BARRIERS AFFECTING DISTRIBUTED SOLAR PV GENERATION IN CHILE: A DEVELOPERS' PERSPECTIVE

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Abstract

Over the past decade, Chile has become one of the most attractive markets for investment in renewable energies. In particular, photovoltaic solar energy from large-scale generators has experience a strong growth in its participation in the Chilean energy matrix. However, despite the high potential of distributed solar PV generation in the country and its potential benefits, the capacity of this segment is comparatively low, evidencing the presence of barriers that hinder its greater adoption and diffusion. In this context, this study investigates the main barriers to the implementation of distributed solar PV projects from the perspective of developers in Chile, through a methodology that consists of two phases. In the first phase, the most relevant barriers to the implementation of projects in this segment are analyzed through surveys completed by the developers of distributed PV generated projects in Chile, who were selected through a non-probabilistic quota sampling technique. Based on these results, the data is prioritized using a multi-criteria decision analysis method known as the Order of Preference for Similarity with the Ideal Solution Technique (TOPSIS). In the second phase, the most critical barriers are analyzed in depth through interviews with industry experts. The results show that the main barriers identified for the greater adoption and diffusion of distributed solar generation are the network structure, its capacity

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and regulation for expansion, the extensive administrative process and the costs of connection to the network, the uncertainty due to prices stabilized by blocks and other regulatory requirements, and the financial structure and financing costs.

Highlights:

Advance of distributed solar PV in emerging countries has been low.

Generation of new data from project developers in distributed solar PV in Chile

Main barriers identified for the greater adoption and diffusion of distributed solar PV projects

Lessons for market players are provided by proposing appropriate policies

Keywords: Distributed solar PV, Barriers, Project developers, Chile

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Introduction

The world energy market has undergone fundamental changes in recent times as a result of the expansion of renewable energies, mainly photovoltaic solar energy (PV), due to the decrease in its costs, new energy policies, and more demanding environmental goals. In 2020, the global PV installed capacity exceeded 714 GW, with a growth rate of around 18% compared to the previous year [1]. According to the projection of the International Energy Agency (IAE), solar energy generation will increase at a faster rate than expected, reaching an installed capacity of 4,600 GW in 2040. This shows that there is a future with a very favorable potential for PV power.

In recent years, the expansion of Non-Conventional Renewable Energies (NCRE) in the Chilean matrix has been significant. In fact, the participation of NCREs in the total installed energy capacity increased from only 5% in 2014 to 30% in August 2021 [2]. Solar PV technology is the most developed among renewables, with an installed capacity corresponding to 16% of the energy matrix. However, it is important to note that unlike other countries where small-scale distributed generation plays an important role, 76% of this capacity comes from utility scale projects. Despite the benefits that distributed solar PV generation can offer, such as low emissions, lower electricity costs, reduction of electrical losses, improvement in the quality of service, and reduction of congestion in transmission lines, the advance of these technologies in the country has been low, is still in a development stage and faces several major obstacles. Currently, the small-scale distributed solar PV segment has a capacity of 1.14 GW, which is very limited despite its high potential of more than 6,000 GW [3]. Therefore, considering the benefits of distributed generation, its potential and high availability of solar resources in Chile, having the highest solar radiation in the world [4], it is relevant to identify and mitigate the main barriers that hinder the advancement of this segment to allow its successful deployment. In this context, this research seeks to establish and analyze the main barriers that affect the implementation of distributed PV projects from the perspective of developers in Chile.

In the academic literature, there are several barrier studies that identify opportunities and factors that influence distributed solar PV adoption in the world. However, most of this research considers only developed and/or large countries, such as the US, Germany and China [5]. In the case of Latin America, few studies have been carried out on the subject. Regarding Chile, most of the works have focused on the analysis of large-scale photovoltaic generation and the few existing studies on small-scale PV generation have focused on evaluations of minor aspects [6-7]. Consequently, there is an important space to contribute to the knowledge and analysis of the main barriers in a comprehensive manner. In this context, we examine the key barriers that influence the implementation of small-scale PV projects in Chile from the perspective of project developers, whose point of view is relevant given their direct involvement in the implementation of distributed generation projects.

One of the main contributions of this study is the generation of new data, from project developers, and its subsequent analysis in order to understand the main barriers that prevent a greater penetration of distributed solar PV projects (Small Distributed Generation Means (PMGD))[5] in Chile. The analysis, based on new data, is a relevant contribution to the literature, to the industry and to policymakers, since it allows them to improve their knowledge regarding the difficulties

[5] According to Chilean regulation, distributed generation composed of Small Distributed Generation Means (PMGD) and residential Net Billing projects. This research focuses on PMGD which are small-scale projects with installed capacity up to 9 MW.

that this segment faces today in Chile. Besides, unlike many studies on barriers, the selection and classification of the barriers in the study has been an industry specific. Additionally, the study uses a known multi-criteria decision-analysis method, the TOPSIS, which can be replicated in other countries to identify and prioritize the main critical barriers for the implementation of distributed solar PV projects. Finally, along with analyzing the most critical barriers, useful lessons for market players and policymakers are provided. In this sense, it contributes to the objective of promoting the development of this segment by proposing appropriate policies and serving as a guide for other developing countries with similar barriers. The discussion of the main barriers for the deployment of distributed PV projects is certainly an important topic, given that many countries want to promote this type of renewable generation, due to its multiple benefits. While barriers to distributed solar PV development and deployment may, in principle, correspond to a specific situation in any region or country, we believe that identifying barriers from the perspective of developers in Chile and discussing their specific characteristics compared to other international experiences, could provide valuable contributions to the literature and to other emerging economies.

