations becoming more inclusive, see Vale et al. (2017), who show the implementation of PVDG in low-income areas or housing programs as a solution for a more inclusive use of PVDG through the case study of the Brazilian government's housing program, "Minha Casa, Minha Vida". Moreover, Faria Jr et al. (2017) and Lacchini and Rüther (2015) raise main concerns about high investment costs and financial issues being challenges to PVDG-enabling in developing countries such as Brazil. It is interesting to note that this paper dates from before the Brazilian PVDG policy's actualization (resolution nº 482/2012 and nº687/2015). Most suggestions were addressed on the resolution's revision, such as creating new subsidized financing options and reducing bureaucracy and installation costs for low-tension consumers, mainly in residential areas. Even in the absence of a proper regulatory impact assessment, the changes showed some efficacy. At the end of March 2015, there were 515 PVDG projects, corresponding to 5.6 MW of installed capacity. At the end of September 2019, Brazil had 311,025 PVDG projects and 3,711 MW.

Despite the fact that Chile's installed capacity is not as large as that of Brazil and Mexico, it is a country that has seen a significant increase in the levels of installed capacity of PVGD. Annex A2 shows five programs directed to promote this type of energy: (1) Program to Protect Family Assets (PPPF), (2) Better Home, (3) Support for Non-Conventional Renewable Energy Development Program (SNRED), (4) Public Solar Roof (TSP) and (5) PV Pumping Program. Some of the programs are targeted to households, like PPPF and Better Home, others to industry, like PV (agriculture) and SNRED (transversal to all industries), and finally, TSP is directed to provide solar panels to public buildings.

PPPF allows vulnerable households to build, maintain or repair equipment related to solar panels. The program channels funding for households via subsidies to this equipment and maintenance. For firms, SNRED directs funds to enterprises that want to develop renewable energy projects related to wind, hydro and solar components. The fund has about $85.5 USD million to be used as subsidies for eligible projects. Additionally, the rural customer could find financing through the PV program, a program that targets renewable energy specifically for agricultural sector. It promotes renewable energy by financing PV pumping systems for water irrigation. The main channels for this funding are subsidies up to 90% of the required financing. It has so far developed approximately 743 kW of PV pumping systems. If the business activity is focused on forestry, the Energy Access Fund (EAF) is tasked with promoting renewable energy projects in the agriculture and forestry sectors. The fund provides support to these projects as subsidies, managing $2.2 USD million.

More specifically, to deal with matters of rural electrification, the Chilean government devised the PERYS program. The program promotes small-scale renewable energy projects to extend electrification in Chile, focusing on interested households. The program has $5.5 USD million to distribute as financing and support for other potential suggested projects (i.e., help with design and research of new types of implementation with the same goals as the program's).

For government buildings, the public potential consumers can fit well within the stated goals of the TSP program. TSP is the only program in Chile that specifically promotes solar panels in public buildings. The project has an endowment of $13 USD million, to be assigned to public buildings that present viable projects.

1.1.3. Mexican Solar Photovoltaic Distributed Generation Policies

Mexico is another country with a relatively long experience regarding DG. The country started the implementation of this type of generation in 2010. It is the only country that uses net-metering and net-billing interchangeably. Prosumers can sell their surplus to the distribution company for cash credits that can be used in subsequent billing periods. The accumulation period of these credits is one year, after which the household will receive the net balance as cash back. Mexico has limited the maximum capacity for household DG up to 500 kW.

Numerous stakeholders in Mexico are involved in Distributed Generation (DG) activities, including consumers, industry, academia and government. The Ministry of Energy (Secretaría de Energía, SENER) is in charge of determining the public policy for DG and promotes loans and other forms of financing to support DG. It also develops and submits proposals to the Ministry of Finance to implement financial incentives that boost DG deployment. The Energy Regulatory Commission (Comisión Reguladora de Energía, CRE) is the government's energy regulatory body that develops standard contracts for DG interconnection and compensation. The CRE also ensures the efficient and fair development and exploitation of energy technologies. The National Center for Energy Control (CENACE) is Mexico's independent system operator in charge of the national electricity network. Its responsibilities related to DG deployment include defining technical specifications and infrastructure requirements for

DG system interconnection. Finally, the electricity supplier will receive and manage all interconnection requests for DG, manage and compensate DG exports to the grid and sign the compensation contract with the applicant.

The government of Mexico has issued several laws, strategies and programs to support the development and integration of renewable energy generally, and DG in particular. The Electricity Industry Act was one of the foundational pieces of legislation of the Energy Reform in 2013. The act assigns the responsibility of drafting DG policy to SENER and guarantees open and nondiscriminatory access to transmission and distribution networks. On the other hand, The Energy Transition Act incorporates the definition of clean distributed generation and requires SENER to promote credit and financing availability for clean DG and requires the creation of the Smart Grid Program.

Prior to March 2017, Mexico only offered net-metering as the mechanism to promote DG. Later, on March 7, 2017 in the General Administrative Dispositions for Distributed Generation the following DG contracts where approved: net-energy metering, net-billing and a buy /sell all. The distribution company must include in its yearly modernization and expansion plan, reinforcement and expansion projects to enable DG integration to the grid.

In the case of Mexico, plenty of programs exist to promote renewables, and solar energy in particular. Annex A2 shows seven of these programs: (1) Fund for the Energy Transition and Sustainable Use of the Energy (FOTEASE), (2) Trust for Electric Energy Saving (FIDE), (3) 25,000 Solar Roofs for Mexico (SRM), (4) Universal Electricity Fund (FUE), (5) Light for Mexico (LPM), (6) Retrofit Program of Sustainable Improvement in Existing Housing and (7) Bright Distributed Generation Solar Projects (BDG). Several of these programs seek to extend the electricity coverage to rural areas of Mexico providing households, small firms and public buildings with solar panels to mitigate the lack of coverage.

The FOTEASE was created by the Law of Energy Transition to incentivize the sustainable use of energy, as well as renewable energy-related matters, for wind and solar DG with the objective to contribute the accomplishment of the National Strategy for the Energy Transition. This fund promotes renewable energy projects not only at the household level, but also at the public and industry levels. The program subsidizes, offering financing and loans to a total amount of 53.3 million Mexican pesos, to those interested in acquiring a solar PV system. It additionally supports other renewable energy activities, such as seminars and information sessions.

FIDE is a non-profit organization initiated under the Federal Commission of Electricity (CFE) to support the program Electricity Energy Savings, which includes solar energy. It is targeted to households and small firms and its budget of $22.6 million USD has been used for subsidies and financing. To date, it has developed more than 16 MW of renewable energy projects.

SRM is a partnership with Germany (GIZ) to specifically promote solar energy. Its main objective is to help households to acquire solar panels, with 25,000 units as the ultimate goal. To do this, the fund provides subsidies that partially cover the cost of solar panels.

The Universal Electricity Fund (FUE) is a fund empowered by the Electricity Law of 2014, whose main objective is to extend electrification to rural and isolated areas of the country via solar panels and other technologies. The fund was expected to benefit more than 200,000 Mexican people. The budget of the fund is about $100 million USD, which is mostly used as a financing mechanism to rural electrification and for provision of solar panels, among others.

The LPM program was created by the Ministry of Energy to bring electricity to isolated communities. This program provides financing for electrification, which includes solar energy, for rural areas. The Retrofit Program of Sustainable Improvement in Existing Housing is under the National Housing Commission to promote EE and other renewables in households, such as solar. Subsidies are the primary vehicle used.

Finally, the Integrated Energy Services Program, PSIE, is a project in partnership with the World Bank to bring electricity to isolated communities. The starting budget of the program was $100 million USD to fully finance electrification with renewable energy sources. One of the key features of this program is that it considers indigenous communities a priority for electrification. The program considers indigenous communities in Chiapas, Guerrero, Oaxaca and Veracruz, among others.

Finally, BDG is a partnership with the IADB to provide credit access to low-income households. This credit access is intended to be directed to the purchase of solar panels and other renewable energy sources. The novelty of this program is the new financial structure proposed to allow small communities to access loans. The program has $5 million USD to help with subsidies and financing certain projects.

To summarize, in the Mexican case, six programs support other renewable energy source projects, to which customers can apply to in order to attain financing for their PVDG projects in the form of both subsidies and financial aid at lower rates.

2. REGULATION CHALLENGES OF SOLAR PHOTOVOLTAIC DISTRIBUTED GENERATION IN LAC IN TERMS OF SOCIOECONOMIC INEQUALITY

As expressed in the last section, the growth of PVDG brings benefits -- but also many challenges -- to the electric sector. First, PVDG can result in less predictable /more volatile demand. Therefore, a more significant penetration of small-scale solar power systems requires more efficient planning and forecasting models to minimize the costs of electricity supply while maintaining electric system resiliency. PVDG can also generate supply disruptions and disturbances in the network, especially to constrained low voltage networks (Johnson & Mayfield, 2020). The expansion of PVDG will probably require infrastructure reinforcements to avoid quality problems such as blackouts and brownouts, resulting in more investments and higher fixed costs for distribution companies.

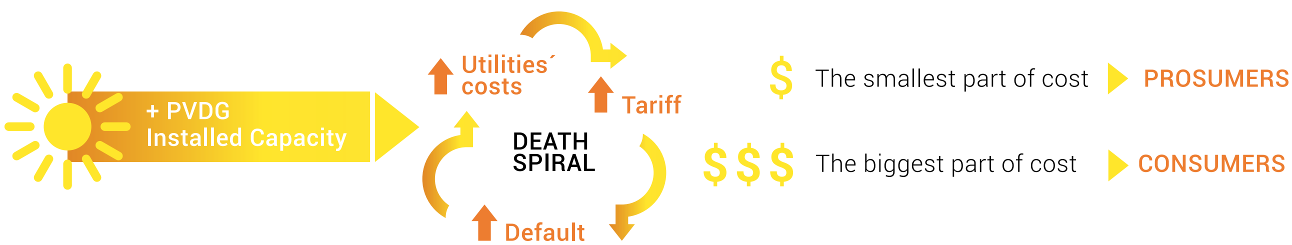
The electricity bill is often split into two parts with different rate structures, usually known as the energy rate and customer rate. The energy charge is usually based on electricity consumption for a specific period (e.g., in kWh/month), resulting in a volumetric rate (e.g., $/kWh/month). In contrast, the customer rate addresses the utility's fixed costs (regardless of consumption). It is typically a periodic flat charge per connection point (e.g., $/connection/month) or per power demand (e.g., $/kW/month). Nonetheless, in many countries like Brazil, residential and small commercial consumers pay only a volumetric charge that embodies both the energy rate and the customer charge. This user-friendly solution has worked well up until now, particularly due to low consumption levels of these two sectors. However, the volumetric charge can create an additional complication if LAC countries experience exponential market penetration of PVDG (as discussed by Hallack et al., 2020).

When customers implement PVDG for self-use (in a net-metering compensation scheme), their consumption (in kWh) decreases. As the proportion of consumers doing this rises, the utility's sales tend to fall, leading to increased rates to maintain their revenue and recover fixed costs. For example, Vieira and Carpio (2020) estimate that the current Brazilian net-metering scheme could increase residential electricity fees between 22–47% by 2035. The increased rates would be borne proportionally more by residential and commercial consumers without PVDG, as they would need to purchase all their electricity from the grid. In essence, utilities argue non-prosumers indirectly subsidize prosumers, creating a space for cross-subsidization and potentially reinforcing inequality among electricity users since prosumers tend to be wealthier than those covering the cost of the cross-subsidy. Furthermore, this possible increase in electricity tariff could lead to two simultaneous scenarios: 1) a higher tariff will result in a larger burden on non-prosumers' finances, leading to a rise in consumer default levels; 2) as tariffs rise, more non-prosumers with enough income will become prosumers, increasing the fixed costs due to infrastructure investment needed to regulate voltage and avoid disturbances caused by an increased penetration of PVDG. This will require further increases in the electricity tariff by the utility, which will worsen inequality, increase PVDG adoption, and so on, spurring a vicious cycle. This cycle is represented by Figure 6 and it is commonly referred to as the "Death Spiral" (Hoarau & Perez, 2019; Pollit, 2018).

Some scholars suggest adaptions to the electricity network tariff design are needed for low-voltage consumers to preempt and mitigate negative outcomes of PVDG policies such as those discussed above. Hallack et al. (2020), Schittekatte et al. (2018) and Schittekatte

et al. (2019) argue that the volumetric network tariff is no longer adequate for low-voltage consumers. Nowadays, these consumers are sensitive to the value of the network tariff and the crossed subsidies related to PVGD policies. Pollit (2018) defends the inclusion of a specific charge for covering network use and remunerating the distributor (by KW or kWh) on the tariff design for the energy consumed from the grid as well as for the power generated by PVGD, which needs to be injected to the grid for later consumption. Pollit (2018) also suggests that utilities should be implementing charges for ancillary services and other new services; Pollit's (2018) seems to be compatible with the net-billing compensation mechanism.

Figure 6. Representation of the Death Spiral



Source: Elaborated by IDB using MORENO et al., 2017

To help the regulator, Pollit (2018) also recommends modeling the possible impact of PVGD on the distribution network using many model types and methodologies. However, it is not easy to measure PVGD's costs and benefits. Costs, such as those related to the reinforcement or modernization of distribution networks, and benefits, such as savings due to investment deferrals in generation and transmission, are difficult to measure separately. Similarly, costs and benefits, such as risk mitigation, a decrease in environmental impacts, energy security, and economic impact, are difficult to monetize. Moreover, these costs and benefits can vary depending on the level of penetration, location, consumer behaviors, and other variables. In the initial stages, it is most likely that the positive effects are larger, and even if the net effect is negative, it should not have relevant weight on the revenue recovery process of the distribution companies. The question that requires constant attention is at what point distortions need to be addressed before becoming a problem to the system. The complexity and inherent evolution make it difficult to predict and quantify these costs and benefits. It is a challenge to estimate the disequilibrium caused by PVDG policies among consumers, producers, and utilities.

Furthermore, PVDG policies impact different perspectives, such as security of supply, CO2 emissions, prices, and service quality, among other variables. However, depending on the electricity tariff framework and socioeconomic background, these effects may affect the population's income in different ways and intensify socioeconomic disparities. Therefore, in countries where income distribution inequality and poverty are latent concerns, the design of PVDG incentives and policies requires, more than ever, previous regulatory impact studies showing that these policies are distributive neutral or even contribute to reducing socioeconomic disparities. In developing countries, an effective policy design must generally avoid, mitigate or compensate for negative distributional externalities in order to foster sustainable development. The same is true with PVDG policies.

Discussed the regulation challenges of solar photovoltaic distributed generation in LAC in terms of socioeconomic inequality, it is time to better understand the profile of the adopter of this technology in LAC in the last decade. The next section will contribute to the discussion about PVDG policies in LAC by improving our understanding about the profiles of PVDG early adopters in the residential sector and adoption geographic concentration, as well as possible impacts on socioeconomic inequalities of PVDG adoption.

3. DATA AND METHODOLOGY

Based on our literature review, we identified the potential significant drivers for PVDG adoption, and tested which of them are explicative for Brazil, Chile and Mexico. Using publicly available data and a multilevel model, we consider variables related to the viability of the investment in PVDG (electricity tariff[12] , PVDG system capacity, and solar radiation[13]), socioeconomic variables (income per capita, years of education, rural and urban regions)[14], and a demonstration effect[15] variable (neighborhood factors, distance from the closest neighbor with PVDG, his/her time of adoption and installed capacity)[16]. In addition, we designed a variable that measures the concentration of residential projects based on their size, called Solar Inequality Gini, that will be presented at greater length later in this paper. This variable is a proxy for the concentration of projects based on household purchasing power. The reason we chose to use it is because of the lack of data of adopters' income needed to measure inequality of PVDG adoption.

With that model, we want to see if the actual PVDG policies result in a socioeconomic-unequal adoption of PVDG over time in Brazil, Chile and Mexico. Our assumption considers that in a democratic adoption, socioeconomic variables should not impact adoption time. In other words, early adoption should be based on technical factors, as solar radiation. A historical and statistical analysis will complement the econometric analysis in order to conclude with some PVDG policy recommendations.

In this section, we will present the data used in our analysis, as well as the models used. We developed three databases, one for each country, from different sources based on data availability and variables of interest. Once the data were collected, we merged the different databases and homogenized data prior to carrying out the regression analysis. We developed two models. The first is a multivariate Ordinary Least Squares model with fixed effects specifications. The second is a mixed effect 3-level (multilevel) analysis with random intercepts and slopes.

12. The grid electricity tariff is a key element in the individual investment decision. This is particularly true in LAC, where most incentive policies for fostering PVDG use compensation mechanisms, such as net-metering and net-billing. Hoarau and Perez (2019), Pollit (2018), Schittekatte et al. (2018), and Schittekatte et al. (2019) reinforce that nowadays, with the possibility of investment in distributed energy resources, the consumers are less inelastic to electricity tariffs and base their decision about investing in PVDG on the avoided grid electricity price or /and the comparative cost of electricity generated by the solar system.

13. The irradiation level is one of the variables tested in several studies, with mixed results. While Rodriguez-Urrego & Rodriguez-Urrego (2018) show that around 70% of PVDG are in areas with high solar radiation levels in Colombia, results need to consider that government and public entities built most of these projects. When studying only the individual and private investments on PVDG, much of the development was in the Bogotá Capital District, a low solar radiation area. Therefore, authors theorize that adoption can be related to the higher economic capacity and income levels of Bogotá consumers. Vale et al. (2017) found similar results for Brazil. Despite lower average solar radiation, investments in PVDG systems in São Paulo seem to be more attractive than in states with higher solar radiation (e.g., Piauí). The authors attribute it to a tax incentive (the ICMS exemption) and higher-income level in São Paulo. At the same time, Garlet et al. (2019) also showed that solar radiation levels are not so relevant. By contrast, they found that tariffs and tax exemptions are key variables.

14. Lukanov and Krieger (2019) expose that years of education and access to information are the critical drivers behind disparities in solar uptakes.

15. Demonstration effects is behavior effect, and it can be defined as the effect on the individuals behavior as consequence of observation of others actions, McCormick (2018).

16. Another factor that can accelerate early adopters' decision to invest in PVDG systems is the demonstration effect or neighborhood effect. The installation of a PVDG system by a neighbor can work as an advertisement and a source of information about PVDG technology. Although PVDG is not the focus of Wollni and Andersson (2014), it is an illustration of the demonstration effect found in the literature. The authors show that farmers whose neighbors are adopters of organic agriculture have greater availability of information about the technology and are more likely to adopt organic techniques on their farms.

4.1 DATA

Both the OLS and the multilevel model have the dependent variable of "days since regulation", which is the difference between the date of a specified regulation regarding distributed generation (different for each country) and the particular installation date. Furthermore, the independent variables in our models are: PV installed capacity of the individual installation (size of the system), income per capita at the municipal level, PV output (in kWh) per m of KW installed capacity (solar radiation), Solar Gini Coefficient (that measures the project's size concentration per municipality, a proxy for adopters' purchasing power concentration per municipality), average years of education, average electricity tariff, electricity consumption, average spending in electricity, nearest neighbor distance, days since neighbor installed, and neighbor's installed capacity. The last three variables are related to what we call the 'neighborhood effect': the distance, capacity, and days since the nearest neighbor (both in time and space) has installed PVDG. Additionally, we include an inverse of the distance to account for a decreasing effect of distance to days since regulation and interaction variables between the inverse distance, neighbor's capacity, and days since the neighbor's installation.

