ELECTRICITY INTERRUPTIONS IN CHILE: CAUSES AND REGULATORY IMPLICATIONS

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1. Abstract

We are currently transitioning towards a more electric future with higher proportions of electricity consumption in the energy mix. At this state, quality of supply measured by power interruptions become a major issue, not only for the energy sector but also to climate policy. In middle-income countries like Chile, where access to electricity has reached developed countries rates, the following step should consider how to improve quality of supply. For that purpose, this research characterizes the evolution of the number of hours of interruption during the period 2012-2018 by commune throughout the country. We identify main determinants in terms of seasonal, geographical, demographic and climatic factors for the evolution of outage hours. We found that communal income level does not have a significant effect on outage hours but climatic variables as wind speed, amount of rains and snow do have a positive effect. Larger distribution companies seem to have a better handling of hours of interruptions accounted as force majeure. Finally, we take into consideration the regulation for electricity distribution, finding out that distributors who were used as referential firms in the tariffication process have lower level of interruptions than the rest, linking the regulatory model to quality of service in electricity distribution.

2. Introduction

According to the World Energy Outlook 2020, 20% of total energy consumption in the world is based on electricity. Considering the prompt and continuous transformation that the electricity sector is experimenting, becoming more and more renewable, the shift towards more electricity in the consumption mix has become a major source for emissions reductions, both locally and globally. Climate and energy policies are promoting the electrification of transportation, heating and other commonfossil-fuel consumptions. If the sector is going to replace an important part of fossil fuel use with renewable electricity, one of the main issues will be the reliability of the electricity network. At the same time that new renewable plants are built, it will be increasingly important to have a high quality of supply in order to move consumers of oil and gas to electricity, even in some basic uses as heating over winter. Understanding the reasons behind electricity outages it is important to address, not only a better quality of service for consumers but also to strengthen climate policies that promote electrification.

The issue of quality of supply and outages in electricity has different characteristics and challenges depending on the level of the development of the country and the state of the electricity network. In the case of Chile, having reached an electrification coverage of 99%, the challenge in recent years has focused in the quality of the electricity supply that users receive and perceived as well as the price of it. With a national average of 15 hours of electricity interruptions during the last seven years, Chile is far from other OECD countries[1], but below the average in Latin America[2]. However, any comparison with other countries hide great internal heterogeneity, with communes that exceed 100 hours a year while others are below 5 hours. The 2050 Energy Policy published in 2015[3], aims to reach an annual average of one hour of interruptions per year and 4 hours in 2035, without considering force majeure. These goals are particularly important to advance in electrification as a sustainable measure to reduce global emissions. In terms of energy consumption, electricity represents a 22% of the total consumption in the country and projections are that this share will keep growing, considering than electricity generation is becoming more renewable each year[4].

From the Chilean perspective, up to our knowledge there are no detailed studies of both geographic and demographic factors that describe the country's situation in terms of outages and how the regulatory model in distribution sector is related with these results. This is important considering the current discussion regarding changes to distribution regulation in order to cope with energy transition.[5]

Quality of service in the distribution sector has different attributes. Consumers value the timeliness with which their requests are dealt with (commercial quality), the reliability of electricity supply (continuity of supply), and also the characteristics of the supply voltage (voltage quality). In this paper we will focus on the reliability part of the electricity supply, calling it quality of supply.

The distribution of electricity is a natural monopoly and hence there is a need for regulation in the industry. Distribution companies are typically responsible for the operation and maintenance of the distribution network within a well-defined geographical area. As a natural monopoly, the charges for using of the distribution network are settled by a regulatory process, but also it is regulated threshold of number and duration of interruptions at an agreed cost and at the correct voltage level.