This work is structured as follows: Section 2 briefly describes the Chilean electricity market and the development of small-scale PV generation in Chile, including the associated regulation and the stages for the implementation of these projects. Section 3 provides a brief literature review of related works in this research area and studies applied to Chile. The general objective and the specific objectives are presented in section 4. The methodology is presented in section 5. Section 6 provides the results and a discussion regarding the critical barriers identified. Section 7 presents recommendations for project developers and policymakers. Finally, section 8 contains the conclusions.

2. Literature Review

In the academic literature, there are several studies identifying the main barriers to the development of distributed photovoltaic generation, most of them based on case studies of a particular country or region where greater development is observed. In fact, most of the works are related to the US, Germany and China [5], which are precisely the places where the development of distributed photovoltaic solar energy is most advanced in the world. In particular, China and the US represent 10% and 7% of the distributed photovoltaic installed capacity in the world, respectively.

In general, the evidence presented in the different existing case studies allows us to classify the main barriers to greater penetration of distributed generation from the developer's perspectives into five categories: financial and profitability barriers; awareness and behavior; regulatory and institutional; technological and market; and company resources. Table 1 presents the main barriers based on this taxonomy using the different methodologies under different business models.
A first relevant work to mention is that of [8] , who examined the barriers associated with both the two existing business models -where the client is the owner of the installation or that he contracts the service- as well as the financing mechanisms for Distributed Solar PV Deployment in the US and China, doing for this purpose a literature review and interactive research. Their results allow us to identify that, for the case in which the property belongs to the client, the two most important barriers are the initial investment cost and the transaction costs associated with the interconnection to the network. Whereas, in the case where the client contracts the distributed solar energy management service, the three most important barriers are: liquidity risks, potential default and connection risks. Subsequently, Horváth and Szabó [9], analyzed in greater depth the evolution of distributed photovoltaic business models and the main barriers to adoption they face, considering for these purposes the use of strategic management tools. The results of the analysis show that the low profitability of the projects, the lack of financial resources, the lack of information and education of potential adopters, the deficiencies in the legal framework or in government actions, the reliability, stability and efficiency of the network, and lack of business skills are the main barriers to achieving a higher rate of adoption.

Regarding the South American region, the few existing studies focus on Brazil, probably because it is the country with the greatest development of distributed photovoltaic energy with 4.4 GW of capacity [10]. One of the most complete studies for the case of Brazil is that of Bisognin et al. [11], who investigate the main obstacles faced by distributed photovoltaic development in the southern region of Brazil through a systematic review of the literature and semi-structured interviews with professionals in the sector. The analysis allows us to identify that the most relevant barriers include the durability and quality of photovoltaic systems; the high initial cost and access to financing;

consumer culture and lack of adequate knowledge about photovoltaic technology; inefficient after-sales services and negative publicity; and, finally, the dependence on imports and the lack of attractive mechanisms and incentives for consumers. In the case of Chile, there are even fewer studies and most focus on the evaluation of economic and financial aspects of specific distributed solar photovoltaic projects. This is how, for example, San Martín [12] evaluates the technical and financial feasibility of residential photovoltaic generation projects on the roofs of new homes in housing projects developed by real estate companies, using an energy services model (ESCO) for its implementation. The results show a significant number of barriers in different dimensions that hinder the implementation of this type of projects. In particular, the main barriers are the domestic banks' lack of knowledge of this type of business model; the lack of regulatory standards for this type of company; the lack of knowledge to define the business activity code; the payment methodology and tax aspects; the fear of failure; lack of knowledge of the ESCO business model and the return-on-investment time; limited technical staff; and the lack of experience in the domestic market.

Table 1. Barriers to distributed photovoltaic solar generation

Category	No.	Barriers	Methodology	Location/Country/Scope	Font
Financial and Profitability Barriers	1	Lack of financing	Business Model Canvas, Lean Canvas, Interviews	Global, Japan, Germany USA, Brazil, China, Europe.	Horváth and Szabó [9]; Strupeit & Palm [13]; Bisognin et al.[11]; Zhang [8]; Reis et al. [14]; Soysal [15]; Cai et al. [16].
	2	Profitability problems	Business Model Canvas, Lean Canvas	Global	Horvath & Szabo [9]

	3	High initial investment costs	Business Model Canvas, Lean Canvas, Interviews, Surveys, Economic Metrics	Global, Hong Kong, Japan, Germany and the US, Switzerland, Brazil, Thailand, Europe, Brazil, Chile, China, India.	Horváth & Szabó [9]; Mah et al. [17]; Strupeit & Palm [13],; Stauch & Vuichard [18]; Bisognin et al. [11]; Tongsopit et al. [19]; Reis et al. [14] ; Soysal, [15]; Cai et al, [16];
	4	Electricity rate	Business Model Canvas, Lean Canvas, Interviews	Global, Brazil, China; Australia, Europe, Chile	Horváth & Szabó [9]; Bisognin et al. [11]; Zhang et al. [20]; Roberts et al. [21]; Zhang [8]; Reis et al. [14]; Soysal, [15]; Cai et al. [16].
	5	Long amortization periods	Survey, Business Model Canvas, Lean Canvas	Switzerland, Brazil, Europe, Global, China	Stauch & Vuichard [18]; Bisognin et al. [11]; Reis et al. [14]; Cai et al. [16]
Awareness and Behavior Barriers	6	Lack of knowledge	Business Model Canvas, Lean Canvas	Global, Brazil, China	Horváth & Szabó [9]; Cai et al. [16]
	7	Difficulty accessing information	Business Model Canvas, Lean Canvas, Surveys, Interviews	Global, Switzerland, Brazil, Australia	Horváth & Szabó [9]; Stauch & Vuichard [18]; Bisognin et al