Table 2. Variables of the Econometric Model[17]

Variable Code	Variable Name	Category	Type	Level	Hypothesis on Coefficient Signal
days_ sincereg	Days since regulation of PV (Dependent Variable)	Regulation	User-written	Individual	Dependent Variable
cap	PVDG project's capacity (in kW)	Energy	Raw data	Individual	Negative
solar_out	Solar energy potential (in KWh per m^2)	Energy	Raw data	Municipal	Negative
cons	Energy consumption in kWh	Energy	User-written	Regional	Negative
tariff	Estimated tariff by sector, month, year $/kWh	Energy	User-written	Regional	Negative
avgspend	Average spending on electricity	Energy	User-written	Regional	Negative
solar_gini	Solar Inequality Gini (measures inequality 2based on project size concentration)	Socioeconomic	User-written	Municipal	Zero or positive
icap	Income per capita	Socioeconomic	Raw data	Municipal	Zero or negative
urban	Urban=1; Rural=0	Socioeconomic	Raw data	Municipal	Zero or negative
yrsedu	Average years of education	Socioeconomic	Raw data	Municipal	Zero or negative
nn_cap	Nearest neighbor's installed capacity	Network	User-written	Individual	Zero or negative
nn_diff_days	Days since installation of nearest neighbor	Network	User-written	Individual	Zero or negative
inv_nndist	Nearest neighbor's distance inverse exponent	Network	User-written	Individual	Zero or negative

17. All references can be found in Annex A5.

Table 2 describes the variables used in our model and the characteristics of the data. Below, we describe two user-written data variables and self-generated data. Other user-written data variables, the Solar Inequality Gini and the nearest neighbor's distance inverse exponent variable deserve special consideration and further explanation. In Annex A5, we present more detailed information about data characteristics of these and other variables, as well as their sources.

As can be seen in Table 2, a column shows the level at which each variable was collected. The level refers to data collected that correspond either to the project itself (Residential Solar PV Installation), the municipality, or data available at the regional level. This will be important when developing the multilevel model. Table 3 summarizes the number of observations or groups per level and per country, which will be further discussed in the methodology.

Table 3. Levels and Countries

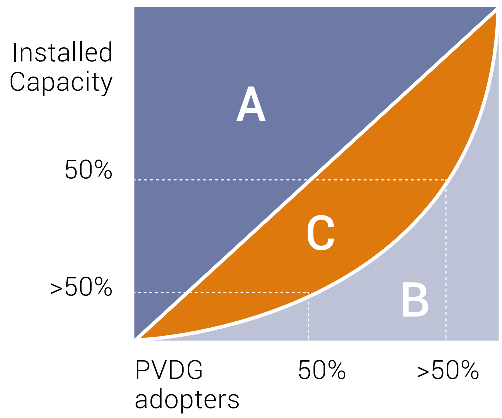
Level	Country	Number of Observations/Groups	Level Description
Individual	Brazil	95,927	Residential solar PV installation
Individual	Chile	4,128	Residential solar PV installation
Individual	Mexico	21,296	Residential solar PV installation
Municipal	Brazil	3947	Municipality
Municipal	Chile	112	Commune
Municipal	Mexico	195	Municipality
Regional	Brazil	96	Distribution companies
Regional	Chile	13	Geographical regions
Regional	Mexico	17	Tariff divisions

4.1.1 Solar Inequality Gini

To examine the concentration of installed capacity of projects (i.e., size of the project), we used a graphical representation of the Lorenz Curve adapted for PVDG. The Solar Gini Index is a single number aimed at measuring the degree of inequality in the distribution of the PVDG installed capacity or how the PVDG installed capacity distribution deviates from a totally equal distribution. In order words, this variable measures whether a given city has a large number of residential PVDG projects with a similar size or a small number of PVDG and the biggest part of the installed capacity concentrated in a small number of projects. It can be a proxy for the concentration of the household purchasing power, in circumstances whether there are a lack of data of PVDG adopters' income.

The concept has been used in different fields of knowledge outside economics. Boreinstein (2015) introduced the graph to depict the share of the total system energy installed capacity by income category. The Lorenz Curve is often used to represent income distribution, where it shows what percentage (y%) of the total income is held for the bottom x% of population. In this case, the Lorenz Curve was adapted to show the distribution of the PVDG installed capacity by PV adopters (Figure 7) to analyze how variable the size of PVDG systems in each city, region, or country is.

Figure 7. Example of the Lorenz Curve for Solar Inequality Gini



The Lorenz curve is used to obtain the well-known Gini index (G). This index will evaluate the unequal distribution of the different countries to examine impact into the speed of adoption in our regression models. The Gini index is calculated by starting with the assumption of a discrete distribution of observations of (n) PVDG adopters that, in this case, would distribute cumulatively the amount of solar energy installed in increasing order of the distribution (y) across the PVDG adopters. The calculation of the solar inequality Gini index is demonstrated by Equation 1:

$$G \quad \frac{2*\sum_{i=1}^{n} i*y_i}{n*\sum_{i=1}^{n} y_i} - \frac{n+1}{n} \tag{1}$$

In other words, it is the progressive addition of the area under the Lorenz curve depicted below the axis that represents B and the area below the line of equality (i.e., the 45 degrees diagonal) to the axis that represents A, with both axes spanning from 0 to 1, since they represent cumulative distributions. Considering the fact that the area of a unitary triangle is one and that the area under the reference equality line A is 1/2, we would find that the Gini coefficient (G) would be equal to Equation 2:

$$G = \frac{A-B}{A} = 1 \ - B \tag{2}$$

On the Lorenz curve diagram (Figure 8), the diagonal line represents perfect equality. We find that "1" would then mean perfect inequality with all capacity installed in one installer, and "0" would represent perfect equality, since the value of B would then be equal to that of A. Therefore, the value of G would be 0. Hence, if Lorenz curves are more distant from the perfect equality, we can deduce that the distribution of PV concentration is heavily clustered around a few users holding most of the capacity. In contrast, when we find that the curve is closer to the reference equality line, it indicates that the capacity installed is well distributed between the users. Since the access to PVDG is equal for the same level of resources and endowment, we would expect to see small installations diverging from larger ones. As such, it is worth bearing in mind the caveat that a perfect Gini could equally be representing a perfectly equal small number of installations in a given location for a given sector.

4.1.2 Neighborhood Variables

To estimate the impact of neighborhood dimension on PVDG adoption, we calculated the nearest neighbor's Euclidean distance to each adopter at the moment of adoption. The distance is the difference between an adopter and its closest adopter-neighbor, in terms of both latitude and longitude. It can be defined as:

$$D(x,y) = \min\left(\sqrt{\left(x_{lat} - y_{latj}\right)^2 + \left(x_{long} - y_{longj}\right)^2}\right) \quad where\ j \in \mathbb{N}\ and\ D,x,y\ \in \mathbb{R} \qquad (3)$$

where D is a function that calculates the Euclidean distance between a given point x and all the points in a vector of bi-dimensional j points in a vector y of points with latitude and longitude coordinates that are returning the minimum value between them. However, it stands to reason that a neighbor's influence might be more decisive when close to the studied adopter, but that it quickly diminishes as it gets progressively further away.

Following the proposed neighbor effect and avoiding long distances from which we can expect a distorted interpretation of the spatial variable, we aim to remove the exponential effects. We assume an inverse square root of the distance to ensure that there is a minimum background effect of installations by using the following formula:

$$D_{inverse\ Sq\ Root} = (D)^{-\frac{1}{2}} \qquad where\ D \in \mathbb{R} \qquad (4)$$

with D being the actual distance and D_(inverse Sq Root) its transformation, which results in a fast reducing effect, as distance increases in order to remove the impact following the inverse exponential component of this variable, and controlling it with the hope of linearizing the spatial diffusion effect. To control the potential endogeneity of the distance to the nearest spatial neighbor, we control for the time difference in adoption, measured in days, and evaluate the potential diffusion impact of the installation's size. We also considered the size of the nearest PV installation in the time of adoption of the individual.

4.2 Methodology

At the beginning of our analysis, we experimented with different combinations of variables, starting with simple, parsimonious models. We justified adding more variables through information criteria testing, as our model fit improved. We ended up with five models: a level-level and a log-log model[18] with all the variables mentioned above, a socioeconomic model with only socioeconomic variables, another model with only energy-related variables, and lastly, a model that accounted only for the network variables. We used both the level-level and log-log models to compare countries as they seem to have the best fit.

To summarize our approach, we used linear regression techniques to evaluate the effects of the components, as mentioned earlier, on the number of days that pass from regulation implementation to PV adoption of each individual. We seek to gain insight into how the democratization of installation (Solar Inequality Gini) in the adopter (municipality) area affected

18. The level and log are indicative of the format or unit in which the variables come.

the decision's timing. We also hope to shed some light on how the spatial-temporal distance to neighbors, and the size of its installation might, through processes of knowledge diffusion and imitation, induce earlier or later PV adoption. Furthermore, we expect to gain perspective on the effect of socioeconomic and energy-related factors, such as tariff and consumption, on early PV adoption.

The regression follows this standard linear model presented in Equation 5.

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_p x_{ip} + \epsilon \tag{5}$$

In this equation, y is our dependent variable -- days between a regulation passing and PV adoption -- and the subscript i represents individuals. β_0 is the intercept of the model and ϵ its residuals, which should take a normal distribution around the prediction. The Xs represent the values of our control variables, and the Betas are the estimated model coefficients.

Nevertheless, it is worth mentioning that the OLS model presented above shows several inconsistencies. First, some of the variables used were municipal or regional averages. As we drilled into these inconsistencies, we found that a hierarchical structure characterized our data. In Figures 8 and 9, we show that individual observation of the dependent variable "Days Since Regulation" is nested inside regions and municipalities. This nesting creates noise in the output of a regular OLS regression model because it ignores the average variation between levels. Each vertical line in the figures below corresponds to a region or a municipality. The solid black connected line corresponds to the mean "Days Since Regulation" of each region or municipality, respectively.

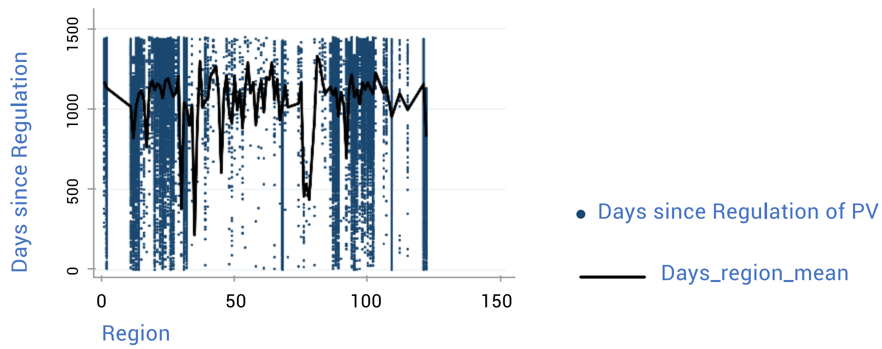
While our analysis focuses on individual project characteristics, there are also variables per municipality or region. In terms of GDP per capita, municipal differences, size of project inequality, and the influence of other adopters (neighborhood effect) all impact the number of days for adopting PVDG systems, since the implementation of the PVDG regulation.

However, some of our data were not individual characteristics, but characteristics of municipalities and regions. In other words, the number of days it takes for individuals to adopt in the same municipality or region may be correlated due to exposure to municipal or region-wide variables such as income per capita, tariff and consumption, among others. Moreover, individual projects are nested within municipalities, and municipalities are nested within regions.

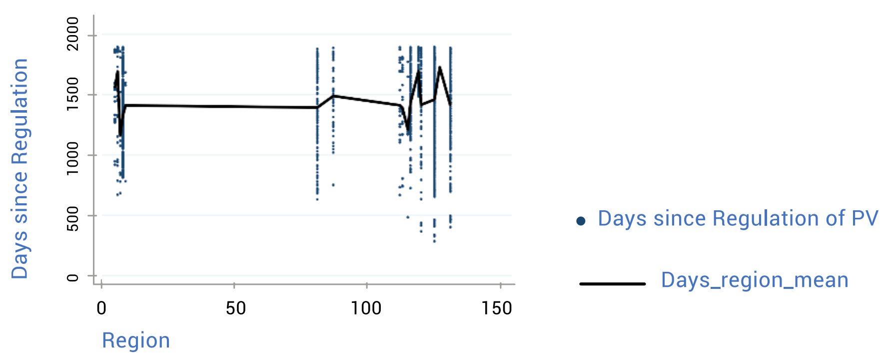
This problem justifies the introduction of a three-level multilevel analysis (Figure 10). While we tried to account for differences between regions in our linear OLS model with fixed effects, we argue that a multilevel regression model could better account for the inconsistencies found in our OLS model and provide better coefficient estimates. The following diagram represents a sample country with two regions, four municipalities, and 12 projects to further illustrate the point of the multilevel model.

Figure 8. Variation between Regions of the Dependent Variable: Days Since Regulation

Brazil



Chile



Mexico

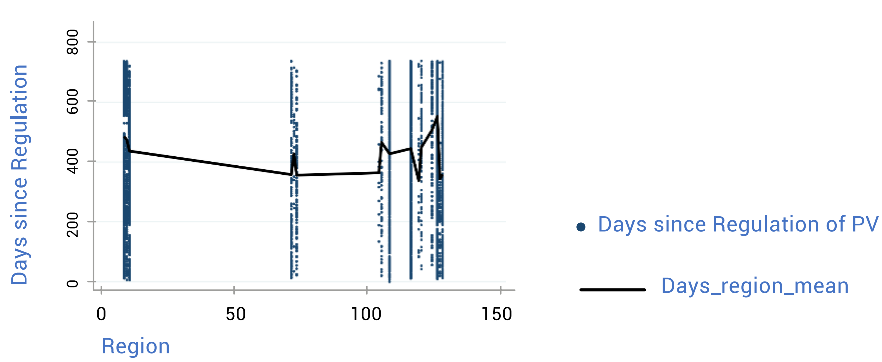
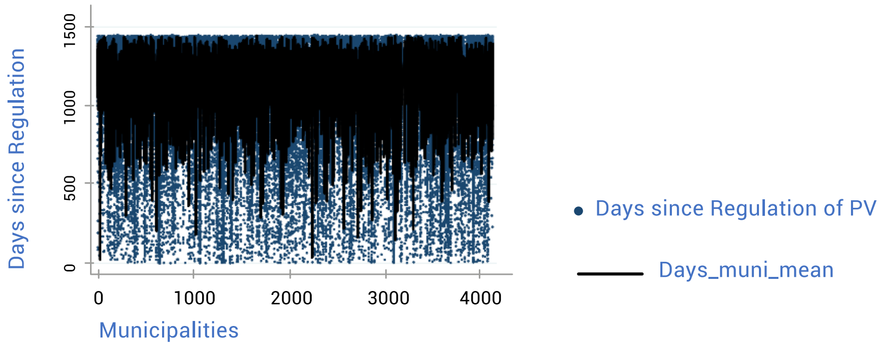
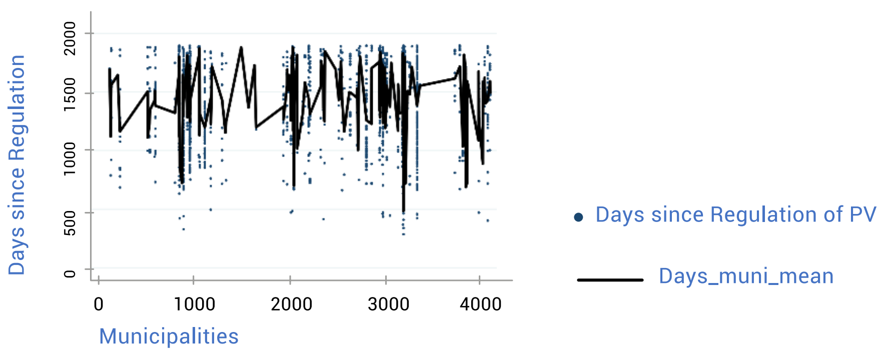


Figure 9. Variation between Municipalities of the Dependent Variable: Days Since Regulation

Brazil



Chile



Mexico

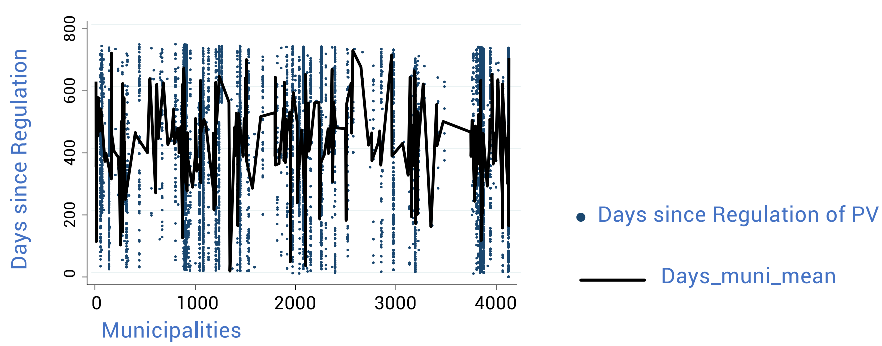
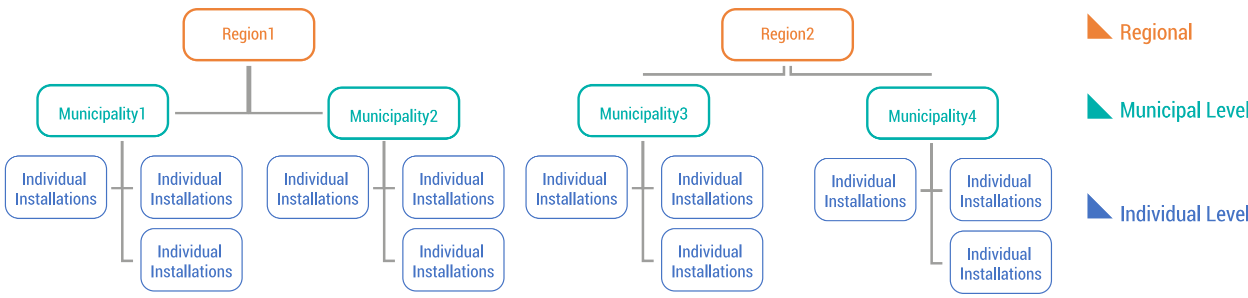


Figure 10. Example of a Fictional Country and its Regional, Municipal and Individual Levels



Source: Authors' elaboration[19]

Variables at the upper levels (i.e., municipal and regional) have repeated observations at the lower level (level 1). When using a simple OLS model at the individual level only, the repeated observations violate the assumptions that the observations are random and independent. Therefore, observations at the individual level are dependent on the upper levels. Moreover, the lack of variance on the lower level in the upper levels' variables creates noise by either over- or underestimating the coefficients in the regression. We concluded that a three-level multilevel analysis could generate more precise estimates.

There are three main components in our three-level, multilevel model: the observed values of the dependent variable, a fixed component of our model (i.e., the independent variables), and the random component or the error term. The difference between the observed and the fixed part of the model equals the random component. However, the fixed component can be disaggregated at each level. This disaggregation corresponds to the variable's mean at each level (regional, municipal and individual). Furthermore, this model accounts for the variability generated at each level to accurately estimate our regression model's coefficients.

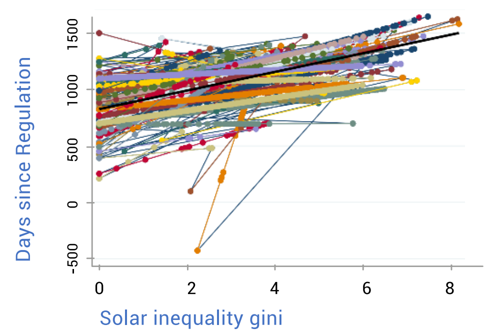
19. It was inspired by Stata Blog (2013) by Chuck Huber, https://blog.stata.com/2013/02/04/multilevel-linear-models-in-stata-part-1-components-of-variance/

4.2.1 Random Intercept and Slope Model

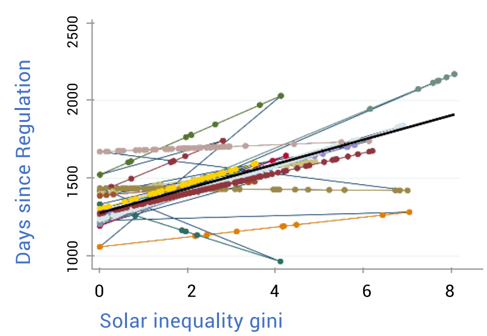
A standard exercise in understanding our data's shape and adapting our model to explain variability in the intercepts and slopes at different levels is to plot the predicted values of our dependent variable both at the regional and municipal levels using the dependent variables. Figure 11 exemplifies a municipal-level variable nested at the regional level to observe both the intercepts and the slopes. Each line represents a different region in each country. Observing these graphs, we can conclude that there are both random intercepts and random slopes in each country, as there are noticeably different trends in each region. In these figures, each line represents a region. We repeated the same exercise at the municipal level in Figure 12. We arrived at the same conclusion: there is variability in each line's intercepts and slopes, which represent each municipality. More examples of this can be found in Annex A4. In sum, the presence in variability in both the intercept and slope indicates that a random intercept and slope multilevel model is appropriate at both the regional and municipal levels.