The Chilean regulatory model in electricity distribution is a recurring reference in the literature. As Bustos and Galetovic (2007) mentions, efficient-firm regulation was conceived in the early 1980s, even before than the liberalisation of the electricity supply industry started in UK. Since then, the regulatory trend has put effort in replacing the traditional cost-plus regulation with incentive regulation models, and in the case of Chile, it was developed a reference firm approach (Jamasb and Pollitt, 2008). However, there is an issue regarding incentive regulation, since sometimes the quality of supply is not properly addressed in capital incentive industries (Ajodhia, Schiavo and Malaman, 2006; Growitsch, Jamasb, and Pollitt, 2009; Ter-Martirosyan and Kwoka, 2010). As a developing nation, Chile focused on the 80s and 90s on cost-efficient supply and only recently quality of service in distribution became an issue[6]. For this reason, it is important to include the regulatory model in our framework and its relationship with the quality of supply.

Our research approach will include three steps. First, we characterize the evolution of the number of hours of interruption during the period 2012-2018 by commune throughout the country. The indicator we use for electricity interruptions is the System Average Interruption Duration Index or

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[1] Council of European Energy Regulators (2018)

[2] Levy and Carrasco (2020)

[3] Energy 2050: Chile's Energy Policy. Available in http://www.energia2050.cl/wp-content/uploads/2016/08/Energy-2050-Chile-s-Energy-Policy.pdf

[4] Chilean government has recently announced a plan to close all coal plants by 2040 and to become carbon-neutral by 2050 as part of the NDC for climate change.

[5] The Ministery of Energy introduced a change in electricity law in September 2020 and has announced other to come in order tu update distribution regulation.

[6] In December 2017 it was published by the regulator the technical norm for distribution services that includes specific levels for quality of supply.

SAIDI. Secondly, we identify main determinants in terms of seasonal, geographical, demographic and climatic factors for the evolution of outage hours. Finally, taking into consideration the tariffication processes, analyzing the behaviour of outages in the distribution sector by group of firms. In the summary section we include regulatory considerations and alternatives to considerate improve quality of supply considering the empirical evidence.

3. Related literature

The related literature to electricity interruptions and its implications has evolved in different directions. An important branch of research has devoted efforts to quantifying the cost of electricity interruptions and the value of it that is considered for tariffication processes[7]. For example, a report from the Congressional Research Service in 2012 for United States mentions that cost estimates from storm-related outages to the U.S. economy are between \$20 billion and \$55 billion annually. In this paper we are not dealing with the consumers cost of outages or willingness to pay for better quality, but on the main factors that explain those outages.

A second line of work has covered the impact of power outages on the economy, in a macroeconomic perspective. As Levy and Carrasco (2020) mentions, poor quality affects the productivity of companies, forcing them to produce their own electricity, or people to resort to candles or batteries, substantially increasing costs. There is plenty of work in the development literature that highlights these costs in developing economies. Cole et al (2018) shows the effect of power outages on sales of firms across different African economies. They find that reducing average outage levels to those of South Africa would increase overall sales of firms in Sub-Saharan Africa by 85.1%, rising to 117.4% for firms without a generator. Andersen and Dalgaard (2013) and Moyo (2013) also showed the negative impact on productivity and growth in African countries. In this paper we do not address the macroeconomic effects of outages, but our research is relevant to discuss how to reduce their negative impact.

More relevant for our analysis is the research area on regulation and quality of service. As Ajodhia and Hakvoort (2005) mentions, there is empirical evidence that show that under rate-of-return regulation, existing reliability levels in the electricity industry are generally higher than optimal from a social point of view. However, at the same time they state that for capital-intensive industries like the electricity network business, a stricter forms of price regulation are likely to lead to degradation in quality. Also, Ajodhia et al (2006) highlights the potential dangers of quality degradation under price-cap regulation, analyzing the Italian experience in the introduction of an incentive scheme for electricity continuity of supply to apply during the period 2000–2003. Ter–Martirosyan (2003) and Ter-Martirosyan and Kwokas (2010) shows that stricter price regulation is associated with lower levels of continuity of supply. In a study of utilities in different states of the US during 1993–1999, they find that a shift towards price-cap regulation results in an increase of the average duration of electricity interruptions. These results are in line with the analysis we will perform, since our research finds out that the regulatory model applied in Chile has an effect in terms of quality of supply.