					[11]; Roberts et al. [21];
	8	Social Concerns and Barriers	Business Model Canvas, Lean Canvas, Interviews, Surveys	Global, Hong Kong, Japan, Germany and USA, Switzerland, China, India	Horváth & Szabó [9]; Mah et al. [17]; Strupeit & Palma [13]; Stauch & Vuichard [18]; Cai et al., [16];
	9	Lack of information or misinformation about the benefits of distributed energy	Business Model Canvas, Lean Canvas, Interviews	Global, Hong Kong, Europe, Brazil, India	Horváth & Szabó [9]; Mah et al. [17]; Reis et al. [14]; Soysal [15];
	10	Split incentives	Surveys, Interviews	Switzerland, Australia	Stauch & Vuichard [18]; Roberts et al. [21].
	11	Not owning the property	Surveys, Interviews	Switzerland, Australia	Stauch & Vuichard [18]; Roberts et al [21]
	12	Low interest	Interviews, Business Model Canvas, Lean Canvas	Brazil, Europe	Bisognin et al. [11]; Reis et al. [14].
Regulatory and Institutional Barriers	13	Deficiencies of the legal framework	Business Model Canvas, Lean Canvas, Interviews,	Global, Hong Kong, Brazil, Chile, China	Horváth & Szabó [9]; Mah et al. [17]; Bisognin et al [11]; Cai et al. [16]

	14	Unpredictable regulations	Business Model Canvas, Lean Canvas	Global, Brazil	Horváth & Szabó [9]; Bisognin et al. [11]; Zhang [8].
	15	Obtaining permissions and connecting to the network	Interviews, Surveys, Business Model Canvas,	China, Switzerland, Australia, Brazil, Chile	Stauch & Vuichard [18]; Zhang et al. [20]; Roberts et al.[21]; Soysal [15]; Cai et al [16].
	16	Insufficient political support	Interviews, Business Model Canvas, Lean Canvas	Hong Kong, Brazil, Europe	Mah et al. [17]; Bisognin et al [11]; Reis et al.[14]
	17	Lack of planning for distributed generation at the distribution and transmission level	Interviews	China, European Union	Zhang et al.[20]; Botelho et al.[22]
Technological and Market Barriers	18	Network capacity	Business Model Canvas, Lean Canvas, Interviews	Global, Hong Kong, Brazil, China	Horváth & Szabó [9]; Mah et al.[17]; Soysal [15]; Cai et al.[16].
	19	System performance risks	Business Model Canvas, Lean Canvas, Interviews	Overall, Chinese	Horváth & Szabó [9]; Zhang [20]; Bisognin et al.[11]
	20	Limited space	Interviews, Surveys, Business Model Canvas	Hong Kong, Switzerland, Brazil, China	Mah et al.[17]; Stauch & Vuichard,[18]; Bisognin et al.[11]; Zhang et al. [20];

	21	Insufficient market information and existence of monopolies	Interviews, Business Model Canvas, Lean Canvas	Hong Kong, Europe, Brazil	Mah et al. [17]; Reis et al.[14]; Soysal [15]
	22	Lack of skilled labor	Interviews	Australia, Global	Roberts et al.[21]; Bisognin et al.[11]
	23	Need to deploy and reinforce communications and smart metering infrastructure	Business Model Canvas, Lean Canvas	Europe, European Union	Reis et al. [14]; Botelho et al.[22]
Company Resource Barriers	24	Lack of competition	Business Model Canvas, Lean Canvas	Global	Horvath & Szabo [9]
	25	Gaps in the product portfolio	Business Model Canvas, Lean Canvas	Global	Horvath & Szabo [9]
	26	Deficiencies in management and business skills	Business Model Canvas, Lean Canvas, Interviews	Global	Horváth & Szabó [9]; Bisognin et al.[11]
	27	Negative publicity and ineffective marketing approaches	Interviews	Global	Bisognin et al.[11]

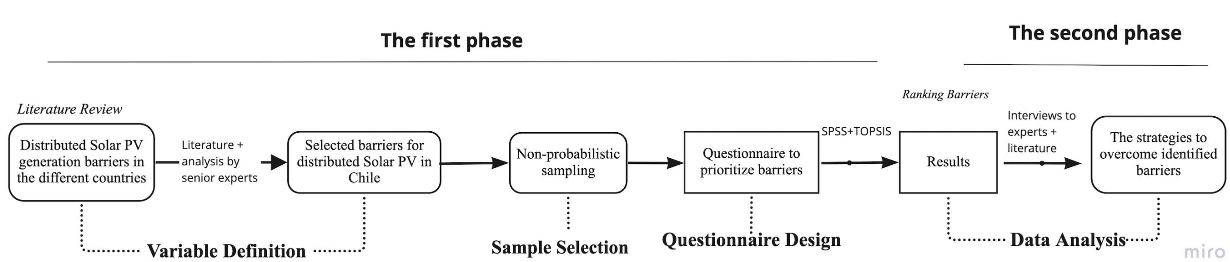
As can be seen from this review of the literature, this line of research is still quite incipient in Latin America, in general, and even more so in Chile, in particular. Most of the studies have also taken a more financial and economic approach, which limits the analysis by not analyzing other non-economic dimensions. In this sense, this work is a contribution that allows for an expansion of the analysis regarding the barriers that prevent a greater development of distributed generation, which has enormous potential in a country with the wealth of solar resources such as Chile.

3. Methodology

The methodology of the study is composed of two main phases. In the first phase, quantitative information is generated on the different most relevant barriers for the implementation of projects in the sector. For these purposes, a survey is carried out on developers of distributed Solar PV projects in Chile, which are selected through the non-probabilistic sampling technique by quotas. This research technique has been widely used in the literature and allows data to be obtained and processed quickly and efficiently [23]. In the second phase, semi-structured qualitative interviews are conducted with experts [8,11, 17, 21] in order to further analyze each of the most critical barriers in depth.

