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Working Paper

Regulatory impact on Quality of Electricity Distribution Services

The case of Latin America and the Caribbean

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Regulatory impact on Quality of Electricity Distribution Services

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Abstract

In this study, we empirically estimate the impact of quality regulation based on economic incentives on the frequency and duration of power outages. First, based on a sample of 143 electricity distributors across Latin America and the Caribbean, we show that between 2003 and 2019, the System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI) decreased after the implementation of quality regulation by an average of 40% and 45%, respectively. Second, our estimations show that the implementation of the quality regulation had a positive and significant impact on reducing both the duration and frequency of outages. Finally, our results show that on average, private firms had a better quality performance, but the worst performing firms in the region were also private. Our results advocate for more quality regulation.

Keywords: Regulation; Electricity; Quality; SAIDI; SAIFI; Latin America; Caribbean.
JEL Classification: L51; L94 ; Q48

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1 Introduction

According to Fumagalli, Schiavo, and Delestre (2007), power quality can be viewed from three angles: (i) commercial quality, where aspects directly related to the distributor's relationship with the customer are considered (installation time for a new connection, precision in the measurement of consumption and billing, assistance with complaints, etc.); (ii) voltage quality, referring to variations as compared to standard values; and (iii) continuity of supply, referring to the number of interruptions and their duration. The latter is in general the most used way of measuring quality due to its importance in ensuring access to key services that affect welfare (e.g., food conservation, temperature comfort, and entertainment). Similarly, industrial competitiveness depends on electricity reliability. If electricity is unreliable, industries lose production and/or need to invest in back-up generators (Levy and Carrasco, 2020). Electricity provision is often rationed, limited, unstable, and/or of poor quality in developing countries (Burlando, 2014).

The avoidance of interruptions in the electricity supply depends on the proper functioning and coordination of the entire chain: generation, transmission, and distribution. In this study, we focus on distribution companies, where the existence of *good regulation* plays the most important role. These profit-maximizing companies are responsible for supplying electricity to final consumers through a low-voltage network infrastructure at the end of the distribution network, and they are closest to the final consumer. Due to economies of scale, a single distribution company provides electricity for each geographical area, acting as a natural monopoly in each zone. Given the absence of intra-zone competition in distribution and the difficulty of creating a cost-effective decentralized option for most consumers, the market structure does not provide enough incentives for service quality. In this context, regulatory frameworks are essential tools for promoting quality of service.

Regulation of network quality is difficult for three reasons. Firstly, measurements are only approximations of actual quality. Secondly, customers' willingness to pay for quality is difficult to estimate, and, finally, there is an informational gap regarding the incremental costs to attain optimal quality (Nepal and Jamasb, 2015). From an economic perspective, efficiency is achieved when the user's willingness to pay for quality is equivalent to the additional costs incurred by the distribution company. For example, Deutschmann, Postepska, and Sarr (2021) evaluate whether the willingness to pay for a quality improvement is compatible with the increase in costs incurred by the electricity distribution company in the case of Senegal. They find that households and businesses are generally willing to pay an additional premium if quality improves. By contrast, in the case of the Dominican Republic, Mori (2021) finds that gaining acceptability for implementing tariffs that reflect the costs necessary to improve infrastructure services can be challenging, even if it generates a lasting effect on customer satisfaction. The previous evidence, together with asymmetries of information regarding both willingness to pay and distributors' costs, makes it difficult to design a regulation that balances quality with affordability.

In the 2000s, most European countries introduced service quality incentives based on a rewards and penalty scheme. Such schemes were implemented in Italy, Norway, and Great Britain in the early 2000s and in France in 2009 (Fumagalli, Schiavo, and Delestre, 2007). Something similar happened in Latin America and the Caribbean (LAC), with some early adopters, such as Peru in 2004, and some very late ones, such as Brazil in 2018. The type of quality regulation we consider here is what is generally called *incentive regulation*, as it provides financial incentives for the provision of service quality (Jamasb and Pollitt, 2000), regardless of whether the incentive is a fine that goes to the government or compensation for or a rebate to consumers (Giannakis, Jamasb, and Pollitt, 2005). In the last two decades, there has been a substantial increase in access to electrification together with an improvement in the quality of electricity services in LAC. However, improvements in quality have been lower than the improvements observed in other regions (Cavallo, Powel, and Serebrisky, 2020).

The international standard for measuring quality as continuity of service comes from the IEEE Std 1366–1998 Guide for Electric Power Distribution Reliability Indices, updated in 2012. The IEEE (2012) defines the System Average Interruption Duration Index (SAIDI) as the total number of minutes of service interruptions in a year divided by the number of customers served. Similarly, it defines the System Average Interruption Frequency

Index (SAIFI) as the total number of customer interruptions in a year divided by the customers served. In this study, we examine whether the implementation of quality regulation impacts quality as defined by the SAIDI and SAIFI indicators in 143 distribution companies from nine countries in the LAC region[1] during the period 2003–2019.

This paper is related to three strands of literature. The first is the theoretical literature studying the impact of regulatory quality incentives on the actual quality of electricity services. The second constitutes a group of papers empirically estimating such impact. The third strand is relevant because of its scope, as it focuses on the performance of electricity distributors in developing countries, particularly in LAC.