Finally, it is important to mention that the literature on power outages and their main factors has developed more in engineering than in regulation and economic literature. Roberts and Rusell (2003) describe the key factors of power interruptions in two groups: inherent and inherited to the network. Among the first group we find demographic features as customer density, topographic features, geography of the service areas (weather, tree cover, geology etc.) and traffic congestion. On the group of inherited factors, they include the network design (size, length, etc.). As the

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[7] LaCommare and Eto (2006), Sullivan, Mercurio and Schellenberg (2009), Abdullah and Mariel (2010), Linares and Rey (2013).

authors mention customer density is directly representative of a number of topographic and demographic factors associated with the area that a company serves, and it is factor beyond the control of the companies. Also, the lengths of circuits as well as whether they are cables or overhead lines directly influence the number and duration of interruptions to supply. In terms of climatic factor, Sumper, Sudrià and Ferrer (2004) showed a strong correlation between lightning activity and power unavailability in Spain. We will built on these approaches to estimate an econometric model, described in the next section, and empirical test the main determinants of power outages in Chile. Up to our knowledge there is no research on this topic in Chile as well as little evidence comparable in other developing countries[8].

4. Methods

Campbell (2012) highlights that high winds, especially when combined with precipitation from seasonal storms, can cause damage to electricity utility systems, resulting in service interruptions to large numbers of electricity customers. Most such power outages are caused by damage from trees and tree limbs falling on local electricity distribution lines and poles. The network of cables enabling electric power to be sent to customers generally exists in an exterior largely exposed to the elements.

Two distribution networks can have very similar networks, but they can have significant differences in interruption indices. As Sumper, Sudrià and Ferrer (2004) mentions a range of factors which may explain the variations of these indices. There are two classes: inherited and inherent factors. The inherited factors are derived from the differences that the distribution companies have inherited due to their long-term network design. Any significant change in this design take years to be accomplished. For example, long overhead lines have a larger probability of faults than shorter and underground lines. The inherent factors are related to the supply area in which a distribution company is serving. It includes differences in topographic, climatic, and demographic factors. For example, customers' density, weather conditions, etc.

Considering these factors, we have carried out an econometric analysis. As the dependant variable we have use the SAIDI indicator (System Average Interruption Duration Index). This is an indicator of electricity outages or unavailability. In order to test the relevance of inherited and inherent factors we will look for the statistical significance of them. As determinants that could affect the interruptions, following the literature, we will use indicators of community income, urban-rural relationship, characteristics of distribution companies and relevant climatic events (rains, snow and wind speed). In the next subsection we will describe how the data we use was compiled and organized.

4.1. Data analysis

To measure electricity outages, we use the System Average Interruption Duration Index, or as it is well known, SAIDI. This is a system index of average duration of interruption in the power supply indicated in minutes per customer.

$$SAIDI_j = \frac{\sum_i^N Clien_{fsi\_j} \cdot t_{i,c}}{Client_{inst\_j}}$$

Where:

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[8] A descriptive analysis has been developed for the case of the metropolitan area of Buenos Aires in Argentina in Martínez et al (2003).

- $SAIDI_j$: Average duration of interruption per client in area j measure in hours in a period of time.
- $Clien_{fsi\_j}$: Total number of clients connected to the distribution system in area j, that had suffered an interruption longer than 3 minutes that are a product of outages i, in a given period of time.
- $Clien_{inst\_j}$: Average total number of clients connected to the distribution system in area j, over the given period of time.
- N: Total number of interruptions in area j in a given period of time.
- $t_{i,c}$: Duration of interruptions of client c, longer than 3 minutes, as a result of outage i.
- For its calculation, all interruptions in power supply longer than 3 minutes are considered.

This data is contained in a public database located in the energy regulator, National Commission of Energy (CNE), open-data platform known as "Energía Abierta"[9]. This database contains SAIDI indicators from 327 communes in Chile. Also, the database contains information on the source of the power interruption: due to force majeure, internal to the distribution system and external to the distribution system[10]. In sum, with Energia Abierta's database we define the next variables that are relevant for our study:

- **Saidi_comunal**: Total Monthly System Average Interruption Duration Index (SAIDI) per commune, from January 2012 to December 2018.
- **FM**: Monthly SAIDI due to force majeure.
- **Externa**: Monthly SAIDI due to interruptions in generation and transmission segments.
- **Interna**: Monthly SAIDI due to interruptions in distribution segment.