This approach, which considers surveys and interviews, has many advantages. On the one hand, surveys require less time and cost less, so their scope can be greater, and additionally they allow greater objectivity and easy comparison and generalization. On the other hand, interviews allow obtaining detailed answers, so using them in a second stage provides more information regarding the most relevant barriers. The different steps of the methodology, which consist of defining the variables, selecting the sample, designing the questionnaire and analyzing the data, are presented in Figure 1.

Figure 1. **Methodology Stages**



3.1 Variable Definition

The main barriers identified in the literature review provide relevant information with which to start the analysis. However, it is difficult to know to what extent these barriers are specific to a country or region or even more general. For this reason, in order to identify the most relevant barriers in Chile, the largely common barriers found in the international literature were initially considered and a preliminary list of barriers was defined, including those that could be important in the context of the Chilean photovoltaic electricity market. For the latter, information collected from publications in national magazines, conferences and seminars held in Chile on distributed generation and industry documents was used. The preliminary list was tested in a pilot study, made up of several expert professionals with more than 10 years of experience in the industry in order to validate the potentially applicable barriers in Chile. In this way, a definitive list was established with the 12 potentially most critical barriers that could affect the development of distributed photovoltaic generation in Chile, which are grouped into 4 categories (see Table 2).

Table 2. Barriers to distributed photovoltaic solar generation in Chile

Dimension	Code	Barriers
Economic and Financial	A1	PV LCOE Compared to Stabilized Price or Power Price
	A2	Difficulty accessing financing
	A3	Financial structuring and financing costs
Technological and Market	B1	Lack of skilled labor and specialist companies
	B2	Network structure, its capacity and regulation for expansion
	B3	Market adaptability in the face of pressure
Regulatory Policies	C1	Uncertainty prices stabilized by blocks and other regulatory requirements
	C2	Long administrative process and connection costs to the network
	C3	Lack of incentives for new models with storage and flexibility
Social and Environmental	D1	Lack of capacity, channels and tools to link the community
	D2	Long evaluation times and demands in the SEIA[6]

[6] The SEIA (Sistema de Evaluación de Impacto Ambiental) is the environmental evaluation system in Chile, which evaluates the environmental impacts of each project, and then approves, proposes mitigations if necessary or rejects the project.

D3	Lack of information to understand and share social benefits and costs

3.2 Sample Selection

The target population for the survey was defined as: expert professionals who work in the development of distributed solar PV generation projects, considering a representative for each company in the market. Since there is no public information with all the individuals that are part of the population, it was decided to use a non-probabilistic sampling technique based on quota sampling, which guarantees representativeness and ensures the collection of the necessary information for statistical significance of the target groups [24-25]. However, one of the disadvantages of this sampling technique is that, when defining the strata, some strata of the population could potentially be left out of the sample. For this reason, the results of the analysis, while informative and relevant, should be viewed as exploratory and not necessarily representative of the target population.

In order to define the population on which to carry out the non-probabilistic sampling, all the companies associated with the different renewable energy organizations and agencies existing in Chile were considered. From this preliminary list of companies, all the companies that were registered under the same code and subcode of economic activity in the database of the Internal Revenue Service (SII) were considered. As a result, 59 companies developing distributed solar PV projects were identified. Finally, based on the defined population size, the sample size was established, using the following finite sample formula for qualitative studies:

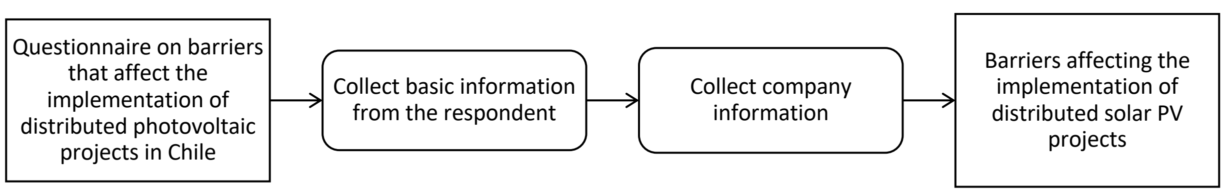
$$n = \frac{NZ^2pq}{d^2(N-1)+Z^2pq} \quad (1)$$

where, p is the approximate proportion of the phenomenon under study in the reference population, q is the proportion of the reference population that does not present the phenomenon under study (1- p), $N$is the size of the population, Z is the critical Z value of a Normal distribution, and finally d is the level of absolute precision or margin of error.

3.3 Questionnaire Design

Questionnaires are a widely used tool to collect expert data on the different factors that influence technologies [24-25]. Precisely with this objective, a questionnaire was designed based on the data collected in the pilot study and considered the institutional and regulatory context of the distributed photovoltaic electricity sector in Chile. Figure 2 shows the structure of the questionnaire, which consists of three parts. The first explains the objectives of the study and collects basic information from the respondents such as position in the company, area of work and education level achieved, among others. The second part collects information regarding the services, projects and business models of the company in which each of the respondents works. Finally, the third part seeks to identify the most important barriers for the implementation of distributed solar PV projects. For this, the respondents had to evaluate the relevance of each of the different barriers using a 5-point Likert scale, where 1 = "extremely unimportant", 2 = "somewhat important", 3 = "moderately important", 4 = "highly important" and 5 = "extremely important". In addition, the respondents had the possibility to freely mention and explain other barriers that they considered relevant.