There is a vast theoretical literature following Baron and Myerson (1982) and Laffont and Tirole (1986, 1993) that studies the impact of regulation on profit-maximizing firms. Most of these papers focus on the incentives given by regulation to increase cost efficiency or on balancing cost efficiency and quality (for the theoretical literature, see Ovaere, 2023). Fewer concentrate on quality regulation. Sappington (2005) reviews the mayor normative insights regarding the design of quality regulation in public utilities, while Ajodhia and Hakvoort (2005) theoretically review the main objectives, methods, and difficulties in regulating quality in electricity distribution. Their main insight is that due to information problems, at some point, the benefits of stricter quality regulation could be smaller than the additional regulatory costs of putting it in place.[2]

Few papers have empirically estimated the impact of regulation on quality. They mostly do so on a country-by-country basis and for developed countries. Moreover, their results are not aligned, as they study different types of regulatory instruments that have been applied in different contexts and regions. Ajodhia, Lo Schiavo, and Malaman (2006) compare quality before and after the introduction of a *rewards and sanctions* type of regulation in Italy between 2000 and 2003. They find that there was a positive effect of regulation on quality, as both the SAIDI and SAIFI national averages decreased significantly. Similarly, Cambini, Fumagalli, and Rondi (2016) find that incentives for quality increased capital expenditures in Italy, while Schmidthaler *et al.* (2015) compare incentive-based schemes with output-based frameworks for European countries, finding that the latter reduces outage duration by a higher rate than incentive-based systems. By contrast, Jamasb, Orea, and Pollitt (2012) show that regulatory incentives to reduce service interruptions in the United Kingdom (UK) were not sufficiently strong to achieve economically efficient levels of service quality.[3]

In the same vein, Ter-Martirosyan and Kwoka (2010) estimate the effects of quality regulation on the SAIDI and SAIFI for the United States. They take advantage of the differences in the regulatory schemes applied to different electricity companies in the period 1993–1999. Some of these firms went from being regulated based on the rate of return to incentive regulation plans based on a ceiling price or similar measures. In addition, in some cases, the regulation by incentives was accompanied by a scheme of compliance with quality standards, involving rewards or sanctions. They find that this second scheme achieved improvements in quality. However, in the absence of appropriate quality controls, incentive regulation led to a deterioration in quality. This last paper is the closest to ours, as the authors were also confronted with the need to use instrumental variables; however, we extend the inquiry both in scope, by considering a panel of numerous firms operating in developing countries, and methodologically, as we use an identification strategy that allows us to present robust

[1] Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Panama, and Peru.
[2] This is in line with the data envelopment analysis (DEA) performed by Giannakis, Jamasb, and Pollitt (2015) in 14 distribution companies in the UK, finding that there are trade-offs between costs induced by this type of regulation and the quality of services achieved. Indeed, incentives-based regulation often pursues the double purpose of cost saving and improving services quality, creating a conflict in optimizing the latter. This result is in contrast with Cambini, Croce, and Fumagalli (2014), who, using a DEA approach, find no significant change in firms' behaviors after the introduction of input- and output-based incentives in Italy.
[3] Another strand of literature is related to our own, albeit from afar. It studies multi-criteria quality definitions, including not only supply continuity (as in this paper) but also voltage conformity and customer satisfaction (for a recent example from Brazil, see de Souza Barbosa, Shayani, and Goncalvez de Oliveira, 2018).

estimations. Our main result is that incentive quality regulation had a positive and significant effect on quality improvement for the case of the distribution companies operating in LAC. Moreover, we calculate that between 2003 and 2019, in a sample of 143 electricity distributors, the SAIDI and SAIFI decreased after the implementation of the quality regulation by an average of 40% and 45%, respectively. We also estimate that on average, private firms outperformed public ones in terms of quality; however, since their performance was more disperse, the worst firms in terms of quality were also private.

Our results are relevant for policymakers since they highlight the need to implement incentive regulation to improve quality in countries that do not yet have it. Moreover, they offer elements for comparison between regulators and between distribution companies in the region.

Finally, we should mention the literature that has studied the impact of regulation on electricity distribution in developing countries, particularly in LAC. For the case of Pakistan, Mirza and Mushtaq (2022) find that the marginal cost of reducing distribution losses was Rs 44/kWh, while the marginal cost of reducing 1 min of interruption was only Rs 0.02, suggesting the use of estimated marginal costs as a benchmark for designing effective incentives-based regulation. Corton, Zimmermann, and Phillips (2016) study output-based incentives in the price-cap regulatory regime of the Brazilian distribution sector, finding a small trade-off between costs and quality and concluding that quality improvements are not costly relative to the potential savings from complying with quality standards. In the case of Colombia, Galan and Pollit (2014) suggest an extension of dynamic stochastic frontier models that accounts for unobserved heterogeneity in the inefficiency persistence and in the technology. Their frontier model incorporates total expenses, service quality, and energy losses over the 15 years following the reform, showing that rural companies and firms with a small number of customers presented low inefficiency persistence and that the largest gains in efficiency were during the last five years.[4]

The paper is organized as follows. The following section offers a panorama of quality in the LAC region and describes why it is a concern for users and policymakers. Section 3 describes the state of regulation in the panel of countries analyzed and shows the average state of quality in the 143 firms considered in this study before and after the regulation. Section 4 introduces the econometric methodology, Section 5 shows our main results, and Section 6 presents some concluding remarks.