It is well known in developed countries that generation and transmission contribute little to customer interruption and the main source of these interruptions is the distribution network. Campbell (2012) cites a report from National Association of Regulatory Utility Commissioners in the U.S. that estimates that 90% of customer outage-minutes are due to events which affect distribution systems. The remaining 10% stem from generation and transmission problems, which instead can cause wider-scale outages.

Since Energia Abierta's database do not include information on distribution companies operating in each commune nor the number of clients by urban/rural classification, this information was requested to the Superintendence of Electricity and Fuels (SEC).

The regulation for quality of service was modified in December 2017, introducing SAIDI as the main quality indicator for electricity supply. For this reason, there is no information on SAIDI per commune and distribution company previously to 2018. This is a problem for communes where there is more than one distribution company since we cannot match exactly the SAIDI indicator for the commune to a distribution company. For that reason, we decided to keep in the analysis only communes with one distribution company, what add up 220 communes in total.

In order to characterize the area of distribution, we use information from SEC to estimate the participation of urban and rural clients in each commune. Also, we obtained as a proxy of the characteristics of the distribution company, the size of it in terms of number of clients. The next variables are relevant for our study:

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[9] http://energiaabierta.cl/

[10] Interruptions due to problems in transmission and generation segments.

- **Tot_clie_c**: Total number of clients per commune per year.
- **Clien1**: Total number of urban clients per commune per year
- **Clien2**: Total number of rural clients (type 1) per commune per year.[11]
- **Clien3**: Total number of rural clients (type 2) per commune per year.[12]
- **P_clie1**: Percentage of urban clients over total clients in the commune per year. (p_clie1 = client1/tot_clie_c)
- **P_clie2**: Percentage of rural clients type 1 over total clients in the commune per year. (p_clie2 = client2/tot_clie)
- **P_clie3**: Percentage of rural clients type 2 over total clients in the commune per year. (La ecuación de cálculo es: p_clie2 = client3/tot_clie)
- **Tam_empr**: Size of distribution company as the percentage of clients of the company in the country with respect to the total number of clients in the country.

To control for communal income, we use data from "Encuesta de Caracterización Socioeconómica Nacional de Chile" (CASEN).[13] The geographical coverage of CASEN is national. However, areas with difficult access are excluded.[14] As a result, we ended with 197 communes. From CASEN we obtained the following variables:

- **Ing_percap**: Average total income per capita in the household per commune, in Chilean pesos per year.
- **P_urb**: Proportion of urban population per commune per year

Also, we have considered geographical conditions that can impact on power interruptions. First, we included a variable that classifies communes according to their average temperature in seven thermal zones. In second place, we include a seasonal variable to account for the winter months, since weather conditions are more severe to electricity infrastructure during those months.

- **Estacionalidad**: Seasonal dummy variable, equal to 1 for months May to September
- **Zon_ter** : Thermal zone of the commune, from 1 to 7, as it has been classified by the termic regulation for construction[15].

Descriptive statistics of all the described variables are presented in Table 1.

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[11] A commune of rural type 1 has a population below 70.000 or more 70.000 inhabitants but with a density below to 350 houses/km2; and the number of distribution clients is below to 10.000 or more 10.000 but with a relationship of kW/kmMT below to 15 kW/km.

[12] A commune of rural type 2 fulfills conditions for rural type 1 and they are supplied by a feeder longer than 75 km with a relationship between capacity and length below to 50 kVA/km.

[13] CASEN is available only for years 2013, 2015 y 2017. Then, we have to do some assumptions. For year 2012 we use the variation between 2013-2015 to set up the trend between 2012 and 2013. The same for year 2014. For year 2016, we use variation 2015-2017. The same for year 2018.