Figure 2. Questionnaire Structure



The questionnaire was sent to all individuals identified as part of the target population via a web link to allow online responses. The survey process continued until the number of responses reached the sample size to obtain a representative sample and allow consistent statistical analysis [26], with a confidence interval of 90% and a margin of error of 0.1 [25]. In the end, a total of 39 representatives of Distributed solar PV energy development companies responded to the survey, thus exceeding the minimum sample size of 33 representatives.

The main characteristics of the respondents are presented in Table 3. As can be seen in the table, the respondents have an average of 10 years of experience in the development of solar photovoltaic projects distributed in Chile. In terms of experience there is quite a lot of heterogeneity, 23% of those surveyed have between 1 and 5 years of experience, 34% between 6 and 10 years of experience, 19% between 11 and 15 years of experience, and 25% have over 15 years. Regarding their role in the industry, 58% of those surveyed are Managers, 11% have a Board of Directors position and the remaining 30% hold other positions such as Consultant or Specialist. Regarding the maximum level reached in academic training, 2% have a professional degree from a technical training center or professional institute, 45% from a university, 11% have a diploma, 38% a master's degree and 4% a doctorate. Finally, regarding the size of the organization, 19% work in a large company, 32% in a medium-sized company, 21% in a small company and 28% in a micro-company.

Table 2. Main characteristics of the respondents

Years of relevant professional experience in the sector:	**Distributed PV solar energy companies**
6-10	31%
+15	28%
1-5	18%
Academic training:	
University Graduate	33%
Master's Degree	49%
Diploma	10%
Position in the Organization:	
Manager	38%
Others (consultant, specialist)	47%
Director	15%
Organization size:	
Medium (25-100 employees)	38%
Micro company (0-9 employees)	15%
Small (10-25 employees)	21%

3.4 Data Analysis

In order to perform a statistical analysis based on the data collected from the survey, the reliability of the classifications is first verified using the Cronbach alpha value. According to Shen et al [5], a Cronbach's alpha value of 0.7 or higher indicates reliable group classifications. Once the reliability of the sample obtained was determined, a multi-criteria decision analysis method known as the Order of Preference for Similarity with the Ideal Solution Technique (TOPSIS) was implemented. TOPSIS is one of the multi-criteria decision-making (MCDM) approach methods based on the fact that the chosen alternative must be the closest to the positive ideal solution and the furthest from the negative ideal solution [27]. In this way, it is possible to rank and prioritize each of the alternatives by comparing the relative distances [28]. The TOPSIS method has been widely used in academic research in various fields of study [29]. The main advantage of the TOPSIS method is its simplicity without losing reliability [30]. Since it is a standard and well-known method, the different steps of the implementation of the TOPSIS methodology are presented in Appendix A.

Finally, in order to discuss how to address the most critical barriers, face-to-face semi-structured interviews are conducted with expert professionals in photovoltaic distributed generation in Chile. Although the interview was based on a set of questions established before the meeting, new questions were incorporated during the interview to better collect the statements made by the interviewee.

4. Results and Discussion

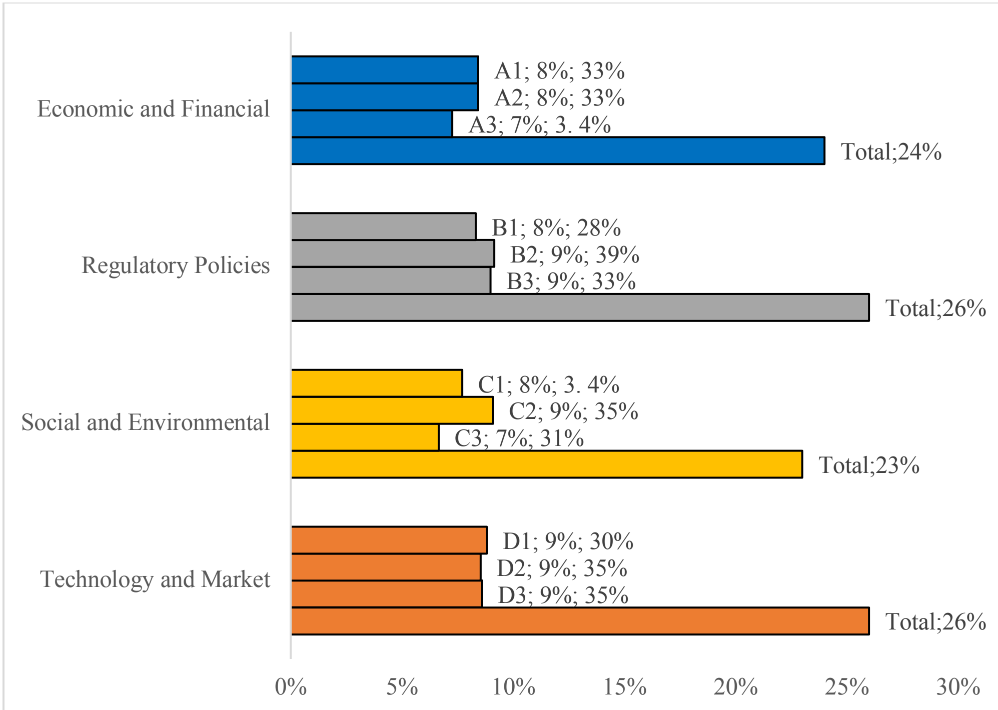
Table 4 summarizes the main results of the analysis on the most relevant barriers that affect the implementation of distributed solar PV projects. As previously mentioned, the data was analyzed using the TOPSIS technique. The results show that the most important barriers that affect the implementation of distributed photovoltaic projects are "The structure of the network, its capacity and regulation for expansion" (B2), followed by "The long administrative process and the costs of connection to the network" (C2), followed by "Uncertainty due to prices stabilized by blocks and other regulatory requirements" (C1) and "Financial structuring and financing costs" (A3). Cronbach's alpha coefficient is 0.796 greater than 0.7, which confirms that the Likert scale of 5 used is reliable.