2 Why is quality of electricity services important?

Regarding production, since electricity is an essential input, the low quality of the electricity service (power outages, low quantity supplied, scarcity, etc.) can significantly impact the productivity, competitiveness, and income of companies, particularly those that use energy intensively (Allcott, Collard-Wexler, and O´Connell, 2016). According to Levy and Carrasco (2020), service interruptions can raise costs due to the loss of production volumes associated with the start and stop of production cycles. In the particular case of LAC, Acevedo and Lennon (2018) state that companies in the region that experienced interruptions reported annual sales losses of between 0.3% and 2.5%, and these losses increased to 3.4% if those with the highest incidence are considered (the 10% most affected). Since losses can be severe, companies with the capacity and resources seek alternative energy to deal with power outages by purchasing their own (off-grid) generators. Other companies, unable to generate their own power in the face of interruptions, may be forced to stop production. In 2010, 22.5% of companies in Latin America had their own generator or had access to a shared generator to reduce the risk of losses due to power outages (World Bank, 2021).

Low quality through frequent and prolonged interruptions can constitute a barrier to economic development and competitiveness, causing high costs, business losses, and negative effects on the population's quality of life

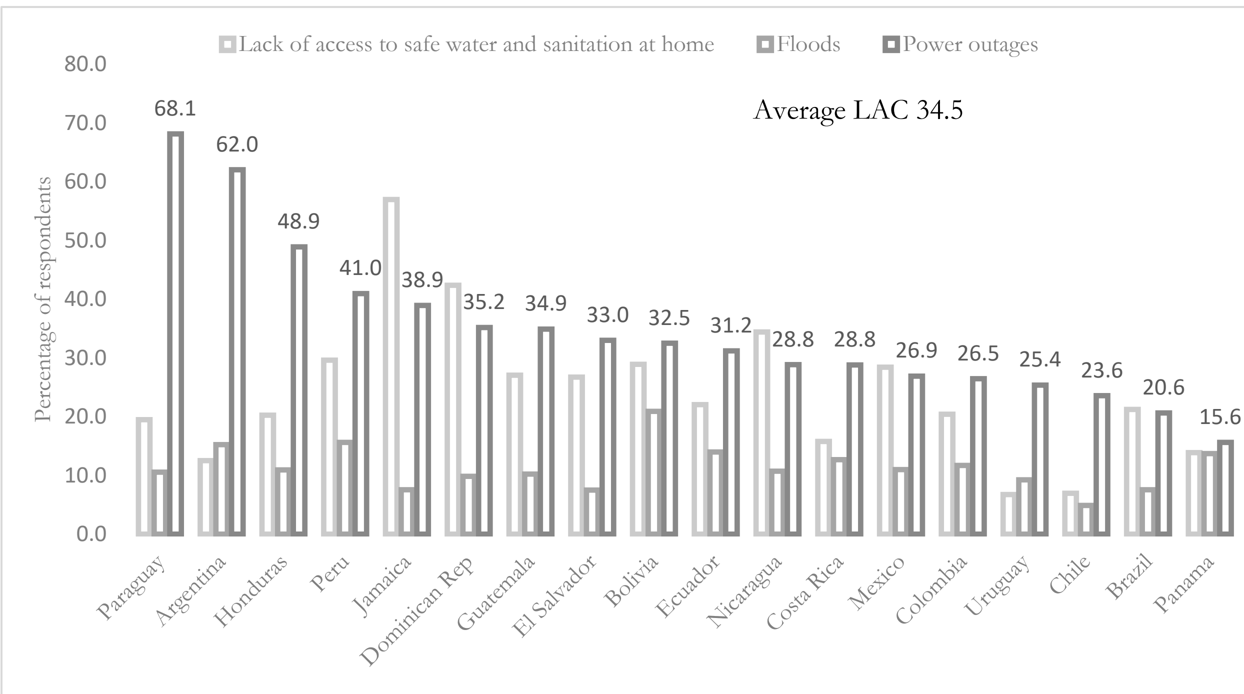
[4] Another paper that is vaguely linked is Ruiz and Rosellón (2012). They suggest a regulatory mechanism to optimize transmission expansion in Peru, which is linked to quality, albeit non-linearly.

(Fay and Morrison, 2007). In homes, interruptions cause discomfort. For example, interruptions affect food preservation, water heat, temperature comfort, educational and recreational activities (mainly at night), access to the internet, and the remote working routine in the home.

Service quality problems, especially when recurrent and prolonged, force households to resort to other energy providers that may involve more expensive and polluting services, such as companies with their own generators or sellers of candles and battery lamps (Levy and Carrasco, 2020). In addition, interruptions can force families in rural areas to collect firewood, purchase kerosene for heating and cooking food, or buy ice packs to keep their food in good condition (Carvajal et al., 2020). This mainly affects women and children in rural areas since they are generally responsible for collecting these alternatives.