Figure 11. Regional Random Intercepts and Slopes: Days Since Regulation and Solar Inequality Gini (Level-2 variable)

Brazil



Chile



Mexico

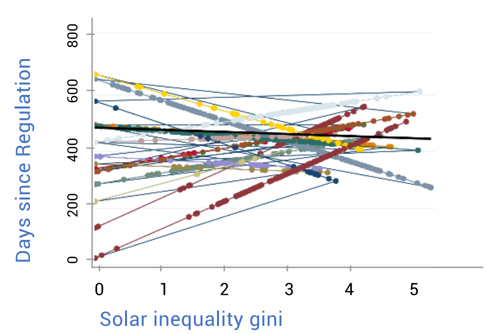
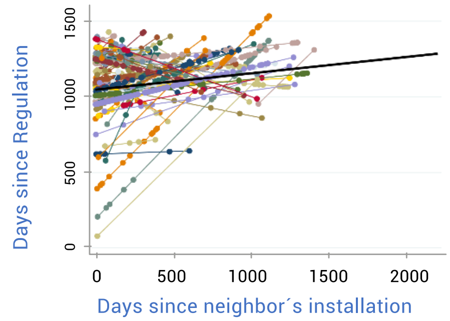
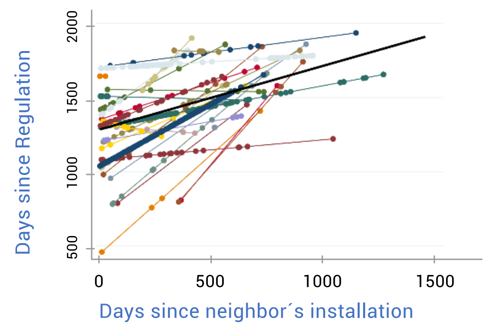


Figure 12. Municipal Random Intercepts and Slopes: Days Since Regulation and Days Since Neighbor's Installation (Level-1 variable)

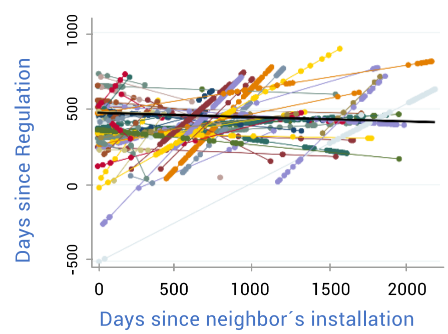
Brazil



Chile



Mexico



4.2.2 Our Model [20]

Due to the variability discussed above, we developed a model that allowed us to have different intercepts and slopes at higher levels (levels 1 and 2). In other words, it enabled us to interpret the relationship between the dependent and independent variables differently at the municipal and regional levels. However, there was an exception. The Inverse Solar Distance has little to no variation in the slopes at the regional and municipal levels in both Chile and Mexico[21]. For this reason, we have excluded this variable in the regional and municipal specification of the model to control for random slopes in Chile and Mexico, but not Brazil. That said, given that our model has three levels and has mostly random intercepts and slopes, we developed the following multilevel regression model described in Box 1 by equations 6, 7, 8, 9, 10, 11, 12, 13 and 14.

Box 1. Multilevel Regression Model Equations

Level 1 – Individual Installation:

$$y_{ijk} = \beta_{0jk} + \beta_{1jk}x_{ijk} + \epsilon_{ijk}$$

Level 2 – Municipal:

$$\beta_{0jk} = \pi_{00k} + \pi_{01k}W_{jk} + \tau_{0jk}$$
$$\beta_{1jk} = \pi_{10k} + \pi_{11}W_{jk} + \tau_{1jk}$$

i – subscript representing first-level observation (individual installation level)

j – subscript representing second-level observation (municipality level)

k – subscript representing third-level observation (regional level)

y_{ijk} – a dependent variable that varies at the individual installation level

x_{ijk} – first-level independent variable

W_jk – second-level independent variable

Z_k – third-level independent variable

β – first-level intercept and slope coefficients

π – second-level intercept and slope coefficient

δ – third-level intercept and slope coefficients

ϵ – first-level error term

τ – second-level error term

μ – third-level error term

20. To validate this model, we used three types of tests: Wald Chi Square, Likelihood Ratio Test, and Interclass Correlation. The Wald Chi Square is a statistic used to test that at least one coefficient in our regression is equal to zero. If the p-value of this test result is zero, we can reject the null hypothesis that at least one coefficient is zero. Similarly, the Likelihood Ratio Test allows you to objectively select the best possible model among nested models. It compares the simple model (the OLS model in our case) with the nested model (the three-level multilevel model). This test generates a statistic similar to Wald Chi Square, and it is rejected whenever it is small (near zero), which would mean that the new model (i.e. the multilevel model) is an improvement from the OLS model (Glen, 2020). Lastly, the Interclass Correlation (ICC) tests correlations within a class of data or a group. It generates a descriptive statistic between 0 and 1 that measures how strongly or weakly observations in the same group are alike. The higher the value of the ICC, the stronger the resemblance among grouped data. In general, an acceptable qualitative interpretation of the ICC is that anything above 0.01 validates that there is inter-class correlation (Bliese, 1998). A value below 0.5 is considered "poor", a value between 0.5 and 0.75 is "moderate", a value between 0.75 and 0.9 is "good", and a value above 0.9 is "excellent" (Liljequisr et al., 2019). These three tests will allow us to determine which model has a better fit given our data.

21. It is plotted in Annex A4, Figure A4.7.6 and Figure A4.7.7.

Box 1. Multilevel Regression Model Equations (cont.)

Level 3 – Regional:

$$\pi_{00k} = \delta_{000} + \delta_{001} Z_k + \mu_{00k}$$
$$\pi_{01k} = \delta_{010} + \delta_{011} Z_k + \mu_{01k}$$
$$\pi_{10k} = \delta_{100} + \delta_{101} Z_k + \mu_{10k}$$
$$\pi_{11k} = \delta_{110} + \delta_{111} Z_k + \mu_{11k}$$

By substituting Level 3 into Level 2, and Level 2 into Level 1, we obtain the following expres

$$y_{ijk} = \delta_{000} + \delta_{001} Z_k + \mu_{00k} + (\delta_{010} + \delta_{011} Z_k + \mu_{01k}) W_{jk} + \tau_{0jk} + ((\delta_{100} + \delta_{101} Z_k + \mu_{10k}) \cdot$$
$$(\delta_{110} + \delta_{111} Z_k + \mu_{11k}) W_{jk} + \tau_{1jk}) x_{ijk} + \epsilon_{ijk}$$

Lastly, we distribute:

$$y_{ijk} = \delta_{000} + \delta_{001} Z_k + \mu_{00k} + \delta_{010} W_{jk} + \delta_{011} W_{jk} Z_k + \mu_{01k} W_{jk} + \tau_{0jk} + \delta_{100} x_{ijk} + \delta_{101} x_{ijk} Z$$
$$\mu_{10k} x_{ijk} + \delta_{110} x_{ijk} W_{jk} + \delta_{111} x_{ijk} W_{jk} Z_k + \mu_{11k} x_{ijk} W_{jk} + \tau_{1jk} x_{ijk} + \epsilon_{ijk}$$

i – subscript representing first-level observation (individual installation level)

j – subscript representing second-level observation (municipality level)

k – subscript representing third-level observation (regional level)

y_{ijk} – a dependent variable that varies at the individual installation level

x_{ijk} – first-level independent variable

W_jk – second-level independent variable

Z_k – third-level independent variable

β – first-level intercept and slope coefficients

π – second-level intercept and slope coefficient

δ – third-level intercept and slope coefficients

ϵ – first-level error term

τ – second-level error term

μ – third-level error term

4. RESULTS

This section will present the results of the case studies of Brazil, Chile and Mexico. As mentioned before, we chose these three countries because of their relevance in the region regarding distributed generation and also because of the data availability. However, they have PVDG heterogenous energy-related policies, energy matrices, tariffs structure, geography and populations. As such, it is expected that different factors will play different roles in these countries. Nonetheless, some of our results are consistent across the different contexts, which helps to validate their robustness.

The model counts on the dependent variable "Days Since Regulation", which is the number of days between the date of the PVDG regulation launch (different for each country) and the particular installation date. Furthermore, the independent variables in our models are capacity of the PVDG project (size of the project in kW), solar energy potential (kWh per m   of KW installed capacity), average electricity tariff, electricity consumption, average spending in electricity income per capita at the municipal level, income per capita, average years of education, urban or rural region, Solar Gini Coefficient (that measures the projects' size concentration and adopters' purchasing power per municipality), nearest neighbor distance, days since neighbor installed, and neighbor's installed capacity. Those last three variables are related to what we call the 'neighborhood effect' and are used in some interaction in the model. We include an inverse of the distance to account for a decreasing effect of distance to days since regulation, too. Table 4 gathers the list of all variables included in the model[22].

Table 4. Results of the Multilevel Analysis Model

Multilevel Analysis Dependent Variables: Days Since Regulation of PV			
	Brazil	Chile	Mexico
Capacity of the PVGD Project (in kW)	-4.431	-3819.6***	-108.5
	(-0.10)	(-3.41)	(-0.22)
Solar Energy Potential (kWh per kW)	-3151.8***	-59.25**	-194.7***
	(-3.49)	(-3.27)	(-14.79)
Average Electricity Tariff (in USD)	-46603.1***	-157810	-1103787.6***
	(-3.63)	(-1.83)	(-5.19)
Average Electricity Consumption (in kWh)	-2.414**	231.8***	-43.36***
	(-2.87)	-18.35	(-32.98)

22. It is worth noting the model's fit by illustrating the output of the three tests we mentioned earlier. As we see in the table above, all three countries pass the Wald Chi Square test significantly, meaning that we reject the null hypothesis that at least one coefficient in our regression is equal to zero. Similarly, all Likelihood Ratio tests demonstrate that the multilevel model chosen is better than the linear OLS model with similar characteristics. Furthermore, the Interclass Correlation (ICC) for Brazil indicates a moderate level of the resemblance for the observations nested at the regional level. At the same time, it shows a low level at the municipal level. Mexico's ICC test shows an excellent level of resemblance for the nested observations at both the regional and municipal levels. Lastly, Chile's ICC reflects an excellent level of resemblance for the data nested at the municipal level, but is moderate at the regional level.

Table 4. Results of the Multilevel Analysis Model (cont.)

Multilevel Analysis Dependent Variables: Days Since Regulation of PV			
	Brazil	Chile	Mexico
Average Electricity Expenditure (in USD)	7.08	-1070.1***	-6.030***
	-1.43	(-21.04)	(-10.57)
Income per Capita USD	-4.219**	-0.453	-0.936
	(-2.67)	(-0.09)	(-0.07)
Average Years of Education	-4144.9**	-2682.1	-1829.1
	(-2.87)	(-1.67)	(-1.59)
Urban	-68.24***	-40.66	1.131
	(-5.76)	(-0.98)	-0.28
Inverse neighbor's distance	-2.073*	0.358***	-0.324*
	(-2.35)	-6.47	(-2.09)
Log of Days Since Neighbor's Installation	-349.5	-708.9	-59632.0***
	(-1.46)	(-0.44)	(-12.39)
Neighbor Installed Capacity	-115.7*	-1575.8	-313.4
	(-2.13)	(-1.77)	(-0.36)
Inverse Neighbor's Distance # Log of Days Since Neighbor's Installation	-0.00281	-0.0198	0.0683**
	(-1.88)	(-1.61)	-2.87
	-0.00046	-0.0164**	0.0317
Inverse Neighbor's Distance # Neighbor Installed Capacity	(-0.68)	(-2.99)	-1.9
Inverse Neighbor's Distance # Neighbor Installed Capacity # Log of Days Since	0.00008	0.00372**	-0.00063
Neighbor's Installation	-0.69	-2.8	(-1.84)
Solar Inequality Gini	1401.9	-10306.9***	-7080.6***
	-0.99	(-4.10)	(-5.74)
Constant	10620.3***	31177.7	371896.5***
	-5.1	-1.8	-15.15

Table 4. Results of the Multilevel Analysis Model (cont.)

Model Tests			
	Brazil	Chile	Mexico
Observations	95927	4128	21296
Wald Chi2	2816.48	2054.35	10696.5
Wald Chi2 - Prob>chi2	0	0	0
Likelihood Ratio	21596.76	1994.43	15748.87
Likelihood Ratio - Prob>chi2	0	0	0
ICC - Regional	0.056087	0.228305	0.974667
ICC - Municipal	0.366805	0.998831	0.999955
AIC	1333116	54967.8	265426.8
BIC	1334016	55467.6	266056.1
t statistics in parentheses, * p < 0.05, ** p < 0.01, *** p < 0.001			

The Impact of the Variables Related to Economic Viability

The variables associated with the cost of investment, such as PVDG project capacity, solar energy potential, electricity tariff, consumption, and expenditure, in general, tend to have a negative effect on the number of days since regulation. The higher the techno-economic viability of the PVDG, the quicker the adoption.

As we can see in Table 4:

Higher solar PV output and the PVDG Project Capacity increase. This means lower investment costs per kW installed and the lower is the cost per kWh generated by the PVDG system. As a consequence, there is an incentive for quicker adoption.

Higher Solar Energy Potential and Capacity of the PVDG Project, means higher project efficiency. As a consequence, there is an incentive for quicker adoption.

The higher the electricity tariffs, consumption and bill costs, the higher the Net Present Value of the aPVDG project. As a consequence, there is an incentive for quicker adoption.

Both Solar Energy Potential and Average Electricity Tariff coefficients presented p-values lower than 0.0001 in all three countries, which means that they seem to be extremely significant in the adoption pace.

The impact of socio-economic variables

The socioeconomic variables (income per capita, years of education, and urban/rural) in general negatively affect the number of days since regulation, as expected. Adopters with higher socioeconomic status (higher income and educational levels) and those living in urban areas tend to adopt PVDG earlier than those with lower socioeconomic status and living in rural areas.

The results above show Brazil's case of socioeconomic disparity of PVDG adoption has a high significance level, while the coefficients do not seem to be significant for Chile and Mexico, at 95%. Regardless, the relationship still holds due to the consistence of coefficients. In addition, the less significant socioeconomic variables can be explained by the existence of more PVDG programs with focus on social inclusion in Mexico and Chile. This raises an important point for discussion that must be further explored, namely, that the socio-economic inequality is not a characteristic of the technology itself, but of how adapted policies and regulations are to deal with the pre-existing socio-economic inequality.

The impact of the demonstration effect

In relation to neighborhood variables (Inverse Neighbor's Distance, Log of Days Since Neighbor's Installation, Neighbor Installed Capacity), the coefficients also show a negative relation between the neighborhood effect and the days it takes a person to adopt solar PVDG, validating our hypothesis. Neighborhoods with PV solar adoption generate quicker adoption. This is outcome that was expected based on the literature review, and which can be explained by the literature as a result of the demonstration effect [23].

According to the model, inverse neighbor's distance is the neighborhood effect variable with bigger significance. Similarly, a PVDG system in the neighborhood can affect how quickly one adopts PVDG. In other words, householders tend to adopt faster if you have a neighbor living nearby with a large PVDG installation. It means, living near someone who has recently installed large-size solar panels increases visibility and, thus, the effect on time of adoption).

Moreover, we can expect that people who live near each other tend to have similar socioeconomic conditions and information levels, and therefore tend to adopt concomitantly. This is another effect that increases adoption inequality and needs to be considered.

The concentration of PV solar adoption

The Solar Inequality Gini variable shows the "equity" of PVDG-installed capacity distribution per number of projects at the municipal level. It aims to analyze the tendency of having bigger or smaller projects. The coefficient was positive, as we assumed in our hypothesis, and it was significant for both Chile and Mexico, but not for Brazil.

23. De Meio Reggiani et al. (2020) discuss the importance of awareness in the adoption of new technologies in the LAC energy sector.

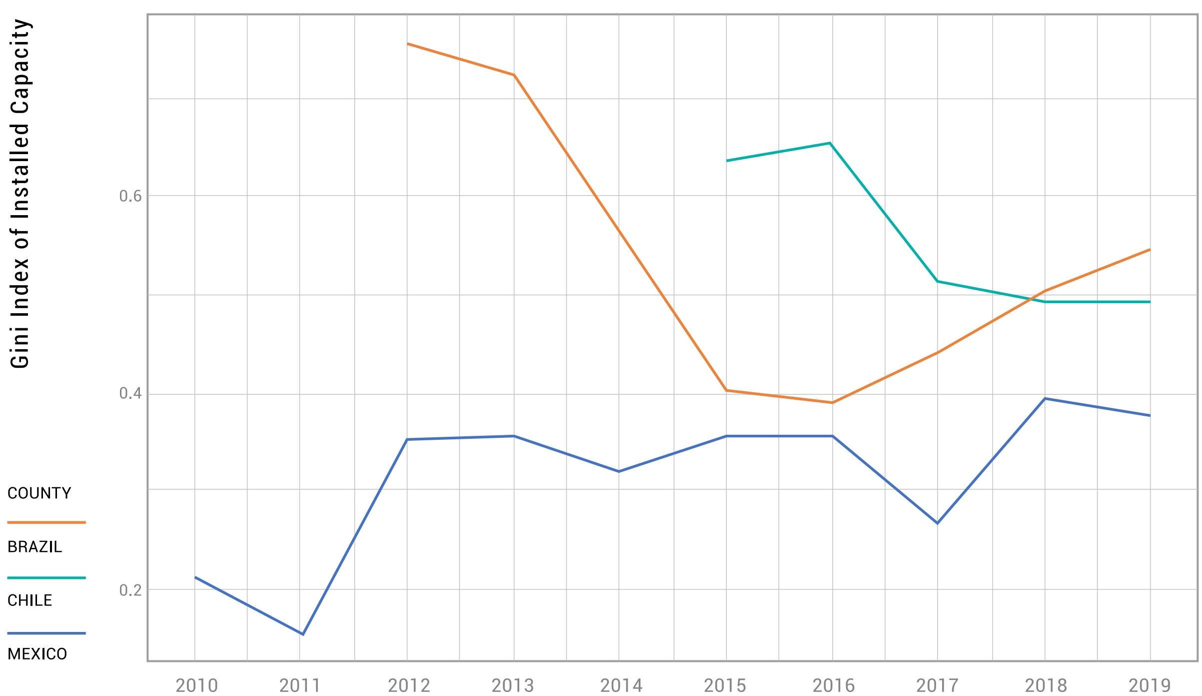
In interpreting the coefficients, we speculate that they can reflect the evolution of the Solar Gini Index in the three countries. Observing Figure 13, we can have a more intuitive look into how the inequality of PVDG installation has shifted over time by examining the quintiles of installed capacity relative to the number of installations present in each country. The evolution of the concentration of installed capacity has taken different pathways for different countries. In Annex A5, it is possible to see this evolution with more detail.

The PVDG-installed capacity in Brazil is the most concentrated, however, the concentration has decreased. It has decreased over the years until 2015, when there was a regulatory change allowing higher maximum installed capacity, remote and shared consumption under the umbrella of PVDG policy. After this change, there was a change in the pattern of PVDG concentration. This example shows that concentration patterns can change during the evolution of the PVDG adoption, and it is impacted by the changes in the regulatory/policy characteristics. Nowadays, Brazil has the higher concentration, if compared with the other two countries. It means that 67% of installed capacity is concentrated in the 20% of the projects (see Annex A4.8.).

Chile is the second with highest PVDG concentration (based on the Gini Index), however, differently from Brazil it has shown, since 2016, a stable tendency of concentration decrease. In 2019, 57% of the installed capacity was concentrated in 20% of the projects. Mexico is has shown a completely different pattern, starting from the lowest concentration, it increased in the first two years and after thar if it has been steady[24], 20% of the projects means 46% of the installed capacity in 2019 (see annex A4.8).

The explanation of the concentration index can be associated with different factors, regulatory and policy constraints, characteristics of the first movers, characteristic of the technology when the policy started and the statistics' significance of the first installations years[25].

Figure 13: Evolution of Inequality among Solar Installations Measured with a Gini Coefficient on Capacity Installed



24. For the figures plotting countries' result by quintile, see Annex A4, Figure A4.7.8, Figure A4.7.9, and Figure A4.7.10.
25. Further studies should explore more the potential convergence in the concentration index from three different countries, they started in completely different frames and patterns and move to a more similar level of concentration. It may indicate a tendency to converge on a zone of concentration of the PVDG installation under the current policies.