Table 4. Results on the barriers for the implementation of Distributed solar PV projects

Barriers	TOPSIS	Order
A1: PV LCOE compared to stabilized price or power price	0.46	6
A2: Difficulty accessing financing	0.47	5
A3: Financial structure and financing costs	**0.48**	**4**
B1: Lack of skilled labor and specialist companies	0.38	12
B2: Structure of the network, its capacity and regulation for expansion	**0.51**	**1**
B3: Market adaptability in the face of pressure	0.39	10
C1: Uncertainty of prices stabilized by blocks and other regulatory requirements	**0.51**	**3**
C2: Long administrative process and connection costs to the network	**0.51**	**2**
C3: Lack of incentives for new models with storage and flexibility	0.44	9
D1: Lack of capacity, channels and tools to link the community	0.38	11
D2: Long evaluation times and demands in the SEIA	0.46	7
D3: Lack of information to understand and share social benefits and costs	0.46	8
Cronbach's Alpha		0.877

Figure 3 shows the relative percentage of each barrier and each category with respect to the total. As can be seen, barriers related to Regulatory Policies is the main category, followed by Technological and Market barriers with 26%, followed by Economic and Financial barriers with 24% and finally Social and Environmental ones with 23%.

Figure 3. Ranking of categories and barriers



Based on the results of the survey and then interviews with experts, the four most relevant barriers to the development of distributed solar energy projects in Chile are discussed below.

Structure of the network, its capacity and regulation for expansion

The most critical barrier for the development of Distributed solar PV projects in Chile is related to the network structure, its current capacity and the regulation to allow its expansion. In this context, according to the opinion of experts, as a result of their original design, distribution networks are not technically prepared to connect and receive energy injections from distributed generators. The connection of distributed generation can lead to power quality problems, degradation in system reliability, reduced efficiency, surges, and even safety issues. Distribution networks operate under a radial typology (flow in one direction), while distributed generation requires flows that move in both directions. This type of radial operation is one of the great limitations for distributed generation, given that if faults or voltage drops occur, they affect all downstream consumers and generators. Experts have the opinion that the voltages of the distribution networks in Chile normally work with bands close to the upper limit of operation, which leaves a narrow margin for distributed generators to inject energy. Additionally, the capacity of many lines, substations and/or feeders is limited [31]. Consequently, new distributed projects must incur in high costs to expand network capacity. There are also information problems regarding the capacity and characteristics of the distribution network, potential expansions and potential distributed generation projects, thus limiting the future development of projects in the sector [32]. According to the existing regulatory framework, all distribution companies must keep all the necessary technical information on the distribution network available to any interested party, but there are still distributors that have not made this information available to interested parties and are in breach of the standard.

Some countries, including China, the US and the UK, have implemented support measures to encourage the expansion of these technologies. One of the most developed solutions has been smart grids that allows the analysis of data collected in real time, in order to improve the reaction time to changes in the electrical grid, ensure a stable and high-quality energy supply [33], adjust the operation to real time supply and demand and meet current and future network needs. In the case of Chile, the government proposed an ambitious plan to migrate most consumers to smart meters. However, this measure faced strong controversy, particularly due to the top-down regulatory process (through a change in the technical standard) without a process of planning, participation and dissemination of the objectives and expected results. The controversy generated rejection from the consumers due to the implementation costs and the uncertainty regarding a possible rise in electricity prices. In fact, around 85% of the population considered that this measure would not directly benefit them and that this change would only benefit large electricity companies. In this sense, one of the greatest challenges is to involve and inform society in order to carry out a comprehensive modernization of the current systems that is beneficial for all economic actors, including final consumers, which certainly not only involves a change in the meter.

Long administrative process and connection costs to the network

The administrative processes required to connect to the network are the second most critical obstacle according to the results of the study. This process is often affected by serious delays, which have a significant impact on the economic benefits of PV systems. Likewise, although the regulatory scheme for the connection process establishes requirements defined by the network operators and market regulators regarding the maximum power to be injected and the capacity at the connection point, these requirements do not consider the characteristics of photovoltaic systems and can represent a significant barrier to their development. This is the reason why, according to data from the SEC (Superintendency of Electricity and Fuels), there are many controversies associated precisely with the connection process. These controversies are mainly concentrated in observations to the Connection Criteria Report (ICC)[7] and connection costs (42%), requests for an extension of the ICC term (24%) and observations to the ICR Consolidated Response Report (17%) [31]. Undoubtedly, this large number of controversies generates an increase in the costs and development timeline of Distributed solar PV projects, since the rather uncertain terms of connection to the distribution network must be added to the construction deadlines of the photovoltaic plant.

Undoubtedly this problem is not unique to Chile, and thus some countries have tried to reduce these barriers. For example, the US has explored a new cost allocation configuration based on pool cost allocation, where initial interconnection costs are distributed among a group of projects being evaluated at the same time, based on their relative contributions. Another alternative, raised from the academic world, consists of the subsequent assignment of all the necessary investments. Under this scheme, a single entity pays all the initial costs and then, as new generators enter and use the investments made, they reimburse the entity that incurred the cost. In the case of distributed generation projects, the implementation of this cost allocation scheme implies that the distribution company pays the initial investment necessary for greater penetrations of distributed generation and then the amount of the investment is paid for all the projects that are interconnected, based on their relative size measured in kW [34].