Moreover, as we show in Figure 1, power outages are an important concern for Latin American citizens. According to the 2018–2019 survey of the Latin American Public Opinion Project (LAPOP), power outages are a concern for more than 34% of respondents. In addition, in most countries of the region, this problem was perceived as the most serious problem associated with basic infrastructure services, compared to water supply (lack of water) and sewerage (floods).

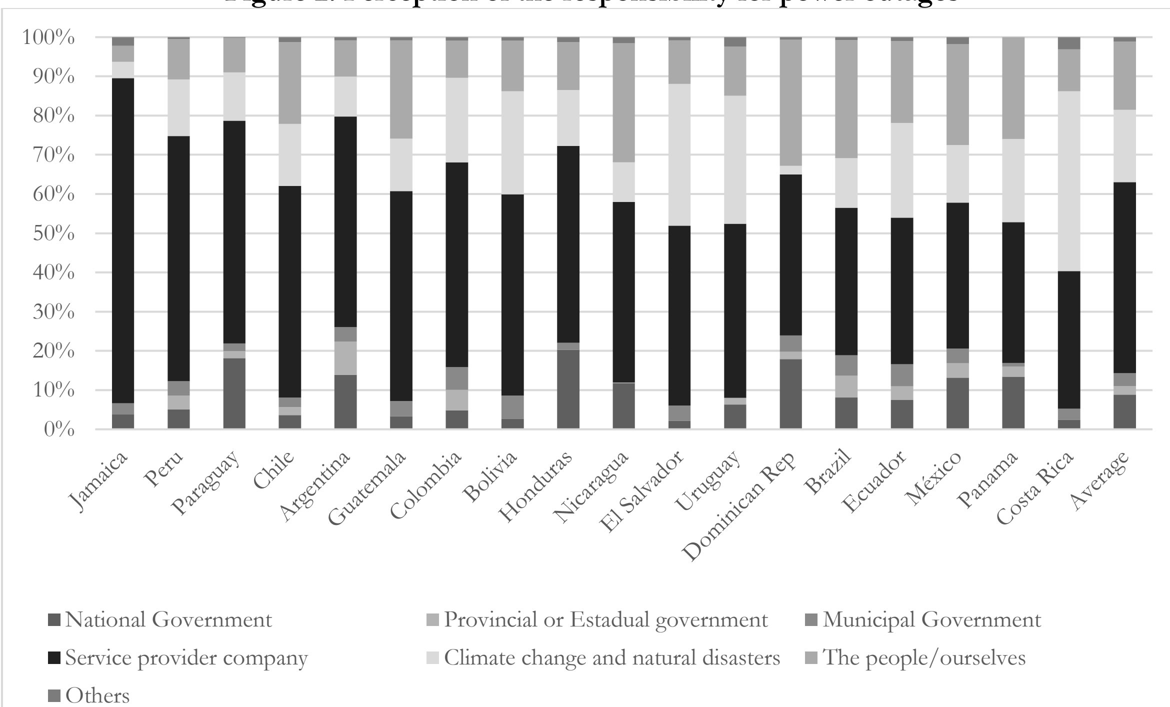
Figure 1. Main concerns in LAC regarding basic infrastructure



Source: Authors' elaboration using the LAPOP database (2018-2019)

Additionally, as we show in Figure 2, on average, 48.8% of those interviewed believed that electricity distributors were to blame for power interruptions in their country, while only 18.4% of respondents associated interruptions with natural disasters and climate change, 17.4% associated them with "people/ourselves" (accidents at home, theft, damage to infrastructure, etc.), and 14.3% considered that national, provincial, and local governments were to blame.

Figure 2. Perception of the responsibility for power outages



Source: Authors' elaboration using the LAPOP database (2018-2019)

Finally, we should expect increasing challenges in the coming years. The digitalization era and all the real-time data generated require cloud storage services and data processing centers, which demand high-quality electricity services. Similarly, in the context of climate change, the increased frequency of extreme events is expected to increase the probability of network disruptions and higher peak demand.

3 State of quality regulation in Latin-America and the Caribbean

Since these countries do not present a separation between the distribution and commercialization of electrical energy, we directly analyze the performance data of the distribution companies. It is worth mentioning that there may be small methodological differences in the ways in which countries compute their SAIDI and SAIFI. These small differences do not influence our results since they stay unchanged throughout the period and generally apply to the national average and not to the firm's calculation. In particular, there is a difference in the weighting of the national indices: some by customers, others by connection point or feeder. Such differences, which also appear among European countries, in any case allow for comparability, particularly in terms of improvement in time.

We show in Table 1 the availability of the data. First, countries with at least two electricity distributors and a single regulator were chosen for the analysis. Of 160 companies surveyed, only 143 had data on SAIDI and SAIFI, which we use as dependent variables.