The solar Gini is an interesting index to evaluate the democratization of the access to PVDG; we can see, for instance, that the characteristics of first adopters in Brazil, Chile and Mexico are quite different. Mexico is less concentrated and more stable, while Brazil presents with a higher concentration and higher variation. It also shows how during the policy evolution, the characteristics of adopters may evolve, and it may be followed and considered by policy makers and regulators when evaluating costs, benefits and potential distortions.

Nevertheless, its evolution should be interpretated carefully, especially in the case where results from PVDG policy are still incipient. It is difficult to measure the disparities in the distribution of a PVDG system when there are few adopters. For example, by the end of 2015, Brazil only had 1,420 systems with a total installed capacity of 5.5 MW in households. In October 2020, the households had more than 239,000 systems with a total installed capacity of 1.5 GW.

Besides this warning about the interpretation of the solar Gini results, we find some other contradicting results among the countries. Some of these results were less significant than expected. This can be mostly explained by the quantity and quality of data. In Chile, for example, there were only 4,128 observations. This can be a problem, especially in a multilevel analysis.

Moreover, a worthy next step would be to explore socioeconomic and neighborhood factors more in a deeper analysis of the individual country's policies and PV adoption rates to figure out why they might be significant in some contexts but not others. This would require focusing on the heterogeneity of adopters and on the underlying economic inequality that characterizes them. The current databases of PVDG in Brazil, Chile and Mexico do not present any socioeconomic details of the adopters, and in the case of Chile and Mexico there is no information about the specific location of the PVDG systems beyond the municipality. This kind of information would be extremely helpful to evaluate the PVDG incentive policies. Similarly, as the installed capacity of PVDG increases in these countries, it may be worth exploring variations of this model in the future and comparing the results with other LAC countries where the development of PVDG happened later. Additionally, examining the specific policy effects vis-a-vis other countries and their situations would complement and advance this study should equivalent data become available or be more precise. For the countries studied we are seeing cases such as the one in Brazil, where they are reviewing the current PVDG policy in order to reform it or renew it on the basis of the current evidence, and it would be interesting to evaluate the effect of the change versus the prior situation.

Finally, the results of this study bring more information about the profile of early adopters and the distribution of PVDG in three LAC countries. While we see a strong relationship between adoption and variables associated with the cost of investment (such as solar radiation and electricity tariff), the socioeconomic and neighborhood variables also show a significant impact on time of adoption. This finding suggests there is more evidence for PVDG concentration in higher income households and neighborhoods, than democratization of PVDG over the whole of potential adopters. Therefore, it is important to analyze deeper the PVDG policies in order to propose adaptations and additional instruments that address these distributional issues and make the PVDG accessible and affordable for more households.

5. FINAL REMARKS

The world has experienced a boom in the implementation of renewable energy sources over the last two decades. Conventional energy sources, such as coal, natural gas and oil, are showing a declining trend, while renewable energy sources continue to grow at a fast pace. In addition to the declining cost of renewables and public awareness of the pollution generated by conventional sources, alternative approaches for electricity generation are gaining momentum, such as decentralized energy generation. As this momentum for PVDG grows, it is important to ensure that this transition reaches the population widely and it's not retained by a few early arrivers or more well-endowed parties in order to foster support for it. It is important that we leave no one behind as we move to a more decarbonized and localized approach to energy generation and consumption.

In general, governments in LAC have actively promoted solar photovoltaic distributed generation - PVDG through different electrification programs, solar energy adoption, and other consumer empowerment measures. A variety of channels have been and are currently used to provide funds, including subsidies and financing the full cost of projects. From the point of view of the electric system, the idea is to increase electricity coverage, reduce electricity losses, promote the use of distributed energy resources in a way that empowers electricity consumers, and to promote cleaner renewable energy. From the point of view of prosumers, the advantage is to reduce their electricity bill by decreasing their energy demand from the grid, to be no longer exposed to electricity tariff adjustments, and to have the liberty of generating their own electricity through a solar photovoltaic power plant that is free of greenhouse gas emissions.

Different regulatory frameworks for PVDG exist, and its promotion programs have propelled a PVDG evolution with different distributional dimensions in LAC. These countries have implemented some PVDG incentive policies, such as net-metering and net-billing mechanisms, special funds and financing programs. However, there is the awareness about how the use of those incentive mechanisms in combination with volumetric electricity tariffs might create some crossed subsidies, where the consumers without PVDG pay for the system and network structure costs related to the prosumers. The consequences of the crossed subsidies derived from PVDG adoption could be even more complicated in the residential sector, considering that prosumers tend to have a higher income than other consumers. Hence, in the medium-term, without any changes in policy and in the regulatory framework, a death spiral might result, where the increase of prosumers would result in successive increases in electricity tariffs and default rates. Thus, especially in countries with high income disparities, such as LAC countries, it is essential to implement PVDG policies that do not indirectly contribute to increasing the exclusion of the most vulnerable socioeconomic groups.

With this objective, the authors of this study reviewed the dimensions of PVDG distribution in the three countries in the LAC region with large PV-installed capacity – Brazil, Chile and Mexico. Our principal goal was to identify the profile of early adopters of PVDG in these countries in order to analyze if the decision and speed of PVDG adoption were also impacted by socioeconomic aspects or only by those variables related to the cost of investment (capacity of the PVDG system, solar radiation, electricity tariff, consumption and electricity bill cost). Understanding better the profile of PVDG adopters and their locations in Brazil, Chile, and Mexico, it was possible to address which adaptations could make the PVDG policies more sustainable from the socioeconomic perspective.

To answer this question, we created a multilevel econometric model whose objective was to identify the most significant characteristics of PVDG's early adopters over time in each country – Brazil, Chile and Mexico. This model aimed to develop a general profile of early adopters. Based on a literature review, the models considered most relevant factors related to investments in PVDG systems, such as factors related to the viability of the investment in

the project (PVDG system capacity, solar radiation, and electricity tariff, consumption and bill cost) and socioeconomic and neighborhood factors (income per capita, years of education, rural and urban regions, solar inequality, distance from the closest neighbor with PVDG, his/her time of adoption and installed capacity). Our hypothesis considered that DG incentive policies would not generate distributive distortions if socioeconomic variables and neighborhood factors demonstrated little or no impact on the time it takes an individual to adopt PVDG.

According to the results, we observe that socioeconomic and neighborhood factors have significant effects in Brazil's case, and to a lesser degree, in Chile and Mexico. We find that the early adopters in these countries are people who live in urban areas with higher solar resource endowments, higher electricity costs, higher income per capita, and higher levels of education. Similarly, the neighborhood variables suggest that adopters tend to install sooner if they have neighbors nearby who have recently installed larger solar PVs. Lastly, we find that at the early stages of adoption, the concentration of PVDG-installed capacity per number of projects in each city tends to be higher, meaning that there is less egalitarian adoption in the beginning, particularly for Chile and Mexico.

The results showed that socioeconomic and neighborhood factors have significant impacts on the speed of PVDG adoption in Brazil. In Chile and Mexico, neighborhood factors showed as particularly important. We found that the PVDG early adopters in these countries seem to be people who live in urban areas with good endowments of solar resources, higher expenditure costs for electricity, higher income per capita and higher levels of education. Likewise, neighborhood variables suggest that adopters tend to install earlier if they have close neighbors who have recently installed larger solar photovoltaics. Finally, we found that in the three countries there is a high concentration of PVDG systems. Twenty percent of household prosumers represent around half or more of the total PVDG-installed capacity of the residential sector. In 2019, the Solar Gini Index for the three countries was around 0.35 and 0.6, which shows a high concentration of PVDG systems.

Therefore, our findings are revealing, in as much as they tell us that socioeconomic and neighborhood factors have significant impacts on the speed of PVDG adoption. Therefore, in the medium- and long-term, a potential massive adoption resulting from PVDG incentive policies that do not address the adopters' heterogeneity, could exacerbate socioeconomic inequalities in the countries. It does not mean that PVDG triggers socioeconomic inequality, but rather that regardless of the PVDG policy, the heterogeneity of adopters and timing of adoption must be considered to avoid the increase of inequality (by cross-subsidizing high income householders).

As the PVDG adoption expands we recommend periodic and accurate impact assessments. For a more precise evaluation of PVDG the polices results, it is necessary a database with technical (such as installed capacity, modality of compensation, and tariff type) and socioeconomic details (such as income and education levels), as well as the location (municipality, and ZIP code) of the PVDG adopters who received incentives. As proposed by this work, the Solar Gini Index can be used as an indicator to measure the heterogeneity of the distribution of PVDG-installed capacity per the number of PVDG systems.

In addition, distributed generation markets can benefit from equity-balancing policies to make PVDG accessible and affordable for a larger number of consumers. For example, in Brazil, where the socioeconomic factor seems to have big impacts, it would be very important to create some solar-social inclusion programs, such as including PVDG systems in low-income housing programs; to create a special financing program with subsidized interest rates only for lower income households; to add the PVDG systems in utilities' energy efficiency programs; to give the opportunity to lower income consumers to decide between the social subsidized tariff and a plan with PVDG panels in which part of the energy generated is deducted from their electricity bill and the other is used by the utility. These policy options would give the opportunity to make PVDG accessible and electricity services more affordable, giving more

comfort and opportunities for lower income households. In Chile and Mexico, where neighborhood factors seem to be more significant, it would be interesting to have a program in which some selected consumers per neighborhood receive a PVDG system. This policy would help disseminate more information about PVDG among the population. In addition, considering the information level about PVDG, it would be worth considering the strategy of implementing a huge publicity campaign to inform consumers about opportunities related to PVDG and the existing incentive policies and financing options for these households.

In summary, the possible reinforcement of socioeconomic disparities due to PVDG incentive policies (especially the use of net-metering/net-billing in combination with volumetric electricity tariff) has been a hot topic in recent years. However, the lack of socioeconomic details about PVDG adopters in LAC countries did not generate enough evidence to prove this hypothesis. Therefore, the main contribution of our work was to develop a proxy to assess the socioeconomic profile of PVDG adopters, crossing the information available in PVDG' adopters register database with the socioeconomic information collected at the household surveys. The biggest challenge of this methodology was that of manipulating data with different levels of granularity. For example, PVDG adopters' register database offers individual-level information, while the information of household surveys is statistically significant to describe at most the municipal or regional levels. Therefore, to make a step further in the analysis, we should be able to assess the real impact of PVDG policies on socioeconomic inequality through a more granular lens, perhaps through the application of a survey administered only to PVDG adopters in LAC. With this collection of primary data, it would be possible to effectively analyze the impact of specific programs on the adoption's heterogeneity and on socioeconomic inequality in each country and then, to make an international comparison.

Finally, in recent years LAC has been creating a solid regulatory framework and PVDG incentive policies to bring light and empowerment to consumers who can afford to install solar panels. However, those policies can become detrimental to consumers in more vulnerable conditions, since without specific support programs, there is a risk they would miss out on the benefits of the energy transition. Therefore, actual PVDG policies should be complemented by other programs that make the PVDG system affordable and accessible for consumers with a lower income, those with fewer years of education, and those who live in rural areas. Such policies can help assuage the differential rates of adoption that arise from the social and geographical heterogeneity of potential adopters. Metaphorically, this is the only way to ensure PVDG policy and regulation would be able to shed light on PVDG as a part of the energy transition.

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ANNEXES

Annex A1. PVDG Programs in LAC

Table A1. Main Financing Mechanisms of DG Programs and Funds in LAC Countries [26]

Country	Program/Fund	Description
Argentina	FANSIGED [27]	Created under Law 2742, the program focuses on supporting firms to develop equipment, certification, research, and other supports to improve DG. Channel: Others (mainly fiscal incentives).
	FODIS [28]	Created under Law 27424, it supports DG projects—Channel: loans, subsidies, and other (research, education, etc.).
Bahamas	SSRG [29]	Created under the Electricity Act, 2015, the program allows households and small firms to connect to the grid and sell their surplus. Channel: Other (education, information, etc.).
Barbados	TC [30]	Technical Cooperation (TC) between the government of Barbados and IADB to promote renewable energy. Channel: Mainly financing.
Bolivia	PEERR II [31]	Created under a partnership between Germany (GIZ) and Bolivia, the program has many objectives, one of which is to study the feasibility of DG in the country. Channel: Other (research or education among others).
	ProDG [32]	Created by The Ministry of Mines and Electricity, the program promotes DG in many sectors, mainly using solar PV. Channel: subsidies and others (e.g., lower interest rates for loans).
	TC	Partnership with the IADB to improve EE and distributed generation adoption in municipalities. Channel: Mostly financing.

26. Here, some of the general programs are included because they also include solar energy in their targets. As we can see from Table A1 (in Annex A1), most of the countries in the LAC region are promoting solar energy.
27. https://www.argentina.gob.ar/normativa/nacional/ley-27424-305179/texto
28. Ibid.
29.https://www.urcabahamas.bs/wp-content/uploads/2018/06/SOR-and-FD_Bahamas-Power-And-Light-Limited%E2%80%99s-Small-Scale-Renewable-Generation-Plan-.pdf
30. http://idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=1866829
31. https://la-paz.diplo.de/blob/2139562/6ddf91d02adae212101eeeab0ebe053b/fact-sheet-energie---peerr-giz-data.pdf
32. http://www.mme.gov.br/documents/10584/0/Relat%C3%B3rio+ProGD+VFINAL+%28SEI%29.pdf/5082ebd8-2391-40d6-965a-57108cbfdde2
33. http://www.guyanareddfund.org/index.php/about-the-grif/fact-sheet
34. http://idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=EZSHARE-256520755-53
35. http://www.diputados.gob.mx/LeyesBiblio/pdf/LTE.pdf
36. https://www.iea.org/policiesandmeasures/pams/mexico/name-148712-en.php

Table A1. Main Financing Mechanisms of DG Programs and Funds in LAC Countries (cont.)

Country	Program/Fund	Description
Chile	Better Home	Created by the Ministry of Housing and Urbanism to promote renewables. Channel: Subsidies
	PPPF	Created by the Ministry of Housing and Urbanism to help households and communities. Channel: Subsidies.
Costa Rica	China Agreement	Created under a China-Costa Rica agreement to buy solar panels. Channel: Financing.
Guyana	GRIF [33]	Created by the Ministry of Housing and Urbanism to promote renewables. Channel: Subsidies.
Honduras	PERLA [34]	Created under a partnership between the government of Honduras and the IADB. The main objective is to provide electricity to rural areas of the country—Channel: Financing.
	FOTEASE [35]	Created as part of The Law of Energy Transition. The fund is dedicated to promoting renewable energy projects in general—Channel: Subsidies, financing, loans, etc.
	ESF [36]	Created by the government to promote research and technology development—Channel: Subsidies, financing, and others.

33. http://www.guyanareddfund.org/index.php/about-the-grif/fact-sheet
34. http://idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=EZSHARE-256520755-53
35. http://www.diputados.gob.mx/LeyesBiblio/pdf/LTE.pdf
36. https://www.iea.org/policiesandmeasures/pams/mexico/name-148712-en.php

ANNEX A2. FINANCING POLICIES FOR SOLAR POWER PLANTS IN LAC

In some countries, laws directed at implementing DG also created specific funds to finance and promote electricity generation. For instance, in Argentina, Law No. 27.424, which regulates DG, created the Fund for DG of Renewable Energy (FODIS for its acronym in Spanish). This fund provides loans and subsidies and grants other incentives and warranties to reduce investment uncertainty [37].

Honduras also has a general fund to promote DG and renewables more generally[38]. The fund for developing electricity generation from renewable energy sources was created in the same decree that regulates DG in Honduras[39]. The idea was to provide the necessary conditions for DG adoption and show the government's commitment to a renewable energy transition. Likewise, when Mexico enacted the Law of Electric Transition[40], the fund for the energy transition and sustainable use of energy (FOTEASE for its acronym in Spanish) served as a booster for renewable energy adoption. This fund is directed to promote DG and any other projects related to renewable energy resources.

In general, the support for DG in LAC comes from government programs that heavily subsidize or fully finance the projects. This financial support is mainly driven by the high initial investment cost of these types of technologies, which necessitate financing be provided. Even though solar and wind energy costs are dropping rapidly, the initial investment cost is a binding restriction that needs to be waived with subsidies or financing for the average household in the LAC region. Governments have identified positive externalities derived from DG, such as less pollution and more awareness of energy consumption, which are among the arguments in favor of these support funds. Table A1 shows the list of countries with general funds to promote DG with renewable energy sources, the program (and its fund), and provides a short description.

These funds are also used toward education about renewables and other types of energy efficiency (EE) programs, like public building light bulb replacements. The four main channels that these programs use are: (1) subsidies, (2) financing, (3) loans, and (4) others. Subsidies imply that the government covers a percentage of the investment (e.g., solar panels or grid connection) and that users usually have to apply for those funds. Conversely, in the case of financing, governments generally assume all the costs associated with the projects and users do not need to apply. Like any other loan, these are a type of financial help that must be refunded within a period. Users normally have access to preferential rates to make these loans more attractive. Finally, other channels cover mechanisms that are not included in the other three categories, such as fiscal incentives, education consultancy programs, and research, among others.

The government finances most of the programs and funds through taxes and other public budget sources. The programs listed in Table A1 in Annex A1 are exclusive programs that mention DG as one of their objectives, without detailing the specific renewable energy source targeted. In the next section, we review the programs and funds in the countries focused on in this study.

37. To review the law, refer to https://www.argentina.gob.ar/normativa/nacional/ley-27424-305179/texto
38. In this context, "general fund" will refer to a fund that has no specific requirement for the type of renewable energy source, or that can be used for other purposes – for example, educational, advertisement and consultancy -- besides projects.
39. To review the decree, refer to http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/laws/4269.pdf
40. To review the law, refer to http://www.diputados.gob.mx/LeyesBiblio/pdf/LTE.pdf

Table A2. Programs for Solar Energy in LAC Countries

Country	Program/Fund	Description
Argentina	FODIS	Created under Law 27424, it supports DG projects—Channel: loans, subsidies, and others (research, education, etc.).
	FANSIGED	Created under Law 2742, the program focuses on supporting firms to develop equipment, certification, research, and others, to improve DG. Channel: Others (mainly fiscal incentives).
	PERMER (I and II) [41]	Created by the Treasury Department to increase rural electrification. Channel: Mainly financing.
	PDS [42]	Created by the Ministry of Production to improve suppliers' efficiency. Channel: Subsidies and others.
Bahamas	SSRG	Created under the Electricity Act, 2015, the program allows households and small firms to connect to the grid and sell their surplus. Channel: Other (education, information, etc.).
	ISEP [43]	This project is in cooperation with the IADB to promote renewables and EE policies in the Bahamas. Channel: Financing.
Barbados	TC	Technical Cooperation (TC) between the government of Barbados and IADB to promote renewable energy. Channel: Mainly financing.
	PSSEP [44]	Agreement among Barbados, IADB, and the European Commission to promote renewables in the public sector. Channel: Mainly financing.
Belize	BREA [45]	Under the Public Utility Commission, Ministry of Energy, auctions to ensure electricity supply.
Bolivia	PEVD [46]	Created by the Ministry of Energy to reach full access to electricity in Bolivia. Channel: Mainly financing.
	AFEM [47]	Under PEVD, focused on the region of Pando, to provide electricity. Channel: Mainly financing.
	CASL [48]	Project financed by FONPLATA to help communities in rural areas. Channel: Financing.
	PERER [49]	Financed by donation of the Nordic Fund for Development (FND) to support renewables. Channel: Financing.
Brazil	ProDG	Created by the Ministry of Mines and Electricity. The program promotes DG in many sectors, mainly using solar PV. Channel: subsidies and others (e.g., lower interest rates for loans).
	FEN [50]	Provisional mandate 677/15, to supply energy to the northeast region. Channel: Subsidies and financing.