In the case of Chile, the government tried to reduce these barriers by establishing new regulations[8]. The main objective of the new regulation was to establish requirements that would discriminate between projects with a real interest in developing and those that were only trying to obtain profit through speculation. Additionally, an attempt was made to establish an objective basis for the calculation of additional facilities and reduce conflict between distributors and project developers. Although the new regulation reduced some of the existing problems to some degree, it has not been enough to ease the uncertainty associated with the costs and deadlines for connecting new

[7] The Connection Criteria Report includes all the costs of the new works, adjustments and adaptations for the small-scale distributed PV connection.
[8] DS No. 88

projects. In fact, in July 2021 alone, 4 different regulatory decrees were issued in which the connection costs set by some distribution companies did not meet the requirements,[9] one of them even established the connection costs without providing any justification or detail [35]. In this sense, there is still a pending challenge from the regulatory point of view in order to allow the connection of distributed energy projects to the network, reducing the uncertainty regarding the terms and connection costs they face.

Structure and financing costs

The structure and financing costs is the third most important barrier for the development of Distributed solar PV projects in Chile. A good financial structure plays a fundamental role in the success of a project, since it manages to optimally combine different sources of financing with different terms and different risks, considering the different actors involved in the implementation of a project, such as suppliers, banks, non-bank lenders and shareholders. In this sense, one of the biggest obstacles that local financing has had is associated with the characteristics of Chilean banking, which since the 1982 crisis when several banks went bankrupt and had to be rescued by the state, have adopted an excessively conservative culture together with a regulation that focuses fundamentally on bank solvency [25]. The financial structuring not only depends on the actors involved but also on the scheme under which this financing is articulated. A large part of Distributed solar PV projects is financed with project portfolios or portfolios under a Project Finance scheme, which is based on the project's ability to generate cash flows that allow it to pay off the debt, as opposed to a scheme of Corporate Finance, which is based on the company's own assets or equity. According to the experts interviewed, compared to the Corporate Finance scheme, a Project Finance model requires more time and has higher transaction costs, which may put the viability of the project at risk.

It is important to mention that the government has tried to reduce the problem of requiring additional guarantees for projects. For this purpose, funds to guarantee these projects are currently available from a government agency, the Development Corporation (CORFO), which cover part of the debt payment if the project's cash flows are not enough to do so completely. However, the view of the experts is that in practice there are no instruments, guarantees or insurance to finance

[9] (Exempt Resolutions No. 7059, 7098, 7099 and 7100)

possible cost overruns during the construction of the project and thus ensure its full implementation. Obviously, one of the biggest obstacles to the existence of these guarantees or additional financing instruments is the moral hazard associated with some actors involved in the construction and implementation of the project. For example, contractors could artificially increase the costs of the project as a third party finances these cost overruns.

Uncertainty of prices stabilized by blocks and other regulatory requirements

Finally, another important risk mentioned by the interviewees is the regulatory risk. There is uncertainty regarding some regulatory changes that have been discussed in the public debate, some of which have already been implemented. Particularly, there is uncertainty regarding the existence and operation of the regulatory scheme of stabilized prices for Distributed solar PV projects.

In their first years of development, distributed solar PV projects were not attractively profitable due to their difficulties in concluding PPA-type contracts due to the low volume of energy generated compared to large-scale projects. For this reason, they could only access the spot market, which increases the risk of the project and investors demand higher returns to compensate for said risk. In 2005, the government decided to make a regulatory change to encourage investment in this type of project. The new regulation established the possibility that Distributed solar PV projects could subscribe to a stabilized price regime, through which the energy produced is paid at an established price, equivalent to the average marginal cost, thus avoiding the volatility of the spot market. [10] These stabilized prices effectively improved the profitability of projects and reduced uncertainty regarding prices, which gave economic viability to many projects that were completed for a total investment amount of approximately USD500 million between 2015 and 2019 [36].

Although this regulatory change encouraged investment in small-scale distributed PV projects, other players in the market considered that this mechanism was a subsidy for this type of projects, which was paid by all other generators. For this reason, in 2020 the government modified the regulation, establishing a stabilized price mechanism based on hourly blocks[11]. This new scheme

[10] DS No. 244
[11] DS No. 88

is similar to the marginal cost of the spot market in its calculation since it considers the expected marginal costs and the total energy demand, particularly in hourly blocks where different technologies with completely different marginal costs are dispatched. The change was not neutral and generated greater uncertainty, especially for the projects that were being developed. The new regulation, once implemented, would notably adjust the stabilized price of the solar block downwards. Due to this effect, the entry of new projects increased strongly since a transition period was established during which it became possible to sell energy at the stabilized price defined by the previous regulatory framework. In addition, this change reduced the interest in the development of new small-scale distributed PV projects, since the new regime of prices stabilized by blocks implies a decrease in the price of energy during the solar block *[35].*

Despite the disadvantages regarding the expected profitability due to the new stabilized prices, the interviewed experts mention that there is a new opportunity for the development of projects with storage, which would allow them to benefit from potential price arbitrage and thus improve the income for these projects. However, there is currently no regulation on energy storage, mainly because it is still unknown how the contribution of these systems will be remunerated. This is a new regulatory discussion in the world, which has arisen as different storage systems have strongly reduced their costs and are beginning to be profitable. This is how China, for example, has implemented regulations to incorporate distributed solar photovoltaic generation including storage. The basis for this type of regulation arises from the work of Yang and Zhao [37], who analyze the role of regulation in the economic viability of projects in Shanghai. Their results identified remuneration according to the size of the storage system as the most important variable, the reason why they propose establishing policies that subsidize construction per kWh or reimburse taxes on storage technologies. Based on this study and the experience of other countries, it is possible to evaluate and discuss regulatory changes and public policies that allow promoting the development of distributed solar PV energy projects with storage in Chile.