Table 1. Companies with available information on quality

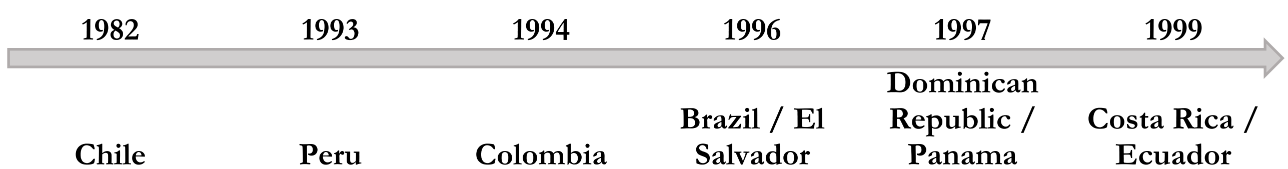
	Countries	Companies	Companies with SAIDI Information	Companies with SAIFI Information
1	Brazil	63	63	63
2	Chile	18	1	1
3	Colombia	21	21	21
4	Costa Rica	8	8	8
5	Dominican Republic	4	4	4
6	Ecuador	22	22	22
7	El Salvador	6	6	6
8	Panama	3	3	3
9	Peru	15	15	15
	Total	**160**	**143**	**143**

Source: Author´s elaboration

In addition to the data on SAIDI and SAIFI per company, we built a database for the quality regulation implemented in each country and the data on the characteristics of the companies, such as the number of clients and the capital structure. Public companies are those whose capital is controlled by the government (a capital holder of at least 51%), and private companies are those that do not have the government as the majority shareholder. We use this data to construct the explanatory variables as well as the instrumental variable.

The existence of regulation depends on the different ways in which the electricity sector has been liberalized. In LAC, the electricity sector liberalization process took place progressively. It started in Chile in 1982, followed by other countries in the 1990s (Figure 3). Of the countries analyzed, Peru was the second country to liberalize its electricity sector (in 1993), followed in 1994 by Colombia and in 1996 by Brazil and El Salvador. A year later, in 1997, the Dominican Republic and Panama liberalized their electricity sectors. Finally, Costa Rica and Ecuador[5] joined in 1999.

Figure 3. Liberalization of the electricity sector in Latin American and Caribbean countries



Source: Authors' elaboration

The liberalization process in these countries opened the market to investment by private companies. In this process, legal and regulatory frameworks were developed for the concession and operation of electricity transmission and distribution services. These regulatory frameworks normally describe the concessionaires' obligations regarding supply in their concession area, and they sometimes provide economic signals to stimulate the quality of the electricity supply service.

[5] It is worth noting that since 2015, the Ecuadorian electricity distribution market is no longer competitive. The Organic Law of the Public Service of Electric Power (LOSPEE) establishes in Articles 43 and 49 that the purchase and sale of electric power that are carried out between participants in the electric power sector through contracts, as well as short-term transactions, will be settled by the National State Electricity Operator (CENACE).

Regarding our main interest in the quality of electricity distribution, regulatory instruments aiming to ensure the reliability and good quality of energy distribution appeared from the second half of the 1990s, being modified in subsequent years. Moreover, countries have only progressively adopted the SAIDI and SAIFI international indicators. Looking at the history of regulations, as well as the implementation of continuity indicators compatible with international quality standards, we consider the year of the most important quality regulation as the explanatory variable in our model. The results of this analysis, with the year in which the significant regulatory instruments were implemented, are described in Table 2.

Table 2. Most important regulatory measures to improve the quality of electricity service

Country	Name of Regulation	Regulatory instrument implemented	Year selected
Brazil	Resolución Aneel 24/2000	Standards regarding continuity of services	2009
	Resolución Aneel 395/2009	Penalty imposed if standards are not fulfilled together with a customer compensation mechanism	
	Resolução Normativa nº 457/2011	Continuous incentive mechanisms	
Chile	Nota Técnica 2017	Standards regarding continuity of services	2019
	Nota Técnica 2019	Penalties imposed for distributors	
Colombia	Calidad de servicio CREG 070 de 1998	Limits regarding outages and compensation for customers if not respected	2008
	Calidad de servicio CREG 097 de 2008	Incentives with limits, compensation for worst served consumers and contracts considering "extra quality"	
	Informe Superservicios 2016	Creation of OpenData database as well as an on-line service to delcare problems with utilities	
	Calidad de servicio CREG 015 de 2018	Reinforcement of Incentives with limits, compensation and contracts considering "extra quality"	
Costa Rica	AR NT SUCAL y SUCOM 2015	Limits regarding outages and compensation for customers if not respected	2015
Ecuador	Regulación No. CONELEC-004/2001	SAIDI and SAIFI adoption as well as limits	2018
	Regulación No. ARCONEL 005/2018.	Different sanctions depending on the way standars of quality are not respected. Compensation mechanism	
El Salvador	Norma de calidad-2014	Compensation to costumers	2014
Panama	Resolución JD-764 1998	Penalties for voltage disruption	2013
	Resolución AN 6001-2013	Penalties and compensation mechamisms for costumers	
	Reglam. de distribución 2019	Reinforcement of penalties and compensations	
Peru	NTCSE 1997	Limits regarding outages and compensation for customers if not respected in urban areas	2004
	OSINERG 074/2004	Clear adoption of a regime for limits and compensation for customers monitored by the regulation	
	NTCSER 016/2008	Actualization of previous measure	
Dominican Republic	SIE 56/2002	SAIDI and SAIFI adoption	2012
	SIE 20/2003	Ractification of SIE 56/2002	
	SIE 19/2012	Limits regarding outages and compensation for customers if not respected	
	SIE 66/2016	End of the transition period regarding standards for quality	

Source: Authors' elaboration on the regulations of the countries

To study the impact of the regulation that we identify as the key regulation, we analyze the average SAIDI and SAIFI before and after the regulation was implemented for each company over time. Table 3 summarizes the country average SAIDI and SAIFI before and after regulation. We see that the two indicators are smaller after the implementation.[6] Moreover, the average SAIDI changes from 40.8 to 24.1 and the average SAIFI from 29.7 to 16.2 (Table 3).