[14] The exclude communes are: General Lagos, Colchane, Ollagüe, Juan Fernandez, Isla de Pascua, Cochamó, Chaitén, Futaleufú, Hualaihué, Palena, Lago Verde, Güaitecas, O´Higgins, Tortel, Laguna Blanca, Río Verde, San Gregorio, Cabo de Hornos (ex Navarino), Antártica, Primavera, Timuakel, Torres del Paine.

[15] The Ministery of Urbanism and Housing defines them in the general norm for urbanism and construction.

Table 1: Summary Statistics of main variables

Variable	Obs	Mean	Std. Dev.	Min	Max
saidi_comunal	16,548	2.229	4.757	0	260.6
interna	16,548	0.852	1.692	0	98.25
fm	16,548	0.998	3.793	0	259.23
externa	16,548	0.378	1.565	0	51.27
tot_clie_c	16,548	19,564.97	29055.07	35	236300
p_clie1	16,548	0.335	0.470	0	1
p_clie2	16,548	0.512	0.484	0	1
p_clie3	16,548	0.151	0.339	0	1
tam_empr	16,548	0.157	0.131	0.002	0.418
ing_percap	16,548	260,893.1	158,086.3	80,561.36	1,855,463
p_urb	16,548	0.691	.2938646	0	1
zon_ter	16,548	3.253	1.533613	1	7

For weather conditions, we obtained historical information from OpenWeather[16]. The historical information includes hourly data of each of the communes under analysis of wind speed in km per hour, rains in mm per hour and snow in cm by hour. In order to consider weather factors as determinants of power outages, we have to create indicators of extreme events. For the case of extreme windy days, we create a variable, **wind_40km**, that accounts for the number of days in a month that the wind speed was higher than 40 km per hour. We also consider a variable with number of days in a month higher than 50 km per hour. These thresholds are usually use in Chile as an indicator of extreme wind for the electricity sector.

In the case of rains and snow, we created two variables to account for two different climatic events. On one side, if a lot of rain occurs in a couple of hours, that can affect the electricity supply. On the other side, an accumulation of rains can have also an effect on electricity supply after a longer period of time. The fist phenomena measure de intensity of the rains and the second the accumulation of them. To account for the two effects, we create the next variables:

- **lluvia_1hs_cri**: number of days in a month where the amount of rains was higher than the historical average of one hour (1992-2019) plus a standard deviation.
- **lluvia_acum_cri**: number of days in a month where the amount of rains was higher than the historical average of one day (1992-2019) plus a standard deviation.

The same methodology was applied for snow precipitations, creating the variables **nieve_1hs_cri** and **nieve_acum_cri**. Since we don't have a threshold from expert criteria as in the case of wind speed, we created three different levels, considering one, two and three standard deviations from the 1992-2019 average.

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[16] For each point on the globe, OpenWeather provides historical, current and forecasted weather. https://openweathermap.org/

Table 2: Summary Statistics of weather variables

Variable	Obs	Mean	Std. Dev.	Min	Max
wind_40km	16,548	0.915	3.455	0	31
wind_50km	16,548	0.305	1.698	0	25
lluvia_1h_cri_1d	16,548	3.316	4.193	0	24
lluvia_1h_cri_2d	16,548	2.770	3.486	0	24
lluvia_1h_cri_3d	16,548	2.310	2.932	0	24
lluvia_acum_cri_1d	16,548	1.494	2.102	0	22
lluvia_ acum_cri_2d	16,548	1.024	1.576	0	19
lluvia_ acum_cri_3d	16,548	0.733	1.260	0	18
nieve_1hs_cri_1d	16,548	0.195	1.216	0	21
nieve_1hs_cri_2d	16,548	0.165	1.005	0	16
nieve_1hs_cri_3d	16,548	0.139	0.832	0	15
nieve_ acum_cri_1d	16,548	0.085	0.514	0	9
nieve_ acum_cri_2d	16,548	0.058	0.363	0	8
nieve_ acum_cri_3d	16,548	0.040	0.271	0	6