Conclusions and Recommendations

In recent years, the penetration of photovoltaic solar technology has had an exponential growth due to the decrease in its costs, the high potential of the existing solar resource, a growing concern about climate change and a configuration of policies towards a more sustainable world. Chile has the advantage of being one of the countries with the largest availability of solar resources and this is how solar energy generation has experienced great growth in the last decade, reaching 16% of the capacity in the energy matrix today. Most of this capacity comes from large-scale generators that represent 75% while 24% belongs to distributed generators. The low participation of this last segment is because it is just beginning its development and currently faces some obstacles for further advancement.

The greater development of photovoltaic distributed generation in Chile can play a key role in the success of the energy objectives established in the National Energy Policy, including that renewable energies contribute 80% of electricity generation by 2050, for example. Therefore, identifying the barriers that this segment currently faces is key to finding solutions that allow for its further development.

In this context, this study identifies and analyzes the main barriers that affect the implementation of distributed photovoltaic solar generation projects from the perspective of developers through data collection from surveys. The analysis of the data is carried out with the TOPSIS methodology to prioritize the barriers, and then carry out face-to-face interviews with experts in the sector. The results of the analysis indicate that "The structure of the network, its capacity and regulation for expansion", followed by "The long administrative process and the costs of connecting to the network", followed by "The uncertainty due to prices stabilized by blocks and other regulatory requirements" and "Financial structuring and financing costs" are the most critical barriers for the implementation of small-scale distributed PV projects, in the distributed generation segment.

Based on the opinions of experts and the experience of countries with high distributed solar photovoltaic development, some recommendations are discussed and proposed to address the identified barriers.

In the case of distribution networks, the main obstacle for generation purposes is that they were not designed to connect this type of distributed energy resource. However, today it is possible to change the type of distribution network operation from a radial to a ring type, thus allowing the addition of other lines for the injection of small-scale distributed PV, which would reduce potential congestion and saturation of the distribution networks. Likewise, this possible solution can reduce costs for small-scale distributed PV, given that, with a better distribution of consumption and injections, investments in new infrastructures can be avoided, or reinforcement costs can be lower. Another alternative to reduce or eliminate this barrier would be to change the reactive power flow of the small-scale distributed PVs, in order to limit network congestion. Currently, the regulation establishes leaving the power factor in a 1:1 ratio, which could be changed so that the small-scale distributed PV inverters absorb part of the reagents and thus prevent them from having to go through the transformers, thus reducing the voltages and potential line congestion.

In the case of the existing uncertainty regarding the new stabilized prices by blocks, a possible solution would be to carry out synthetic PPAs, through a portfolio of small-scale distributed PV projects. In this way, small-scale distributed PV projects can offer a much higher volume of energy and compete with other large-scale generators. Another alternative to mitigate this barrier is to develop contracts by difference, in which an intermediary covers the operating costs and the debt that cannot be covered with the project's income, in exchange for a percentage of sales. These structures are not very common in Chile, but they exist in other markets in the world and can play an important role in mitigating the risks of variations in income as a result of the new regime of stabilized prices.

Finally, it is important to point out that although this study contributes to identifying and analyzing the existing barriers to greater penetration of distributed generation, it has two limitations. The first is the fact that the non-probabilistic quota sampling used has the risk of generating a sample that is not completely representative of the population. The second is that the analysis focuses on the four most important barriers among all those identified, so it would be relevant in future research to analyze and delve into the other existing barriers.

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Appendix A

Here is a step-by-step description of this technique:

I. A decision matrix is constructed as shown below

$$\beta = (\mu_{iz})_{m\,x\,n} = \begin{matrix} & a_1 & a_2 & \cdots & a_n \\ x_1 & \mu_{11} & \mu_{12} & \cdots & \mu_{1n} \\ x_2 & \mu_{21} & \mu_{22} & \ddots & \mu_{2n} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ x_m & \mu_{m1} & \mu_{m2} & \cdots & \mu_{mn} \end{matrix} \text{(two)}$$

where μ_{iz} denotes the score of the alternative x_i for the criterion a_z(z = 1,2,3)

II. Since the values of μ_{iz} can have different dimensions, it is necessary to normalize them to make them dimensionless, using the following formula:

$$\mu_{iz}^N = \frac{\mu_{iz}}{\sum_{i=1}^m \mu_{iz}} (3)$$

III. Then the normalized weighted decision matrix is calculated

$$v_{iz} = \mu_{iz}^N * w_i \qquad z = 1,2,\ldots,n;\ i = 1,2,\ldots,m \qquad \sum_{i=1}^m w_i = 1 (4)$$

IV. Then the worst alternative is determined (A^-)and the best alternative(A^+)

$$A^- = \{v_1^-, v_2^-, \ldots \ldots, v_n^-\}$$

$$A^+ = \{v_1^+, v_2^+, \ldots \ldots, v_n^+\} (5)$$

Where,

$$v_i^- = (min_i v_{iz}, z \in Z'), (max_i v_{iz}, z \in Z'')$$

$$v_i^+ = (max_i v_{iz}, z \in Z'), (min_i v_{iz}, z \in Z'') (6)$$

Where Z' and Z'' denote the set of positive and negative criteria, respectively.

V. Obtaining the Euclidean distances of the worst and the best alternative based on the following equations:

$$d_i^- = \sqrt{\sum_{i=1}^m (v_{iz} - v_i^-)^2}$$

$$d_i^+ = \sqrt{\sum_{i=1}^m (v_{iz} - v_i^+)^2} (7)$$

VI. Calculate the relative closeness (D_i) using the following equation:

$$D_i = \frac{d_i^-}{(d_i^+ - d_i^-)} (8)$$

VII. Preference order ranking (the greater the relative closeness, the higher priority the alternative has)