[6] The evolution of the SAIDI and SAIFI indicators for each of the 143 companies is presented in Appendix 1.

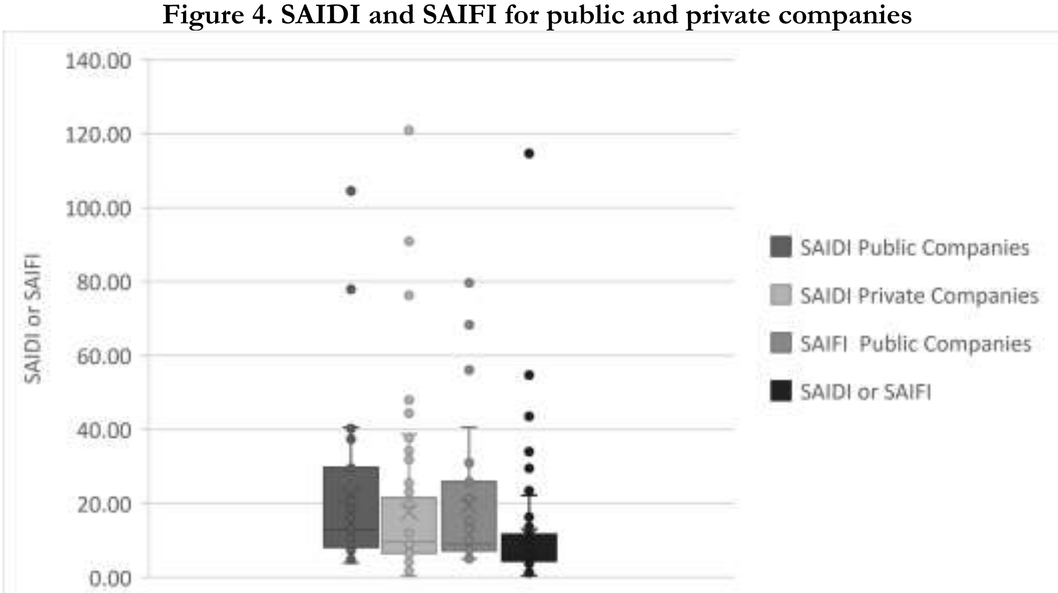
Table 3. Quality before and after the implementation of the regulation

Country	Year of Regulation	SAIDI or equivalent		SAIFI or equivalent	
		Before	After	Before	After
Brazil	2009	17.6	16.8	16.2	12
Chile	2019	3.6	n.a.	9.1	n.a.
Colombia	2008	130	32.9	83.7	33.6
Costa Rica	2015	9.7	10	11.1	7.8
Dominican Republic	2012	128.5	115.7	40	26.8
Ecuador	2018	104.4	14.1	82.5	9.3
El Salvador	2014	21	8.4	9.9	3.5
Panama	2013	22.8	43.6	10.3	18.5
Peru	2004	n.a.	32	n.a.	15
Total Sample of Companies		**40.8**	**24.1**	**29.7**	**16.2**

Source: Authors' elaboration.

We also consider in our estimation the importance of ownership for quality results. On the one hand, we observe (Figure 4) that on average, public companies tend to have a higher SAIDI and SAIFI. On the other hand, the worst performances are verified as private companies, as the SAIDI and SAIFI dispersion is greater in private companies.

Figure 4. SAIDI and SAIFI for public and private companies



Source: Authors' elaboration

4 Methodology

To estimate the impact of regulation on the quality of electricity services, we regress a variable that captures the quality of services, defined as SAIDI or SAIFI, respectively, on the variable of interest (regulation) and other relevant control variables. We use panel data with i firms across t years and include both firm fixed effects and year dummies.[7] The independent variable *regulation* is a dummy variable that starts taking the value 1 the year immediately after the key quality regulation measure is approved (and 0 otherwise). This is the case because in general, there is a small delay between the approval of a measure and its actual implementation.

Equation (1) presents the first stage of the final specification of the model as just described:

$$Quality_{i,t} = \beta_0 + \beta_1 * Regulation_{jt} + \beta_2 * PubliRegulator_{it} + \beta_3 * Public_{it} + \mathrm{u}_i + z_t + \mathrm{e}_{it} \quad (1)$$

where β_1 represents the coefficient of the variable of interest *presence of quality regulation* ($Regulation_{i,t}$), β_2 represents the coefficient of the control variable *presence of transparent publication of the companies' SAIDI and/or SAIFI on the regulator's website* ($PubliRegulator_{it}$), and β_3 represents the coefficient for the control variable that reports whether or not the company is public ($Public_{it}$).[8] The company fixed effects are captured by u_i, the yearly effects byz_t, and the residuals by $\mathrm{e_{it}}$. Table 4 details the variables of this model.