Finally, in order to account for regulatory conditions that set up the business model in Chile, we need to have a brief description of the regulatory framework. Since the key determinant of costs in distribution segment is customer density in the service area, not the scale of production, two distributors that serve areas of similar density should have similar costs, even though the sizes of the firms may be very different. For that reason, the Chilean regulation uses the concept of pricing areas or "typical areas". In Chile there are more than twenty distribution companies, but the regulator can set up tariffs calculating them for only five or six typical areas with similar distribution costs.[17] Typical area Nº 1 has the lower average cost of distribution while typical area Nº 6 has the higher. In the first one we find the denser area of distribution in the country while in the latter there are the more rural ones. Distribution cost (called VAD in Chile) is higher in the latter. For this reason, in order to control for any effect of the tariff level on interruptions, we include as a variable the typical area for tariff determination (**Area_tipica)**.

In each typical area, a referential distribution company is used to calculate the distribution cost or VAD. This cost corresponds to an efficient firm adapted to demand in the geographic zone of the referential firm. The practice of the regulatory model can have an impact on the quality of supply. In the case of Chile, tariffs are set by groups of distributors that have similar average cost of distribution. Firms in the same group or typical area, as the regulation defines it, are allowed to charge the same tariffs. However, the level of tariffs in each group are set considering a "referential distributor" among all the distributors in the group. Since the efficient firm is modelled using referential firm data, it is possible that these firms face different regulatory conditions than the firms that are in the same typical area but where not used to estimate the efficient firm. Considering the period under analysis, we create the dummy variable **Emp_ref_1216** equal to 1 if the distribution company was the reference firm for its typical area in tariff process 2012-2016.[18]

4.2. Empirical strategy

An econometric analysis has been carried out based on the following information and empirical strategy based on Ter-Martirosyan and Kwoka (2010). As dependent variable we use the SAIDI indicator (System Average Interruption Duration Index). This is the indicator of electricity outages, separating them in interruptions due to failures in generation-transmission and

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[17] In a legislation change in 2019 allowed that the number of typical areas was increased for the period 2020-2024 up to 12.

[18] There was another tariffication process (2016-2020) but where tariffs were finally published in December 2017 having little impact in the period under analysis. Also, since almost the same firms that were reference firm in 2012 were also in 2016, we use the 2012-2016 process as reference.

distribution, as well as by force majeure. As determinants that could affect the number of interruptions, following the relevant literature, we will use indicators of income, urban-rural relationship, characteristics of distribution companies and geographic/climatic conditions. Also, in order to estimate the effect of regulation on power interruptions, we will consider differences between communes with distribution companies that have being the referential firm in the tariff setting processes with respect to other companies.

In order to separate the analysis, we will present three sets of models:

- Basic Model
- Model with climate variables
- Full model with regulatory variables

Since each commune has different characteristics and we don't know if individual effects are random. For that reason, we applied a Hausman Test for fixed effect testing the null hypothesis that individual effects are random. The test rejects the null hypothesis that a panel estimation with random effects provides consistent estimates. For this reason, we will continue our analysis with a fixed effect model.

5. Results

In table 3 we have included estimations for the Basic Model, where power outages are explained by commune income (in logs), seasonality, size of the distribution company and percentage of urban population. We separate this model in four regressions. Each regression has a different dependant variable: (1) SAIDI, (2) Internal SAIDI, (3) External SAIDI and (4) SAIDI due to force majeure.

As it is expected, winter season increases SAIDI, but not all the components of it. External SAIDI, due to transmission and generation problems, has no significant effect from winter season. The opposite for interruptions due to force majeure and distribution issues. This result can be explained by the fact that winter season, with more precipitations in the form of rain and snow as well as other weather conditions increase the cases of force majeure and also impact heavily on distribution lines but not on higher voltage lines in the transmission segment or in the operation of power plants. The next model includes climate variables to address this issue in more detail.

In the basic estimation model, we also find that the log income per capita at the commune level is relevant to explain external SAIDI. External SAIDI is significatively lower than internal SAIDI since outages due to transmission and generation issues are less likely. However, when there is a transmission or generation problem the magnitude of the outage can be large. It is possible than lower income communes are more vulnerable to these kinds of events.