41. https://www.argentina.gob.ar/sites/default/files/manual_operativo.pdf
42. http://servicios.infoleg.gob.ar/infolegInternet/anexos/260000-264999/263853/norma.htm
43. http://idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=EZSHARE-2056220512-5381
44. http://www.energy.gov.bb/web/license-area-block-map/264-public-sector-smart-energy-program
45. http://www.bel.com.bz/files/request_for_proposals_for_electricity_generation.pdf
46. https://www.pevd.gob.bo/prensa/noticias/181-el-pevd-contribuye-a-la-cobertura-del-servicio-electrico-en-el-area-rural-de-bolivia
47. https://www.pevd.gob.bo/nosotros/componentes/198-afem
48. https://www.pevd.gob.bo/nosotros/componentes/200-fonplata
49. https://www.pevd.gob.bo/nosotros/componentes/195-perer
50. https://www.camara.leg.br/noticias/471884-mp-cria-o-fundo-de-energia-do-nordeste/

Table A2. Programs for Solar Energy in LAC Countries

Country	Program/Fund	Description
Chile	PPPF [51]	Created by the Ministry of Housing and Urbanism to help households and communities. Channel: Subsidies.
	Better Home [52]	Created by the Ministry of Housing and Urbanism to promote renewables. Channel: Subsidies.
	SNRED [53]	Created under the 2013 Budget Law to help non-conventional energy and new transmission lines. Channel: Subsidies.
	TSP [54]	Created by the Ministry of Energy to promote renewables in public buildings. Channel: Financing.
	PV [55]	Created by the Ministry of Agriculture to help sustainable irrigation systems. Channel: Subsidies and financing.
Colombia	FENOGE [56]	Created under Law 1715 to promote the development of renewable energy. Channel: Subsidies and financing.
Costa Rica	China Agreement [57]	Created under a China-Costa Rica agreement to buy solar panels. Channel: Financing.
Dominican Republic	ECO RAS [58]	In charge of the Social Subsidies Administration to promote renewables. Channel: Subsidies and financing.
Ecuador	PERVA [59]	Partnership among Organización Latinoamericana de Energía (OLADE), Organización de las Naciones Unidas para Desarrollo Industrial (ONUDI) and government of Ecuador for electrification. Channel: Financing.
El Salvador	PESAE [60]	Under the Program of Energy Efficiency for LAC. Channel: Subsidies and financing.
	PSPV [61]	The loan from the IADB to increase solar energy. Channel: Loan and financing.
Guatemala	PURE [62]	Executed by Fundación Solar with funds from PNUD/GEF to promote renewables. Channel: Mainly financing.
Guyana	GRIF	Created after a 2009 memorandum of understanding between the governments of Guyana and Norway. The fund supports renewable energy projects in general, including research on the feasibility of DG. Channel: Financing.
	UAEP [63]	Guyana government's program with a loan from the IADB to increase electrification. Channel: Financing.
	HREP [64]	It is part of GRIF, created to support energy needs in rural areas. Channel: Financing.
	EcoMicro [65]	Partnership with IADB to promote renewables and EE projects in small and medium-sized firms. Channel: Financing.

51. https://www.leychile.cl/Navegar?idNorma=257828&idVersion=2010-04-01&buscar=DS+255
52. https://www.minvu.cl/hogar-mejor/
53. https://www.iea.org/policiesandmeasures/pams/chile/name-37129-en.php
54. http://www.minenergia.cl/techossolares/?page_id=3565
55. http://www.indap.gob.cl/recursos-h%C3%ADdricos-y-ernc
56. http://www.fedebiocombustibles.com/files/1715.pdf
57.https://www.nacion.com/archivo/china-financiara-paneles-solares-para-que-costa-rica-alcance-el-100-de-cobertura-electrica-en-hogares/AH3S2ALYBBGXNK5DJIAIP5RVKU/story/
58. http://www.adess.gob.do/iniciativas/eco-ras/
59. https://www.renenergyobservatory.org/uploads/media/Ecuador_Producto_3__Esp__02.pdf
60. http://www.pesae.org.sv/index.php?option=com_content&view=category&id=43&Itemid=302
61. https://www.iadb.org/en/project/ES-L1091
62.https://www.undp.org/content/dam/guatemala/02%20Tecnolog%c3%adas%20de%20Energ%c3%ada%20Renovable%20Comunitaria%20son%20posibles.pdf
63. https://www.iadb.org/en/proproj/gy0065
64.https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_RE_Latin_America_Policies/IRENA_RE_Latin_America_Policies_2015_Country_Guyana.pdf?la=en&hash=00A7949FB37278EA4EF4F64B532B787CD00EDB7
65. https://www.iadb.org/en/project/GY-T1150

Table A2. Programs for Solar Energy in LAC Countries

Country	Program/Fund	Description
Haiti	DCE [66]	Partnership with IADB to increase electricity coverage and support low-income households. Channel: Mostly financing.
	SEH [67]	Partnership with IADB to assess the potential of renewables. Channel: Financing.
Honduras	The Fund [68]	Decree no. 70-2007 to promote electricity generation from renewable energy sources. Channel: Subsidies, financing, and others.
	PERLA [69]	Created under a partnership between the government of Honduras and the IADB. The main objective is to provide electricity to rural areas of the country—Channel: Financing.
Mexico	FOTEASE	Created as part of The Law of Energy Transition. The fund is dedicated to promoting projects related to renewable energy in general. Channel: Subsidies, financing, loans, and others.
	FIDE [70]	It is a non-profit organization initiated under the Federal Commission of Electricity (CFE) to support the Program Electricity Energy Savings. Channel: Subsidies and financing.
	SRM [71]	Partnership with Germany (GIZ) to promote solar energy. Channel: Subsidies.
	FUE [72]	Empowered by the Electricity Law of 2014. The main objective is to extend electrification—Channel: Financing.
	LPM [73]	Created by the Ministry of Energy to bring electricity to isolated communities. Channel: Financing.
	Retrofit [74]	Under the Housing National Commission to promote EE and other renewables in households. Channel: Subsidies and financing.
	BDG [75]	Partnership with the IADB to provide credit access to low-income households. Channel: Subsidies and Financing.
Nicaragua	PNESER [76]	Partnership with the IADB to improve electrification. Channel: Mainly financing.
	PERZA [77]	Partnership with the World Bank and Swiss cooperation to provide electricity to isolated rural zones. Channel: Financing.
Paraguay	EURO [78]	Partnership with Europe to provide electricity to isolated public schools. Channel: Financing.

66. https://www.iadb.org/en/project/HA-M1052
67. https://www.iadb.org/en/project/HA-T1176
68. http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/laws/4269.pdf
69. http://idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=EZSHARE-256520755-53
70. http://www.fide.org.mx/?page_id=14828
71. https://www.giz.de/en/worldworl/33516.html
72. http://www.dof.gob.mx/nota_detalle.php?codigo=5355986&fecha=11/08/2014
73. https://realestatemarket.com.mx/noticias/infraestructura-y-construccion/9074-presenta-secretaria-de-energia-programa-luz-para-mexico
74. https://www.iea.org/policies/2689-retrofit-programme-of-sustainable-improvement-in-existing-housing?country=Mexico&qs=mexico
75. https://www.iadb.org/en/project/ME-U0006
76. https://seforall.org/sites/default/files/Nicaragua_RAGA_ES_Released.pdf
77. https://seforall.org/sites/default/files/Nicaragua_RAGA_ES_Released.pdf
78. https://paraguay.justia.com/nacionales/leyes/ley-3557-jul-31-2008/gdoc/

Table A2. Programs for Solar Energy in LAC Countries

Country	Program/Fund	Description
Peru	NPHE [79]	The government of Peru to increase electrification through solar energy. Channel: Financing.
	PEI [80]	Auctions to promote solar energy in rural areas. Channel: PPAs.
Suriname	DRE [81]	Partnership with IADB and Global Environment Facility to promote renewables. Channel: Financing.
Uruguay	FUDAEE [82]	Created under Law 18597 to promote the efficient use of energy. Channel: Subsidies, financing, and others.

The most common channels to support solar energy in the region b are subsidies and financing. Subsidies are more common in South America, while financing is more heavily used in Central America and the Caribbean. South American countries promote solar energy through subsidies partially financed by government budgets (with funds coming from taxes and transfers). The funds that Central American countries have devised are mainly sourced from loans and donations of international institutions, like the IADB, World Bank, OLADE, GIZ, and others.

An important exception of subsidies in South America is when programs target the electrification of rural areas through solar panels. Many countries, such as Bolivia (Program of Electricity to Live with Dignity, PEVD), Paraguay (Euro-Solar Project, EURO), Peru (National Photovoltaic Household Electrification Program, NPHE), and Chile (INDP CNR APR), have made it a policy priority to increase access to electricity using renewable energy sources. In these cases, projects are financed largely by government, either by a re-allocation of their budget, creating new revenues from electricity taxes, or loans from international institutions.

79. https://www.iea.org/policies/161787-national-photovoltaic-household-electrification-program-programa-nacional-de-electrificacion-fotovoltaica-domiciliaria?country=Peru&qs=peru
80. https://www.iea.org/policies/161785-regulation-for-the-promotion-of-electric-investment-in-off-grid-areas-reglamento-para-la-promocion-de-la-inversion-electrica-en-areas-no-conectadas-a-red?country=Peru&qs=peru
81. http://idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=37033449
82.http://www.eficienciaenergetica.gub.uy/documents/20182/22851/Ley18597_Uso_Eficiente_Energia.pdf/8611e9ae-2513-4349-b2c8-341ce8da0419

ANNEX A3. FISCAL POLICIES FOR SOLAR ENERGY PROJECTS IN LAC

Additionally, fiscal incentive policies can act as a complement to the policies mentioned in Annex A2. These are policies defined as a policy, program, or project that aims to promote the use of renewable energy sources or EE programs that do not fall into any of the programs and categories discussed above. The main categories of complementary policies are fiscal incentives (i.e., income tax, import tax, and VAT) and others (e.g., PPAs, feed-in-tariffs, reduction of distribution and transmission costs).

An important factor in promoting renewable energy sources is lowering the barriers to obtain the necessary equipment or qualified labor. In this line, several countries in the LAC region have eliminated the import tax for goods strictly related to the execution, research, implementation, and maintenance of renewable energy projects (for example, the Dominican Republic, Colombia, Barbados and Paraguay). Other countries like The Bahamas have not eliminated this tax, but lowered it from 42% to 10%.

Concerning fiscal incentives to promote renewable energy projects, many countries have exempted individuals and firms from income tax for rents derived from renewable energy projects (e.g., energy transactions and sale of equipment related to renewable energy projects). Countries like Barbados, Dominican Republic, Nicaragua, and Uruguay have a different time frame for the income tax exemption, usually between five and 10 years.

Other fiscal incentives that governments provide focus on accelerated depreciation of assets related to renewable energy projects (e.g., Colombia) and elimination of VAT when buying goods that will be used for renewable energy purposes only (e.g., Barbados, Brazil and Uruguay). Some countries have exempted firms from paying transmission and distribution fees for projects based on renewable energy sources (e.g., Brazil, Chile and Panama).

Table A3 shows the main fiscal incentives that countries in the LAC region provide to promote renewable energy projects. As we can see, Barbados, Brazil, Chile, Costa Rica and Mexico have actively promoted renewable energies through fiscal incentives and other policies. Barbados includes all three types of tax reductions as well as corporate tax reduction. Brazil does not modify income tax but includes PPAs and lower transmission and distribution fees for renewable energy projects. In Chile's case, no taxes are affected by the renewables, but the country includes renewable generation quotas, PPAs, and lower transmission fees for renewable energy projects. Costa Rica reduces import taxes and VAT for EVs and other specific goods related to renewables and particular projects in the country. Finally, Mexico, similarly to Chile, does not modify its tax structure but includes other incentives, like clean energy certificates and accelerated depreciation for goods directly related to renewable energy projects.

Table A3: Fiscal Policies for Solar Energy Projects

Country	Income Tax	Import Tax	VAT	Other
Argentina				Feed-in-tariff.
Bahamas		X		
Barbados	X	X	X	Reduced corporate tax.
Bolivia		X	X	
Brazil		X	X	PPAs. Lower transmission and distribution fees.
Chile				Renewable generation quota. PPAs. Lower transmission fees.
Colombia		X		Accelerated depreciation.
Costa Rica		X	X	Other tax reductions for EVs.
Dominican Republic	X	X		
Ecuador				Feed-in-tariff. Renewable energy preferential dispatch.
El Salvador	X	X		
Guatemala	X	X	X	
Guyana	X	X	X	
Honduras	X	X		
Mexico				Clean energy certificates. Accelerated depreciation.
Nicaragua	X	X	X	
Panama		X		It guarantees electricity buy, and lower distribution and transmission costs.
Paraguay		X		Warranty on investment.
Suriname				Renewable energy purchase guarantee.
Uruguay	X		X	PPAs.

ANNEX A4. DATA ANALYSIS

A4.1. Data Specifications: Plotted Regressions at the Regional Level – Brazil

Figure A4.1.1 Variation of Days Since Regulation between Regions - Brazil

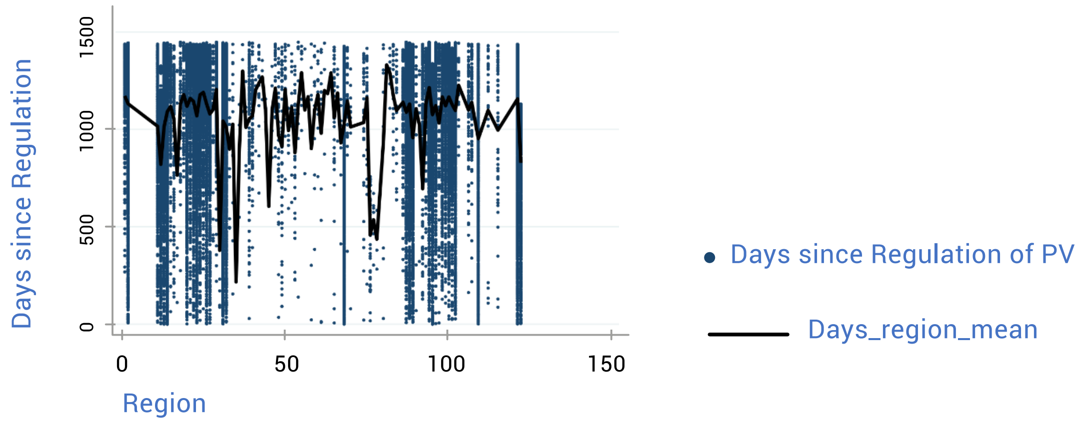


Figure A4.1.2 Plotted Regression Lines at the Regional Level of Days Since Regulation and Income Per Capita USD–Brazil

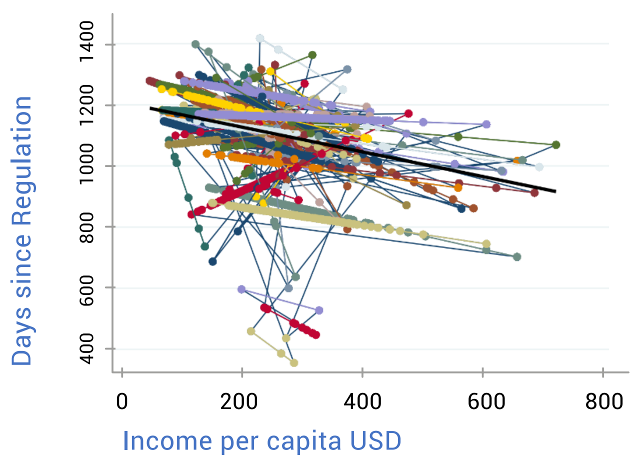


Figure A4.1.3 Plotted Regression Lines at the Regional Level of Days Since Regulation and Average Years of Education–Brazil

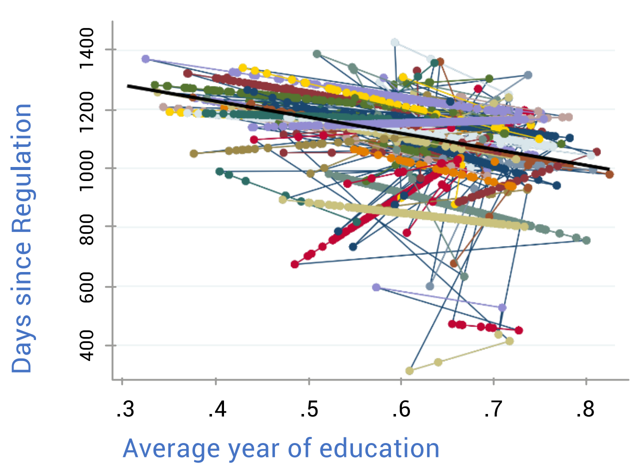


Figure A4.1.4 Plotted Regression Lines at the Regional Level of Days Since Regulation and PV Output per KW Installed–Brazil

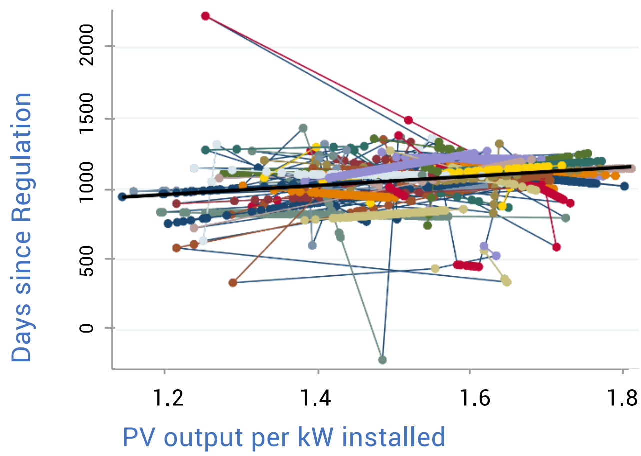


Figure A4.1.5 Plotted Regression Lines at the Regional Level of Days Since Regulation Solar Inequality Gini–Brazil

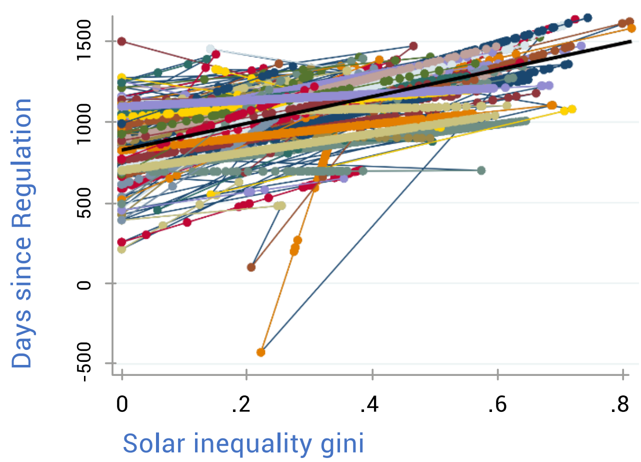


Figure A4.1.6 Plotted Regression Lines at the Regional Level of Days Since Regulation and PV Installed Capacity–Brazil

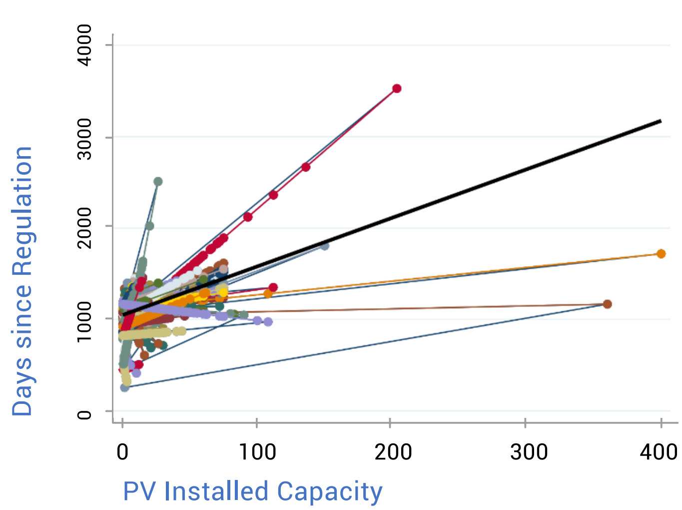


Figure A4.1.7 Plotted Regression Lines at the Regional Level of Days Since Regulation and Inverse Neighbor's Distance–Brazil