There are two main problems with the estimation of Equation (1). First, the implementation of a quality regulation may be motivated by the existence of poor quality. This is what is generally known as reverse causality. Second, it is likely that the implementation of quality regulation is due to administrative changes in regulatory authorities that simultaneously influence service quality and the implementation of the regulation itself. This means there might be an omitted variable bias. These endogeneity problems force us to estimate the model using the two-stage least squares (2SLS) method.

The instrumental variable chosen is the number of clients at the national level.[9] We assume that the number of clients at the country level would only affect the quality of the electricity service, estimated at the firm level, via the regulation.[10] Equation (2) shows the relationship between the number of clients at the country level and the regulation, which is the second stage of the 2SLS with instrumental variable (IV) estimation:

$$Regulation_{j,t} = \gamma_0 + \gamma_1 * UC_{jt} + \varepsilon_{it} \quad (2)$$

Before arriving at the final specification with the instrumental variable and firm-level fixed effects, we estimate other specifications (see Tables 5 and 6), namely standard Ordinary Least Squares (OLS) (with and without year dummies and with and without controls) and the instrumental variable method (with and without fixed effects).[11] The results are presented in the next section.

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[7] When running the estimate of the two-stage least squares (2SLS) with an instrumental variable (IV), factor variables are not allowed, so the variable *year* is instead included as a continuous variable. We also include country fixed effects in the OLS preliminary version, even if most country effects are non-significant, probably due to the country-year-specific regulation that already captures this.

[8] We also estimated a model to include an interaction between the regulation variable and whether the company is public or private, but the results were not conclusive. This can be explained by the sample containing only information on companies from countries that have more than one distribution company and only one regulator. Therefore, in the same country, the same regulation intervenes on both public companies and private companies. The results for these alternative specifications can be made available by the authors upon request.

[9] The choice of instrument was inspired by Ter-Martirosyan and Kwoka (2010).

[10] The selection of the final estimation method and instrumental variable was confirmed by running several statistical tests. The first was an endogeneity test to measure the relevance of the chosen variables to the model. The second was to test if the selected instrument was weak or not (Wooldridge, 1995). In both cases, the null hypotheses that the variables are exogenous and that the instrument is weak were rejected. The results are available from the authors upon request.

[11] We performed the Hausman test to see whether the difference in coefficients was systematic. The null hypothesis of a non-systematic difference was rejected at the 5% significance level; hence, fixed effects were chosen as the preferred method as opposed to random effects (RE). The use of RE would have been challenging due to the endogeneity problem previously mentioned. The results are available from the authors upon request.

Table 4. Variables

Name	Description	Type	Unit	Interval	Expected sign
$Quality_{i,t}$	SAIDI: average interruption duration per customer of firm i per year; SAIFI: number of interruptions per customer of firm i per year	Dependent	Numerical	[0; ∞+]	
$Regulation_{it}$	The regulation has been implemented starting last year (1) or not (0)	Independent/ Variable of interest	Dummy	0 o 1	Negative
$PubliRegulator_{it}$	The regulator's website presents information on distributor´s performance in a transparent, systematic and accessible in that year (1) or not (0)	Independent/Control	Dummy	0 or 1	Negative
$Public_{it}$	More than 50% of shares of company i in year t are publicly owned (1) or not (0)	Independent/Control	Dummy	0 or 1	Zero or Positive
UC_{it}	Number of clients at the country level in year t ;	Instrumental	Numerical	[0; ∞+]	Negative

Source: Authors' elaboration

5 Evidence of the impact of regulation on quality of electricity supply

Table 5 presents the results of the estimations with SAIDI as the dependent variable, while Table 6 presents the results with respect to SAIFI. Columns (1–3) show the results for the standard OLS regressions with and without year dummies and with and without the control variables. Column (4) shows the results for 2SLS estimation with the inclusion of the instrumental variable (number of clients aggregated at the national level). Column (5) is the same as Column (4) but with company fixed effects and robust standard errors.[12]

The coefficients of the variable of interest (*regulation*) are significant, with confidence levels greater than 99% for all estimates and with the expected negative sign. This confirms that regulation was effective in improving

[12] Robust standard errors were included following a Portmanteau test for panel serial correlation, which also allows for unbalanced panel data (Born and Breitung, 2016; Inoue and Solon, 2006).

the continuity of the electricity service, both in terms of a decrease in the duration and a decrease in the average frequency of interruptions per customer.

The estimates also show that the control variable that takes the value of 1 if SAIDI and SAIFI coefficients are made publicly available for each year (*publication by regulator*) had an inconclusive impact on actual quality. In particular, in the final specification in Column (5) of both the SAIDI and SAIFI estimates, it is positive. One possible interpretation is that once the data are published in a transparent manner on the official webpage, there is less incentive to improve service quality. The coefficient of this variable is nonetheless negative and significant when fixed effects are not included in Column (4) of Table 5 (and insignificant in the same column of Table 6).

The control variable that indicates whether or not the utility is public (*public*) shows consistency in its coefficient, which is positive and statistically significant in Columns (3) and (4) of both Tables 5 and 6. It is omitted in Column (6), where fixed effects are included, due to a lack of variation across the panel. The positive coefficient suggests that on average, private companies outperform public ones in terms of quality.