Finally, the size of the distribution firm has no effect on external SAIDI, as it is expected, but neither to internal SAIDI. However, a larger distribution company has a negative effect on outages due to force majeure. This is an interesting result, since it seems that larger distributors can handle force majeure in a better way.

Table 3: Basic Model (income, season, distributor size and density)

VARIABLES	(1) SAIDI	(2) Internal SAIDI	(3) External SAIDI	(4) Force Majeure SAIDI
Log ing_percap	-0.0536	-0.000940	-0.422***	0.369*
	(0.206)	(0.0738)	(0.0700)	(0.170)
estacionalidad	0.716***	0.152***	0.0248	0.539***
	(0.0700)	(0.0251)	(0.0238)	(0.0577)
tam_empr	-1.328**	-0.164	0.0138	-1.177**
	(0.435)	(0.156)	(0.148)	(0.359)
p_urb	-0.600	-0.292	-0.240	-0.0674
	(0.624)	(0.224)	(0.212)	(0.515)
Constant	3.217	1.028	5.752***	-3.562
	(2.529)	(0.908)	(0.861)	(2.086)
Observations	16,548	16,548	16,548	16,548
Number of id_comuna	197	197	197	197

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table 4: Model with climatic variables

VARIABLES	(1) SAIDI	(2) SAIDI	(3) Internal SAIDI	(4) Internal SAIDI
Log ing_percap	0.0340	-0.00757	0.0129	0.00663
	(0.205)	(0.204)	(0.0738)	(0.0737)
tam_empr	-1.320**	-1.303**	-0.169	-0.166
	(0.433)	(0.432)	(0.156)	(0.156)
p_urb	-0.714	-0.716	-0.311	-0.312
	(0.621)	(0.620)	(0.224)	(0.224)
wind_40km	0.134***	0.133***	0.0419***	0.0419***
	(0.0216)	(0.0215)	(0.00779)	(0.00775)
lluvia_1hs_cri_1d	0.143***		0.0218***	
	(0.0119)		(0.00431)	
nieve_1hs_cri_1d	0.272***		0.0465***	
	(0.0375)		(0.0135)	
lluvia_acum_cri_1d		0.264***		0.0415***
		(0.0194)		(0.00699)
nieve_acum_cri_1d		0.604***		0.120***
		(0.0831)		(0.0300)
Constant	1.862	2.456	0.815	0.902
	(2.521)	(2.515)	(0.909)	(0.907)
Observations	16,548	16,548	16,548	16,548
Number of id_comuna	197	197	197	197

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table 4 shows the results for the Model with climatic variables. In this case we show the estimates for SAIDI (estimations 1 and 2) and internal SAIDI (3 and 4).[19] Results are similar to the basic estimation model. In this case, winds over 40 km per hour and days of rain and snow are significant and positive sources of SAIDI and internal SAIDI. Again, the size of the distribution company has a negative effect on SAIDI, but not through internal SAIDI but through a reduction in force majeure interruptions. Also, the proportion of urban population and income level does not have any significant effect on the power interruptions of the communes under analysis.

In Table 5 we proceed with the third part of our estimations, including regulatory variables to analyse the effect on power outages. In this section we only use internal SAIDI as dependant variable. The regulatory variables we include are a dummy for distributors that are referential firm in the tariffication process and a variable that indicates the typical area where the distribution company is included for tariffication process. We have also included in two estimarions (3 and 4) an interaction between firm size and the dummy variable for reference firm. We would like to know if there is a relevant effect of reference firms according with their size.

As it is shown, after controlling for climatic events, communal income, urban population and size of the firms, those distributors who were referential firms in the tariffication process have lower internal SAIDI than the rest. This is an important result since it links the regulatory model to the quality of service.