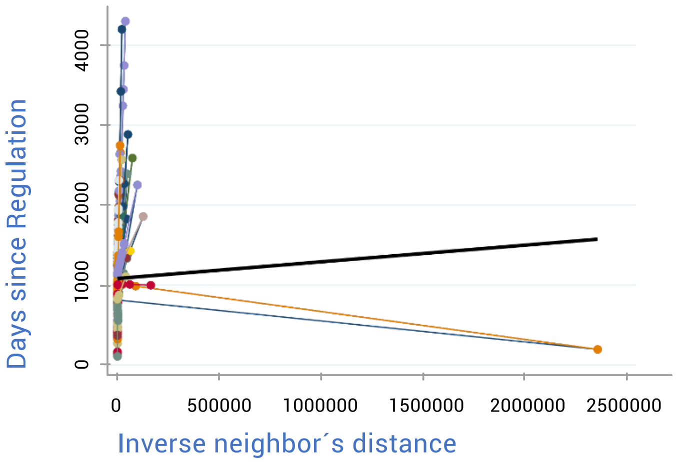


Figure A4.1.8 Plotted Regression lines at the regional level of Days Since Regulation and Neighbor's Installed Capacity–Brazil

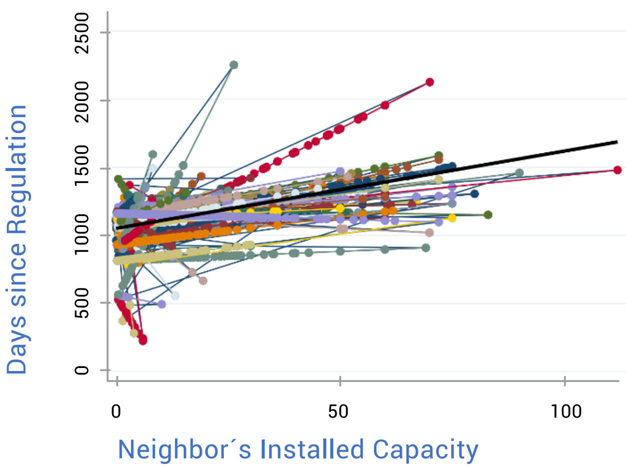
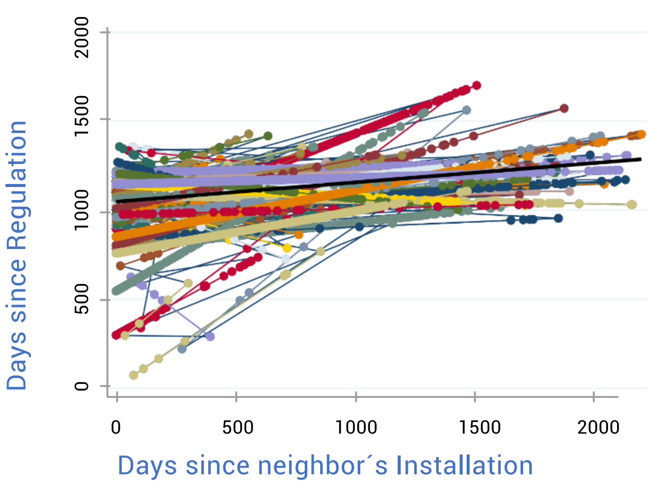


Figure A4.1.9 Plotted Regression Lines at the Regional Level of Days Since Regulation and Days Since Neighbor's Installation–Brazil



A4.2. Data Specifications: Plotted Regressions at the Regional Level – Chile

Figure A4.2.1 Variation of Days Since Regulation between Regions - Chile

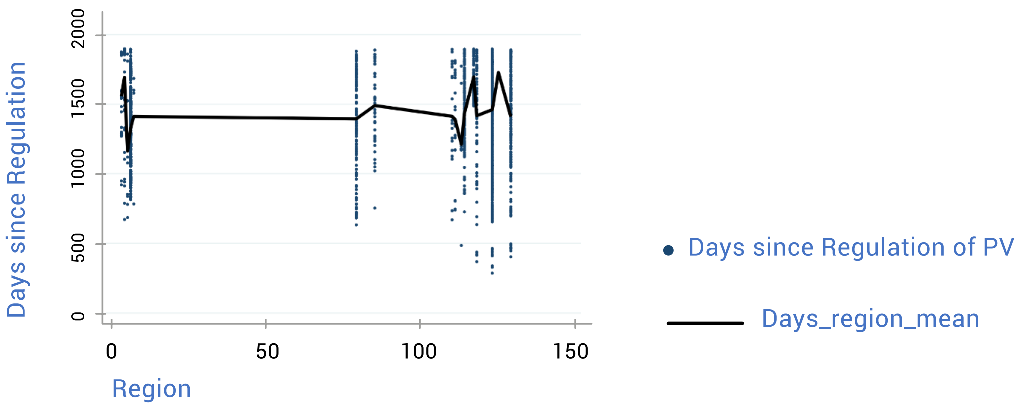


Figure A4.2.2 Plotted Regression Lines at the Regional Level of Days Since Regulation and Income per Capita USD–Chile

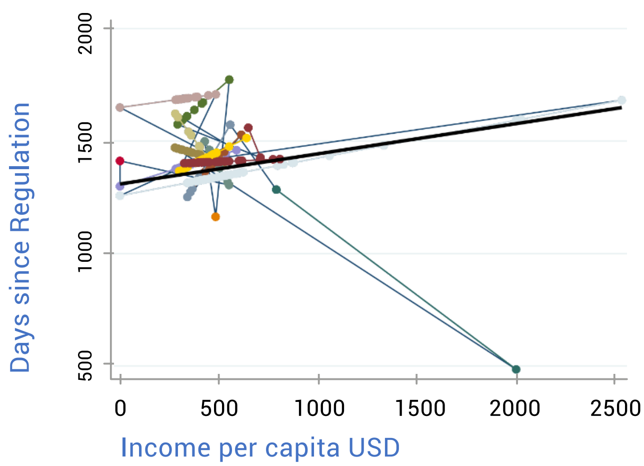


Figure A4.2.3 Plotted Regression Lines at the Regional Level of Days Since Regulation and Average Years of Education–Chile

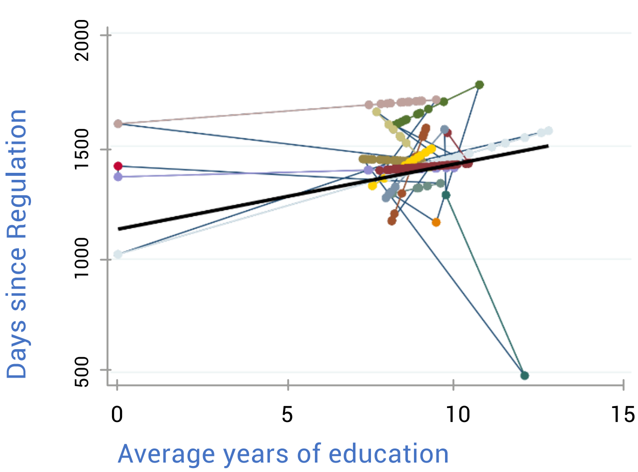


Figure A4.2.4 Plotted Regression Lines at the Regional Level of Days Since Regulation and PV output per kW Installed–Chile

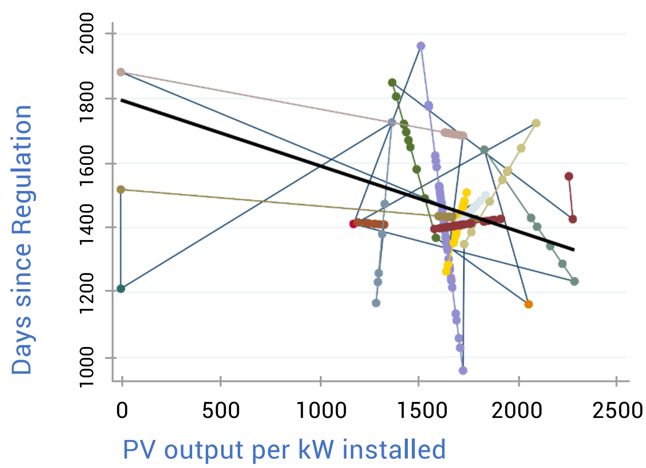


Figure A4.2.5 Plotted Regression Lines at the Regional Level of Days Since Regulation and Solar Inequality Gini–Chile

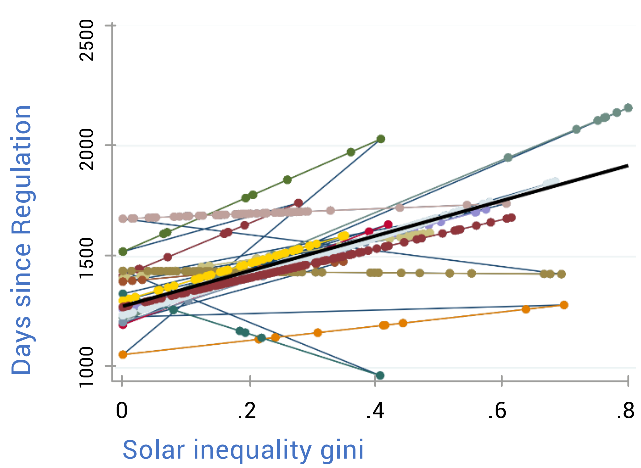


Figure A4.2.6 Plotted Regression Lines at the Regional Level of Days Since Regulation and PV-Installed Capacity–Chile

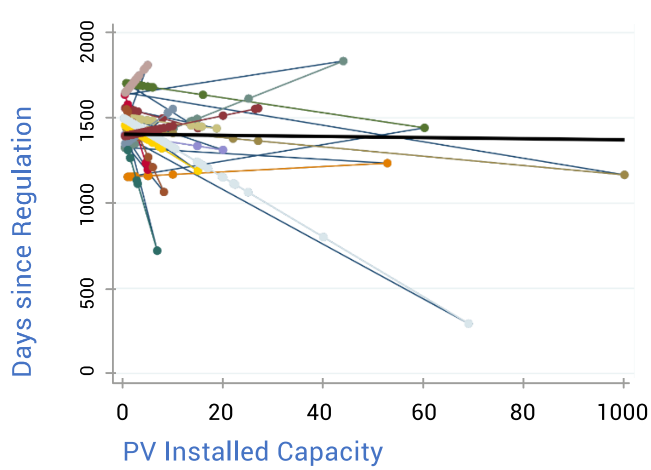


Figure A4.2.7 Plotted Regression Lines at the Regional Level of Days Since Regulation and Inverse Neighbor's Distance–Chile

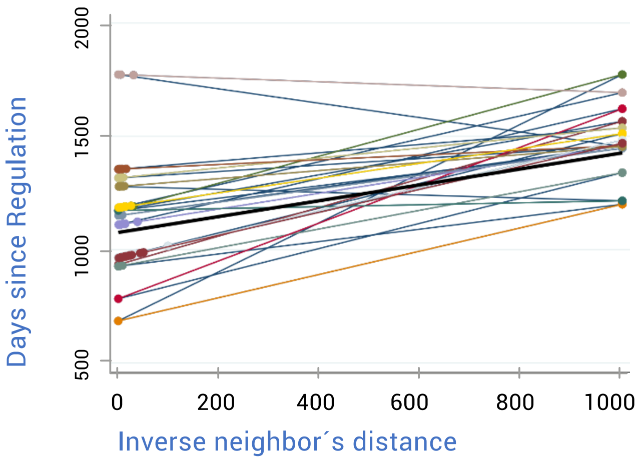


Figure A4.2.8 Plotted Regression Lines at the Regional Level of Days Since Regulation and Neighbor's Installed Capacity–Chile

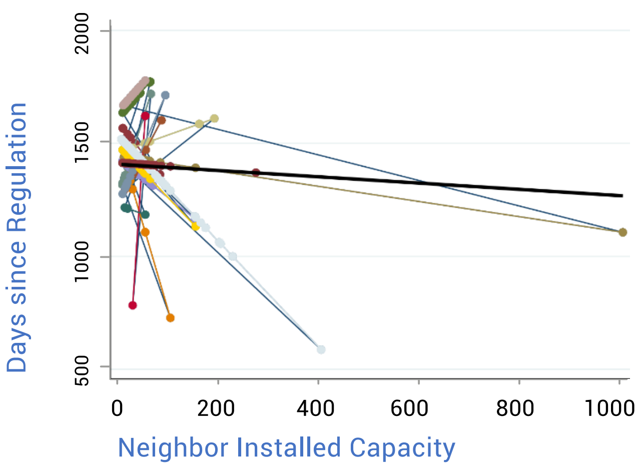
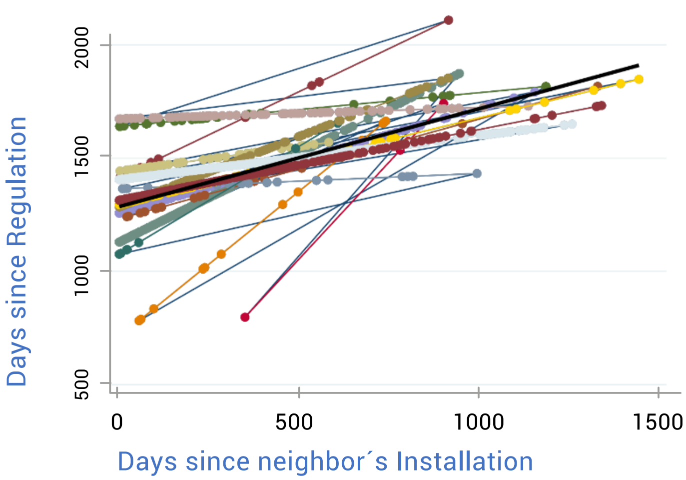


Figure A4.2.9 Plotted Regression Lines at the Regional Level of Days Since Regulation and Days Since Neighbor's Installation–Chile



A4.3. Data Specifications: Plotted Regressions at the Regional Level – Mexico

Figure A4.3.1 Variation of Days Since Regulation between Regions - Mexico

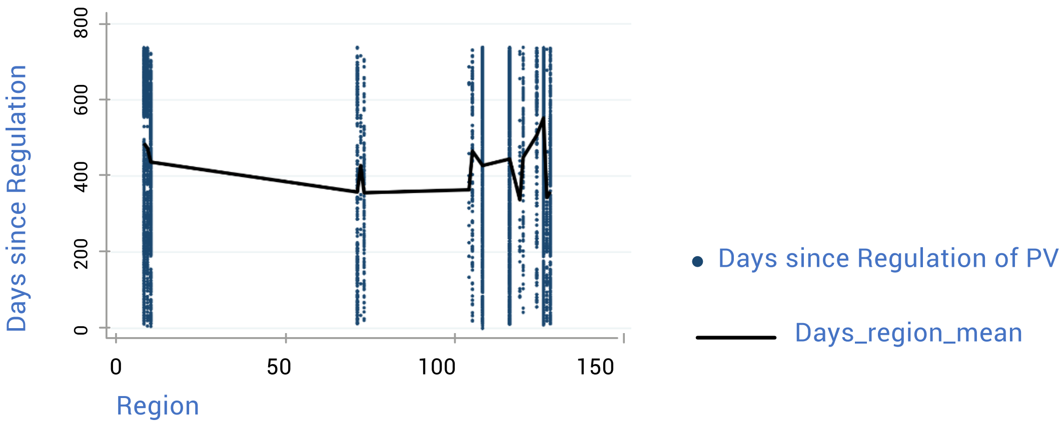


Figure A4.3.2 Plotted Regression Lines at the Regional Level of Days Since Regulation and Income Per Capita USD–Mexico

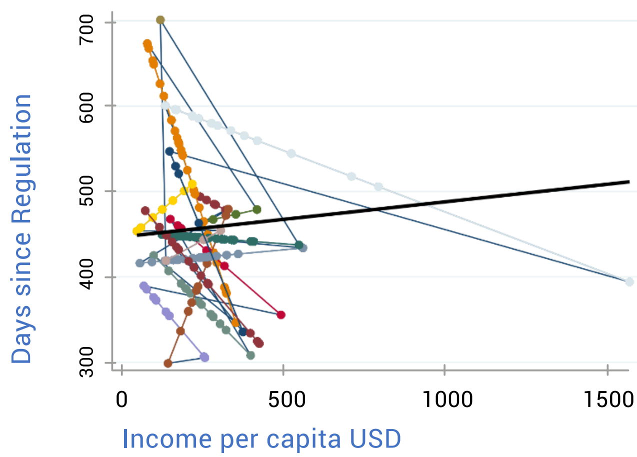


Figure A4.3.3 Plotted Regression lines at the regional level of Days Since Regulation and Average years of Education–Mexico

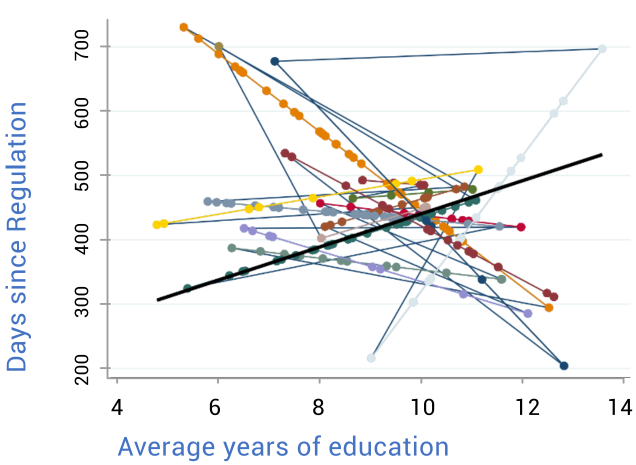


Figure A4.3.4 Plotted Regression Lines at the Regional Level of Days Since Regulation and PV output per KW Installed–Mexico

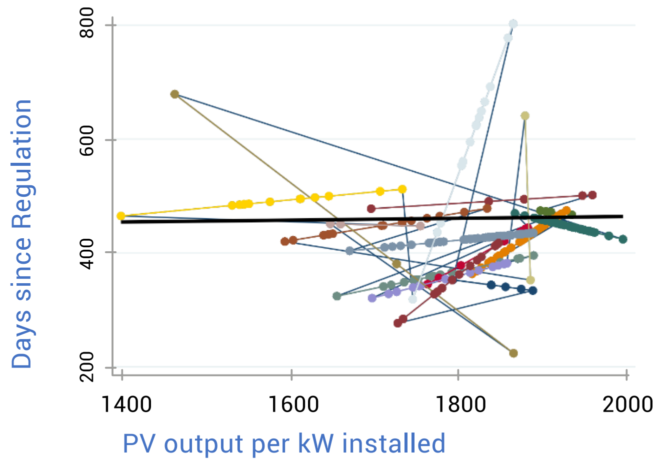


Figure A4.3.5 Plotted Regression Lines at the Regional Level of Days Since Regulation Solar Inequality Gini–Mexico

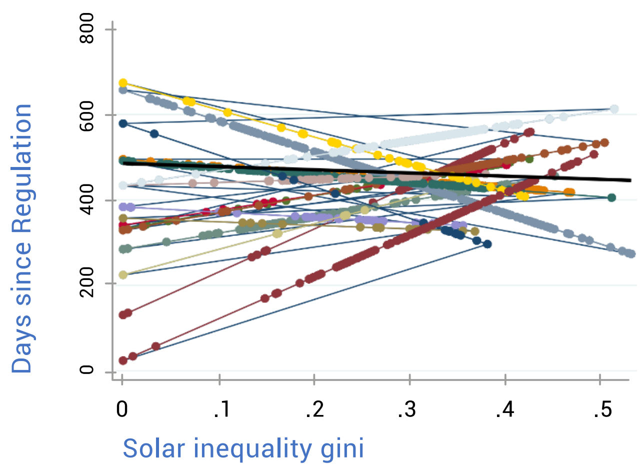


Figure A4.3.6 Plotted Regression Lines at the Regional Level of Days Since Regulation and PV Installed Capacity–Mexico

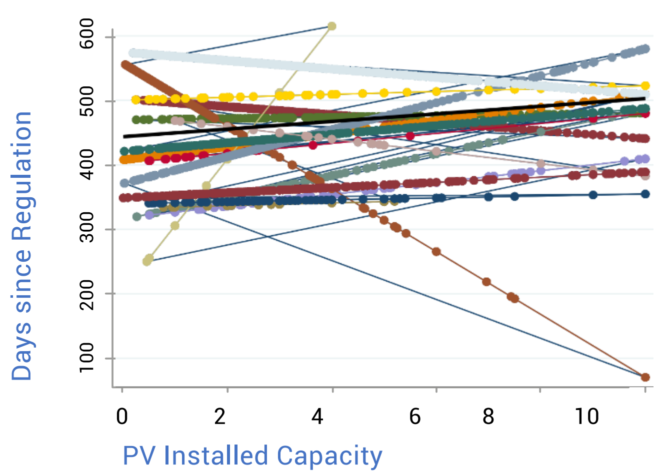


Figure A4.3.7 Plotted Regression Lines at the Regional Level of Days Since Regulation and Inverse Neighbor's Distance–Mexico

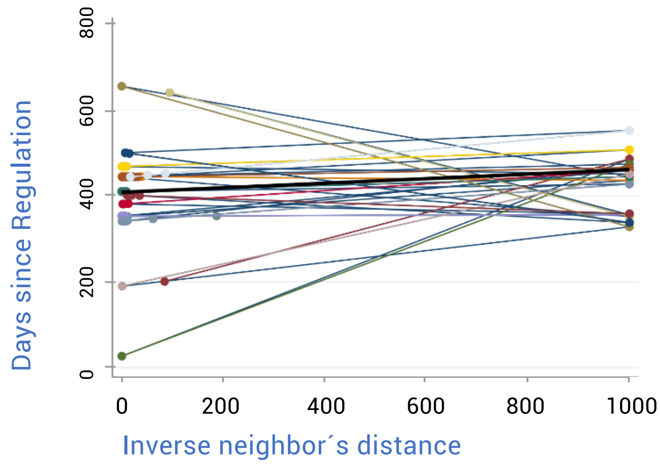


Figure A4.3.8 Plotted Regression Lines at the Regional Level of Days Since Regulation and Neighbor's Installed Capacity–Mexico

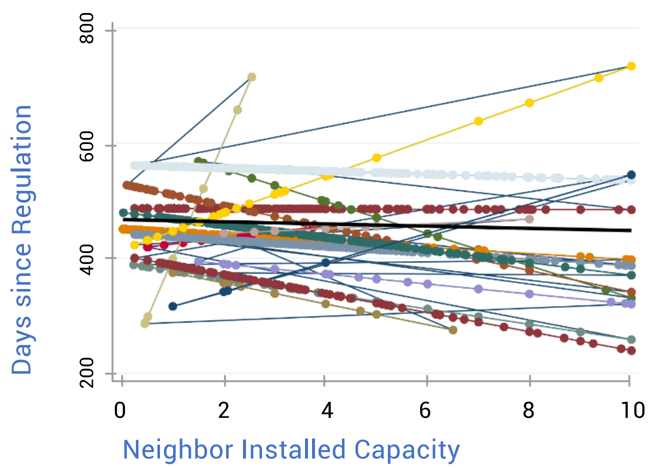
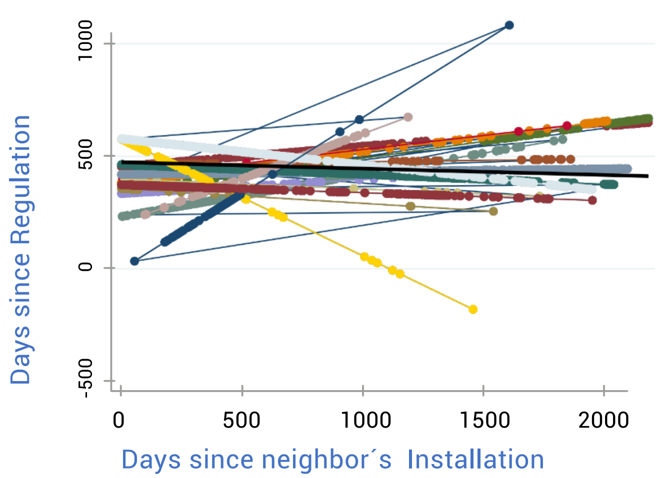


Figure A4.3.9 Plotted Regression Lines at the Regional Level of Days Since Regulation and Days Since Neighbor's Installation–Mexico



A4.4. Data Specifications: Plotted Regressions at the Municipal Level – Brazil

Figure A4.4.1 Variation of Days Since Regulation between Municipalities- Brazil

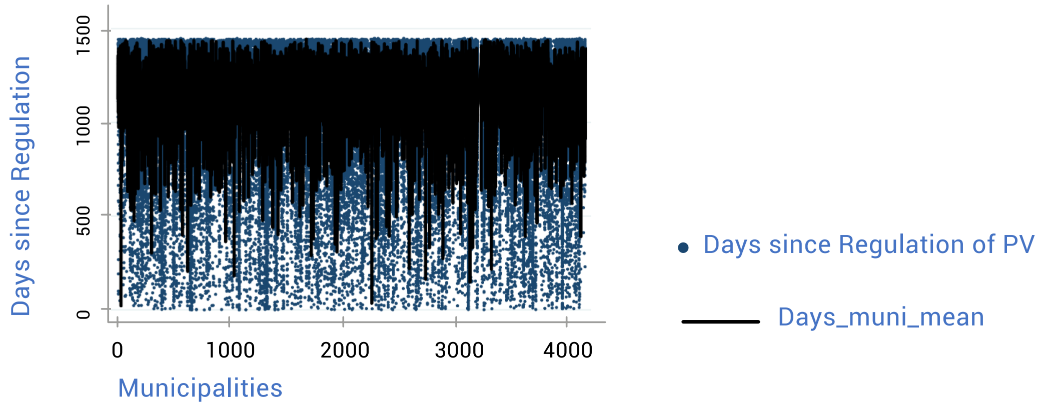


Figure A4.4.2 Plotted Regression Lines at the Municipal Level of Days Since Regulation and PV-Installed Capacity–Brazil

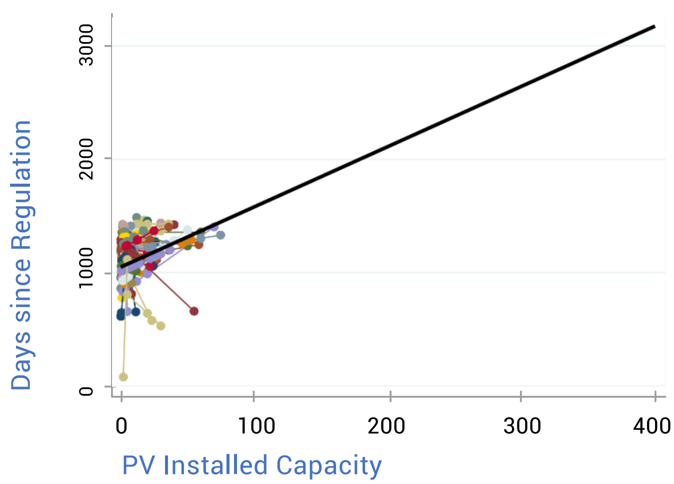


Figure A4.4.3 Plotted Regression Lines at the Municipal Level of Days Since Regulation and Inverse Neighbor's Distance–Brazil

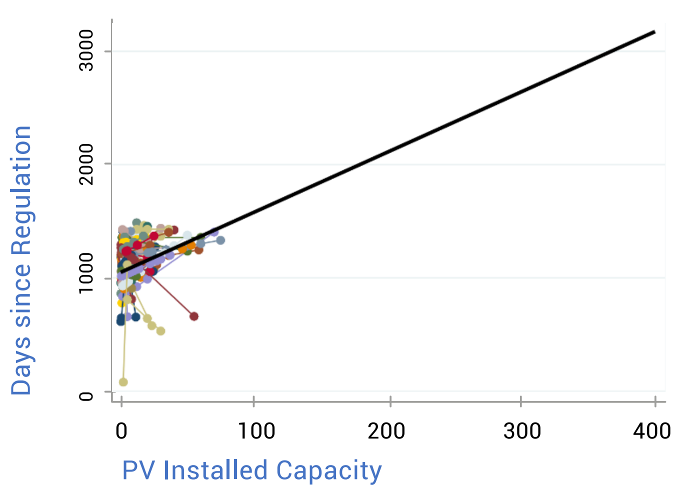


Figure A4.4.4 Plotted Regression Lines at the Municipal Level of Days Since Regulation and Neighbor's Installed Capacity–Brazil

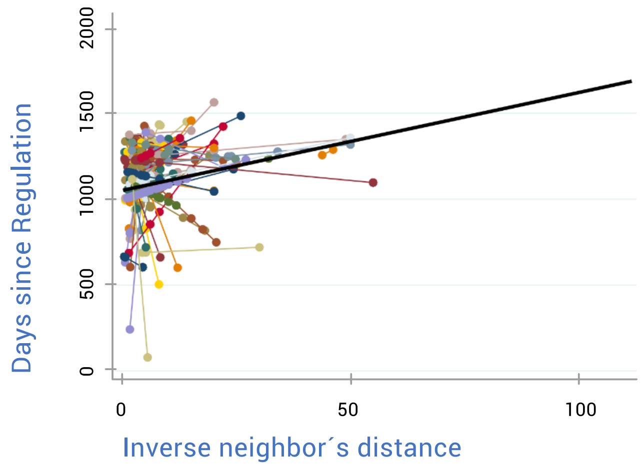
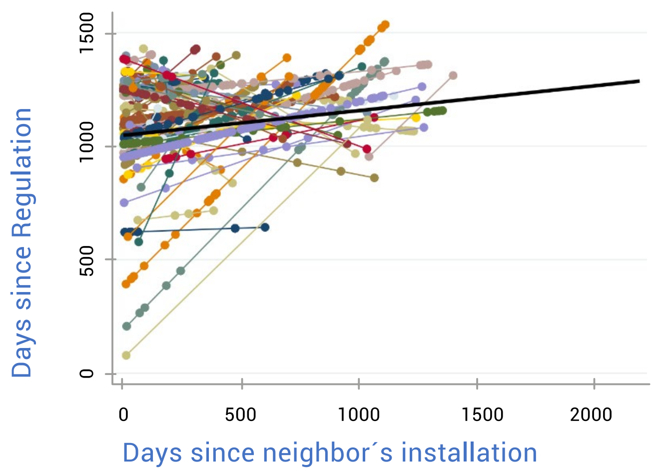


Figure A4.4.5 Plotted Regression Lines at the Municipal Level of Days Since Regulation and Days Since Neighbor's Installation–Brazil



A4.5. Data Specifications: Plotted Regressions at the Municipal Level – Chile

Figure A4.5.1 Variation of Days Since Regulation between Municipalities- Chile

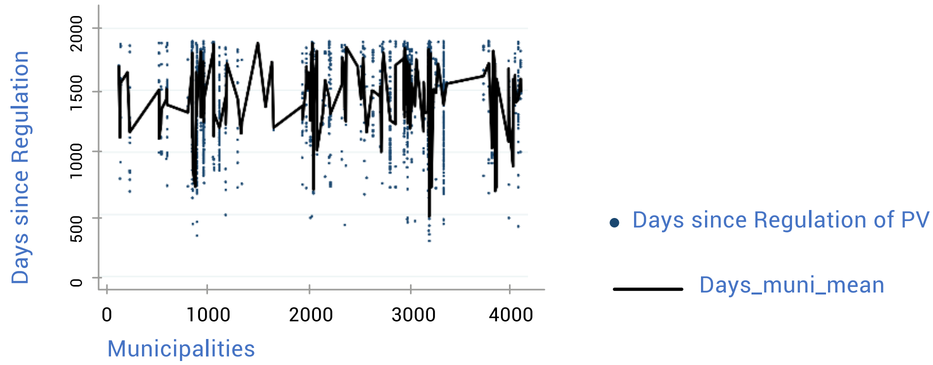


Figure A4.5.2 Plotted Regression Lines at the Municipal Level of Days Since Regulation and PV-Installed Capacity–Chile

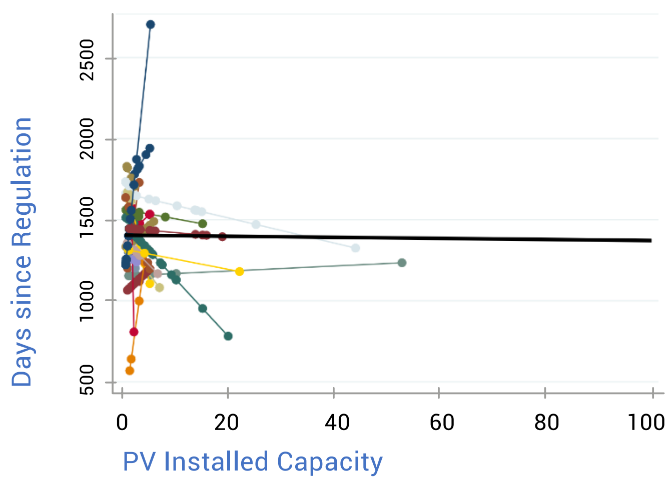


Figure A4.5.3 Plotted Regression Lines at the Municipal Level of Days Since Regulation and Inverse Neighbor's Distance– Chile

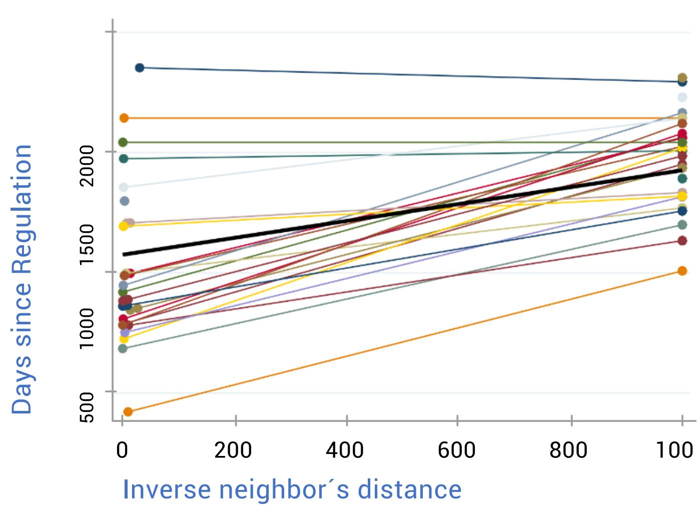


Figure A4.5.4 Plotted Regression Lines at the Municipal Level of Days Since Regulation and Neighbor's Installed Capacity– Chile

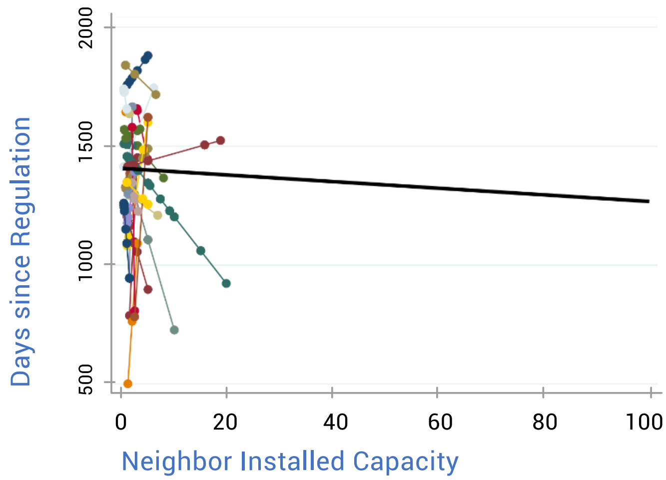
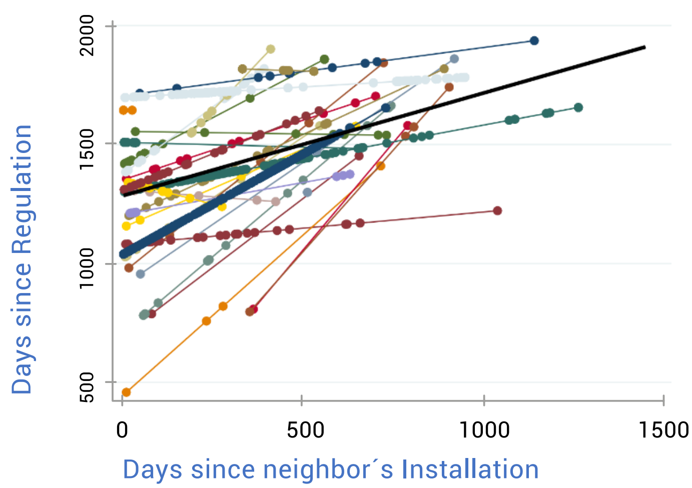


Figure A4.5.5 Plotted Regression Lines at the Municipal lLvel of Days Since Regulation and Days Since Neighbor's Installation– Chile



A4.6. Data Specifications: Plotted Regressions at the Municipal Level – Mexico

Figure A4.6.1 Variation of Days Since Regulation between Municipalities- Mexico

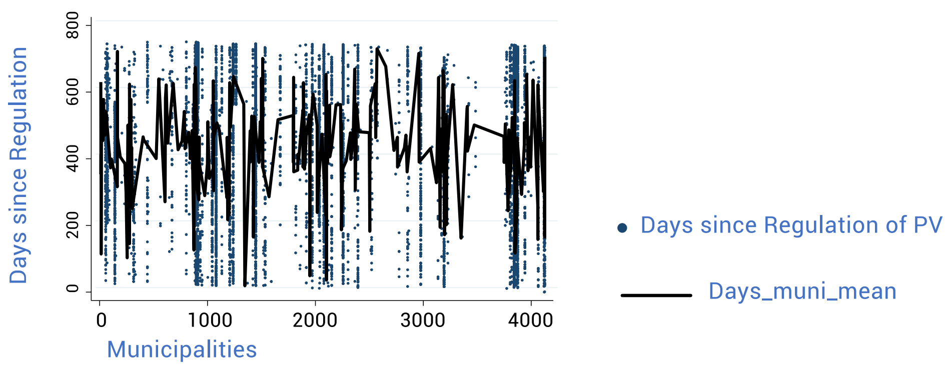


Figure A4.6.2 Plotted Regression Lines at the Municipal Level of Days Since Regulation and PV-Installed Capacity–Mexico

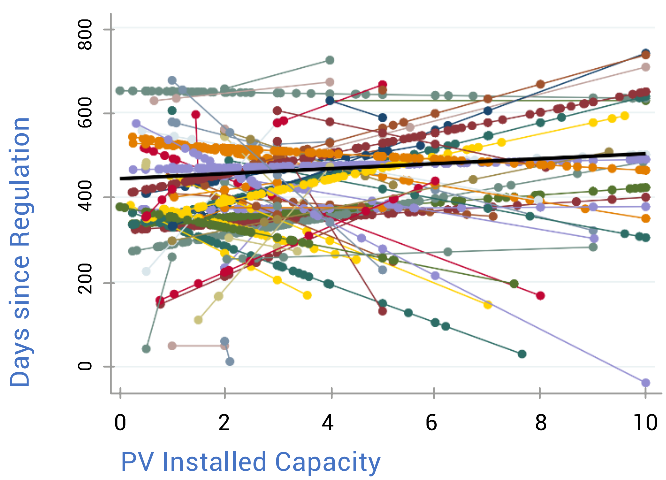


Figure A4.6.3 Plotted Regression Lines at the Municipal Level of Days Since Regulation and Inverse Neighbor's Distance– Mexico

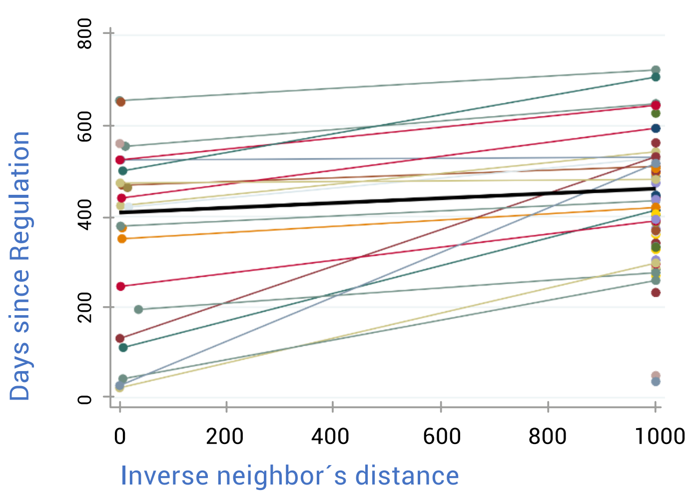


Figure A4.6.4 Plotted Regression Lines at the Municipal Level of Days Since Regulation and Neighbor's Installed Capacity– Mexico