As Bustos and Galetovic (2007) mentions, in order to force firms to be efficient, the regulator set prices according to the costs of a “model” or “efficient” firm, designed from scratch and without considering the real firm. Since there could be a trade-off between decisions that minimize cost at any event and quality of supply it is regulatory relevant to test if the regulation in Chile has an effect on power interruptions. We do not have a counterfactual in Chile since 1982, when the efficient firm framework was established. One way to test this effect could be to compare referential firms with other firms in the same typical area. Our results show that indeed, referential firms perform better than other firms. This could be the result of a tariffication process that gives incentive to the referential firm to invest more in quality of service. However, it is also possible that referential firms are chosen by the CNE because of the quality of information they can have on this firm in order to set tariffs. If this is the case, firms with better quality of information (for tariffication) can be correlated with firms with better quality of service. It would be important to research further on this topic.

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[19] For external SAIDI with climatic variables, we found the same negative effect of average communal income on this kind of interruptions. Snow is not significatively as an eplanation of external interruptions but wind and rains are. This is expected since snow typically affects low voltage lines like distribution ones but rarely affect high voltage transmission lines. For interruptions classified as force majeure, again larger distribution companies have a negative effect on these interruptions, while all climatic variables have a positive effect on them.

Table 5: Full model with regulatory variables

VARIABLES	(1) Internal SAIDI	(2) Internal SAIDI	(3) Internal SAIDI	(4) Internal SAIDI
ing_percap	-0.0280	-0.0331	-0.0358	-0.0411
	(0.0757)	(0.0756)	(0.0758)	(0.0758)
tam_empr	0.572*	0.575*	-3.256	-3.315
	(0.249)	(0.249)	(2.455)	(2,454)
p_urb	-0.273	-0.274	-0.274	-0.275
	(0.224)	(0.224)	(0.224)	(0.224)
wind_40km	0.0421***	0.0421***	0.0424***	0.0423***
	(0.00779)	(0.00775)	(0.00779)	(0.00775)
lluvia_1hs_cri_1d	0.0217***		0.0220***	
	(0.00430)		(0.00431)	
nieve_1hs_cri_1d	0.0465***		0.0465***	
	(0.0135)		(0.0135)	
lluvia_acum_cri_1d		0.0413***		0.0417***
		(0.00699)		(0.00699)
nieve_acum_cri_1d		0.119***		0.119***
		(0.0300)		(0.0300)
emp_ref_1216	-0.295***	-0.292***	-0.513**	-0.513**
	(0.0765)	(0.0765)	(0.159)	(0.159)
Area_tipica	0.0115	0.0145	-0.0223	-0.0198
	(0.0439)	(0.0439)	(0.0489)	(0.0489)
Tam_empr*emp_ref			3.947	4.010
			(2.518)	(2.517)
Constant	1.352	1.413	1.734	1.803
	(0.970)	(0.969)	(1.001)	(1.000)
Observations	16,548	16,548	16,548	16,548
Number of id_comuna	197	197	197	197

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

6. Conclusions

This paper shows that besides demographic or geographic considerations, climatic features as well as regulatory design have a relevant effect of quality of service when we look at outage hours. Since the energy transition is electrifying several items in energy consumption (transportation, heating, etc.), it is important to address these issues in order to improve quality of supply. Chilean results show different ways where developing countries can catch up in terms of quality of service.

Since referential firms have a better record in terms of quality of service, increasing the amount of referential firms can have a positive effect in the sector. In December 2019, a change in distribution regulation authorized the CNE to increase the number of typical areas and referential firms in the following tariffication processes. It could be expected that this regulatory change can have a positive effect on quality of supply. However, it is not clear if that could be enough, considering the international evidence on the effect of strict forms of price regulation, as the Chilean model, are likely to lead to degradation in quality. It would be advisable to review the current regulatory model to include quality of service considerations in a better way.

Alkhuzam, Arlet and Lopez-Rocha (2018) shows that when income per capita, natural resource endowment and geography is considered, power outages measured in terms of duration per customer are not significantly associated with the ownership status of the distribution utility. In our research we find that size of the firm is only relevant to a better management of force majeure cases. One limitation of our analisys is that we could not account for all the communes in Chile, since there was no record of SAIDI per commune per distributor before 2018. In future research it will be interesting to consider a larger sample of communes and firms, for example cooperatives, and how they compare with the rest fo the distribution sector in terms of quality of supply.

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