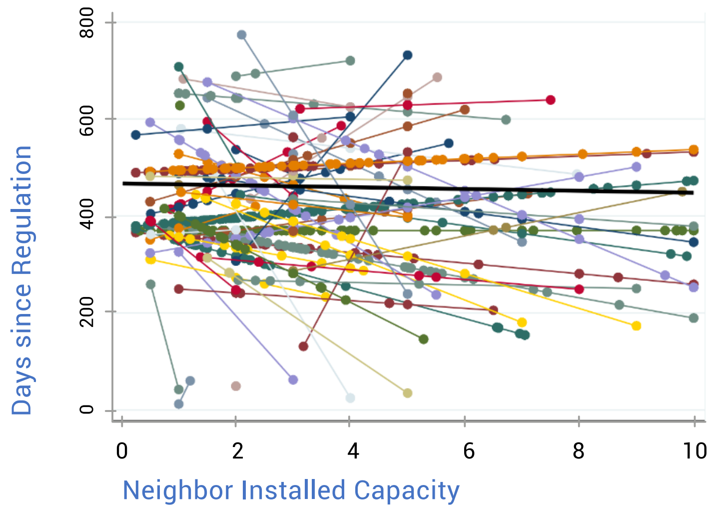
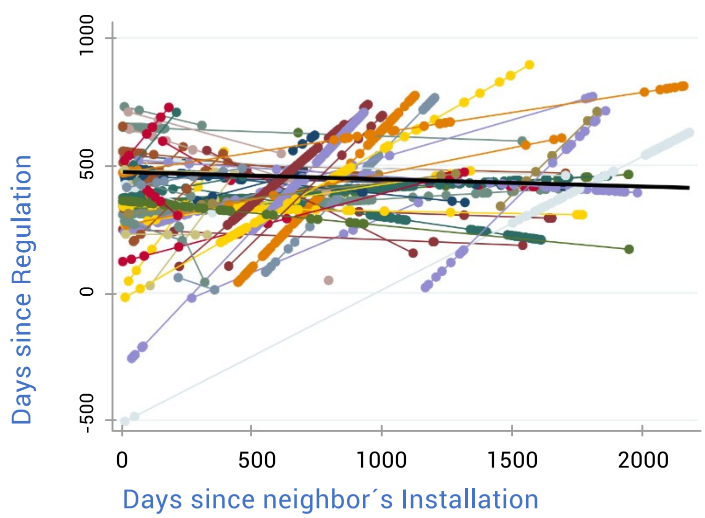


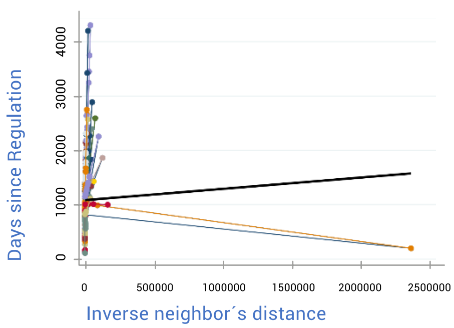
Figure A4.6.5 Plotted Regression Lines at the Municipal Level of Days Since Regulation and Days Since Neighbor's Installation– Mexico



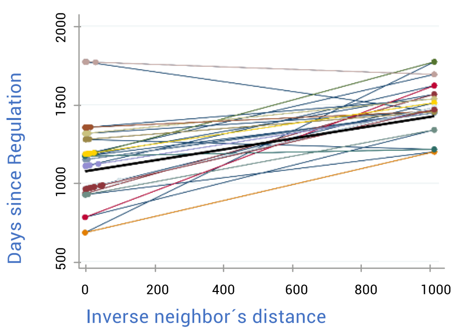
A4.7. Interaction between Days Since Regulation and Inverse Neighbor's Distance at Regional and Municipal Levels

Figure A4.7.1. Regional Random Intercepts and Slopes:
Days Since Regulation and Inverse Neighbor's Distance (Level-1 variable)

Brazil



Chile



Mexico

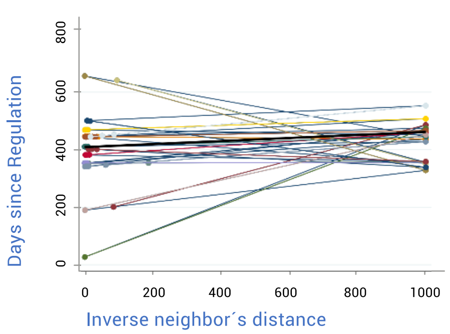
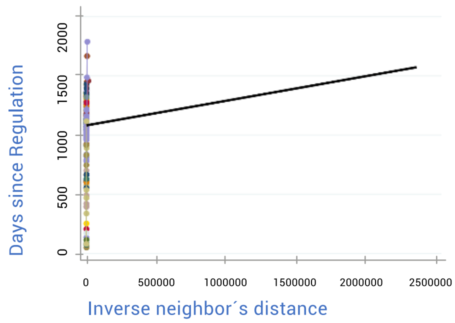
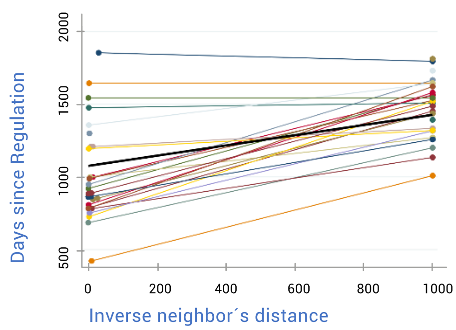


Figure A4.7.2. Municipal Random Intercepts and Slopes: Days Since Regulation and Inverse Neighbor's Distance (Level-1 variable)

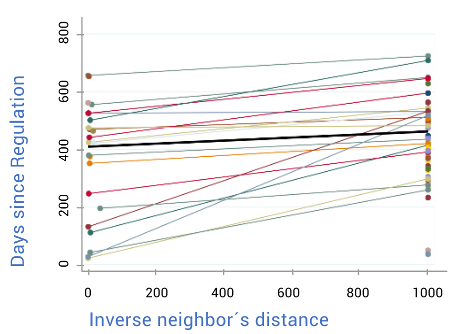
Brazil



Chile

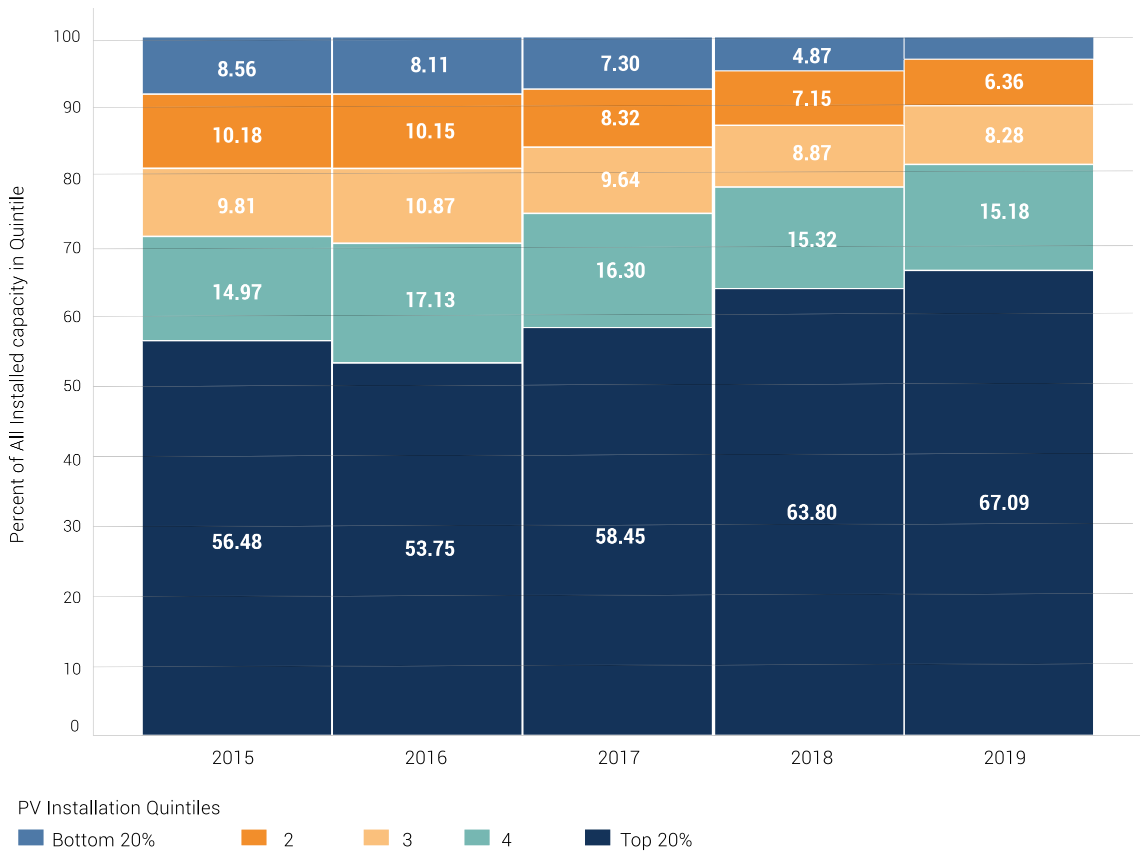


Mexico



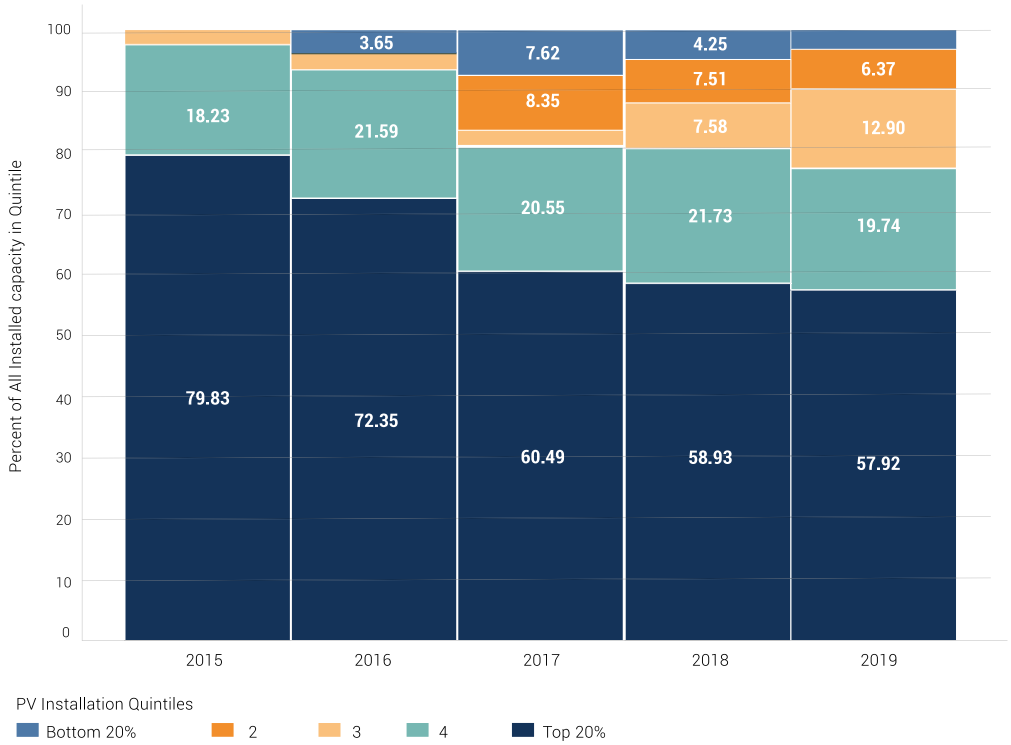
A4.8. Residential Concentration of PVDG Installations

Figure A4.8.1. Residential Concentration of PVDG Installations in Brazil (2015-2019)



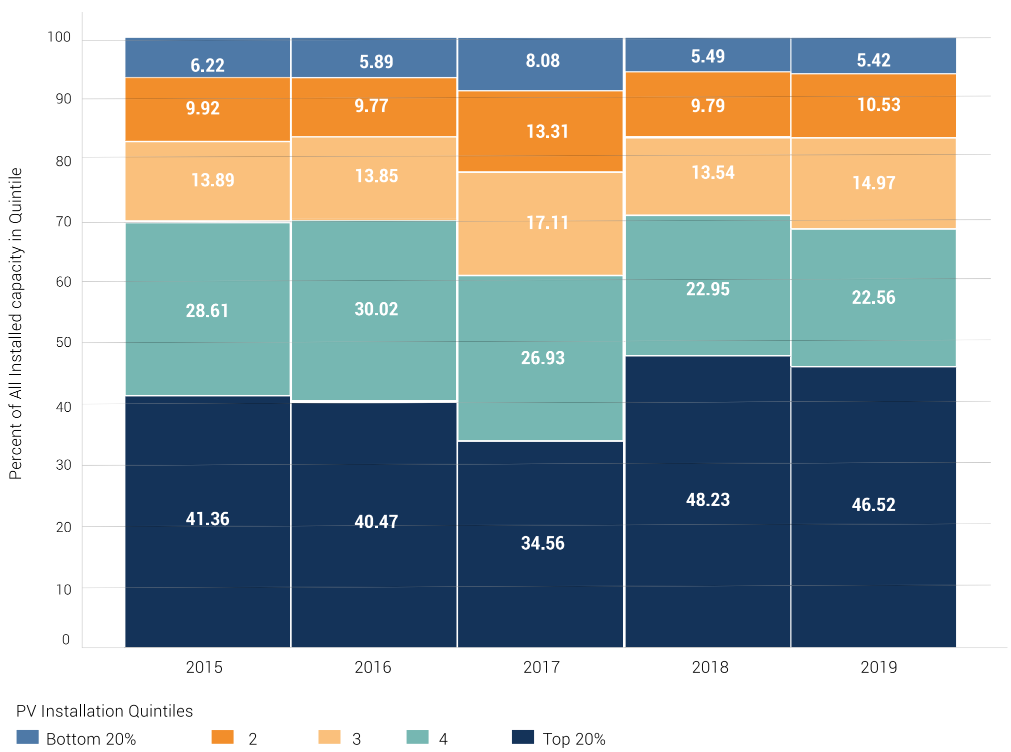
Source: IDB elaboration, with data reported by ANEEL

Figure A4.8.2. Residential Concentration of PVDG Installations in Chile (2015-2019)



Source: IDB elaboration, with data reported by the CNE

Figure A4.8.3 Residential Concentration of PVDG Installations in Mexico (2015-2019)



Source: IDB elaboration, with data reported by the CFE

ANNEX A5. CODEBOOK OF VARIABLES

Variables					Description and Sources by Country		
Code	Name	Subject	Type	Level	Brazil	Chile	Mexico
days_ sincereg	Days since regulation of PV (Dependent Variable)	Regulation	User-written	Individual	Difference between project installation and date of most relevant distributed generation policy/ energy policy. Date:	Difference between project installation and date of most re-levant distributed generation policy/ energy policy. Date:	Difference between project installation and date of most re-levant distributed generation policy/ energy policy. Date:
Cap	Installed capacity of project.	Project characteristic.	Raw data.	Individual.	ANEEL.	Energía Abierta/ Comisión Nacional de Energía (CNE).	Datos Abiertos/ Comisión Nacional de Energía (CNE).
nn_dist	Nearest neighbor distance.	Network (neighbor)	User-written	Individual	Calculated the nearest neigh bor's Euclidean distance to each adopter at the moment of adop-tion using Google API Datum WGS84 to plot geographi-cal coordinates and measure distance.	Calculated the nearest neigh-bor's Euclidean distance to each adopter at the moment of adop-tion using Google API Datum WGS84 to plot geographi-cal coordinates and measure distance.	Calculated the nearest neigh-bor's Euclidean distance to each adopter at the moment of adop-tion using Google API Datum WGS84 to plot geographi-cal coordinates and measure distance.
nn_cap	Nearest neighbor installed capacity	Network (neighbor)	User-written	Individual	Calculated solar PV capacity of nearest neighbor using the nearest neighbor as reference	Calculated solar PV capacity of nearest neighbor using the nearest neighbor as reference	Calculated solar PV capacity of nearest neighbor using the nearest neighbor as reference

Variables					Description and Sources by Country		
Code	Name	Subject	Type	Level	Brazil	Chile	Mexico
nn_diff_days	Days since installation of nearest neighbor	Network (neighbor)	User-written	Individual	Calculated days between the individual installation and the date of its nearest neighbor	Calculated days between the individual installation and the date of its nearest neighbor	Calculated days between the individual installation and the date of its nearest neighbor
inv_nndist	Nearest neighbor distance inverse exponent	Network (neighbor)	User-written	Individual	Calculated the inverse of the nearest neighbor distance to linearize the spatial diffusion effect (increase the effects of shorter distances and decrease the effect of longer distances)	Calculated the inverse of the nearest neighbor distance to linearize the spatial diffusion effect (increase the effects of shorter distances and decrease the effect of longer distances)	Calculated the inverse of the nearest neighbor distance to linearize the spatial diffusion effect (increase the effects of shorter distances and decrease the effect of longer distances)
solar_out	Mean solar raster of municipality	Geographical	Raw data	Municipal	SolarAtlas	SolarAtlas	SolarAtlas
solar_gini	Solar Inequality Gini	Socioeconomic	User-written	Municipal	Calculated Gini coefficient using adopters as population and the cumulative installed capacity in lieu of income at the moment of adoption to measure the distribution of solar PV projects based on their size	Calculated Gini coefficient using adopters as population and the cumulative installed capacity in lieu of income at the moment of adoption to measure the distribution of solar PV projects based on their size	Calculated Gini coefficient using adopters as population and the cumulative installed capacity in lieu of income at the moment of adoption to measure the distribution of solar PV projects based on their size

Variables					Description and Sources by Country		
Code	Name	Subject	Type	Level	Brazil	Chile	Mexico
icapusd	**Income per capita**	Socio-economic	User-written	Municipal	Calculated using IBGE - Censo Demográfico income per capita and multiplied by the survey year's average US dollar exchange rate	Calculated income per capita from national household survey CASEN 2017 by adding sources of income of individuals in households and dividing by the number of members in each household using a household level weight, then multiplied by the survey year's average US dollar exchange rate	Calculated income per capita from national household survey ENIGH 2018 by adding sources of income of individuals in households and dividing by the number of members in each household using a household level weight, then multiplied by the survey year's average US dollar exchange rate
Zone	**Urban/Rural**	Socio-economic	User-written	Municipal	Defined as Urban=1 if 50% or above of IBGE - Censo Demográfico survey respondents identified as living in an urban area, 0 otherwise	Defined as Urban=1 if 50% or above of CASEN 2017 survey respondents identified as living in an urban area, 0 otherwise	Defined as Urban=1 if 50% or above of ENIGH 2018 survey respondents identified as living in an urban area, 0 otherwise
Yrsedu	**Average years of education**	Socio-economic	Raw data/ User-written	Municipal	Calculated by averaging years of education of households from IBGE - Censo Demográfico survey responses of those respondents above the age of 18	Calculated by averaging years of education of household from CASEN 2017 survey responses of those respondents above the age of 18	Calculated by averaging years of education of household from ENIGH 2018 survey responses of those respondents above the age of 18

Variables					Description and Sources by Country		
Code	Name	Subject	Type	Level	Brazil	Chile	Mexico
avgcons	Energy consumption in kWh	Energy	User-written	Regional	Calculated using data from ANEEL of distribution companies of the total electricity consumption of their customers divided by their number of customers to obtain consumption per user and averaged the years between 2017 and 2019	Calculated using data from Energía Abierta/CNE by dividing regional total electricity consumption by the number of electricity users in each region to obtain consumption per user and averaged the years between 2017 and 2019	Calculated using data from Datos Abiertos/CNE by dividing tariff divisions' total electricity consumption by the number of electricity users in each tariff division to obtain consumption per user and averaged the years between 2017 and 2019
Avgtariff	Estimated tariff by sector, month, year $/kWh	Energy	User-written	Regional	Calculated using data from ANEEL of distribution companies of the average of tariffs of the years between 2017-2019 and multiplied by the average US dollar exchange rate of the same years	Calculated using data from Energía Abierta/CNE of the average of tariffs of the years between 2017-2019 and multiplied by the average US dollar exchange rate of the same years	Calculated using data from Datos Abiertos/CNE of the average of tariffs of the years between 2017-2019 and multiplied by the average US dollar exchange rate of the same years
avgspend	Average spending in electricity	Energy	User-written	Regional	Calculated by multiplying avgcons and avgtariff	Calculated by multiplying avgcons and avgtariff	Calculated by multiplying avgcons and avgtariff