Finally, it is worth nothing that the yearly dummies capture potential improvements that could be due to the natural evolution of technology and system optimization independently of regulation. Similarly, company fixed effects capture intrinsic differences that could be due to the varying performances of companies. These are in general significant and omitted for shortness.

Table *5*. Results with SAIDI as the Dependent Variable

VARIABLES (DV: SAIDI)	(1) OLS	(2) OLS	(3) OLS	(4) 2SLS IV	(5) IV with FE & robust s.e.
Regulation	-18.59***	-46.24***	-39.61***	-77.59***	-18.24***
	(2.667)	(3.636)	(3.646)	(7.544)	(3.748)
Publication by regulator			-6.547*	-20.85***	23.16***
			(3.481)	(4.091)	(7.894)
Public			30.29***	21.65***	
			(3.137)	(3.782)	
Constant	41.22***	17.26***	21.06***	-9,430***	9.940
	(1.980)	(6.178)	(6.914)	(1,215)	(7.102)
Observations	1,759	1,759	1,759	1,759	1,759
R-squared	0.027	0.156	0.212		
Number of Companies					140
Yearly dummies/ Year variable		X	X	X	X
Regulation instrumentalized as UC				X	X
Company fixed-effects					X

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Authors' own elaboration

Table *6*. Results with SAIFI as the Dependent Variable

VARIABLES (DV: SAIFI)	(1) OLS	(2) OLS	(3) OLS	(4) 2SLS IV	(5) IV with FE & robust s.e.
Regulation	-14.28***	-37.29***	-29.97***	-55.35***	-18.33***
	(1.978)	(2.660)	(2.674)	(5.596)	(2.952)
Publication by regulator			11.36***	1.567	17.99***
			(2.627)	(3.121)	(6.403)
Public			25.54***	19.83***	
			(2.306)	(2.796)	
Constant	29.22***	14.78***	1.394	-6,973***	8.034
	(1.468)	(4.539)	(5.135)	(896.3)	(5.401)
Observations	1,737	1,737	1,737	1,737	1,737
R-squared	0.029	0.175	0.230	0.008	
Number of Companies					141
Yearly dummies/ Year variable		X	X	X	X
Regulation instrumentalized as UC				X	X
Company fixed-effects					X

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Authors' own elaboration

6. Concluding Remarks

Avoiding frequent and lasting blackouts and brownouts is an important challenge for distributing companies. These phenomena hinder productivity in electricity-dependent industries and decrease household welfare that is derived from the use of electricity services, such as food conservation, temperature comfort, and entertainment. In LAC, one out of three citizens are concerned about power outages according to the LAPOP database 2018-2019.

Regulation plays an important role in promoting a better quality of electricity services since distributing companies are profit-seeking firms operating in local monopolies in their distributing area. In this regard, they may be tempted to minimize costs, which can negatively affect quality.

We gathered data on electricity service quality, measured by the SAIDI and SAIFI indicators, for 143 electricity distributors based in Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Panama, and Peru between 2003 and 2019. We also surveyed the adoption of a quality regulation in the period, defined as an *incentive regulation* in the sense that it includes some type of penalty paid by the company in the case of an outage. On average, we observe that SAIDI and SAIFI improved after the quality regulation's implementation, changing from 40.8 to 24.1 hours of outage per customer per year and 29.7 to 16.2 outages per customer per year, respectively.

We then used the data to test whether the above-mentioned improvements in terms of quality could actually be attributed to the regulation itself. Our results show that quality regulation in this panel of countries had a significant impact in improving the quality of electricity services since it negatively affected the SAIDI and SAIFI indicators. We also found a significant impact of ownership: on average, private firms outperformed private ones, while the dispersion in quality among them was higher.

The results of this research point to the importance of regulation for the quality of electricity service implemented in LAC countries. In this regard, it is in line with most of the theoretical literature on the matter, as well as with empirical studies for Italy (Ajodhia, Lo Schiavo, and Malaman, 2006) and the United States (Ter-Martirosyan and Kwoka, 2010). In contrast to the findings of Jamasb, Orea, and Pollitt (2012) for the UK, quality regulation in LAC has been sufficient to increase electricity quality measures in terms of continuity of service. The lack of stylized facts on the matter underlines the importance of continuing efforts to understand the impact of regulation on quality as well as the best way to formulate that regulation to achieve the optimal quality of electricity services.

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7 Appendix

Table A.1. SAIDI and SAIFI before and after quality regulation – continues.

Country	Year of Regulation	Business	SAIDI or equivalent		SAIFI or equivalent	
			No Regulation	With Regulation	No Regulation	With Regulation
Brazil	2009	AME		50.21		35.68
Brazil	2009	BOAVISTA	14.24	24.12	32.06	41.99
Brazil	2009	CEA	40.51	61.94	45.96	44.23
Brazil	2009	CEBDIS	13.21	13.74	13.83	11.38
Brazil	2009	CEEED	23.16	19.40	17.86	12.72
Brazil	2009	CELESCDIS	18.10	13.94	13.86	9.71
Brazil	2009	CELGD	23.03	31.40	22.31	20.18
Brazil	2009	CELPE	15.20	18.24	10.20	7.52
Brazil	2009	CEMAR	48.06	17.09	29.57	9.53
Brazil	2009	CEMIGD	12.23	12.11	6.66	5.99
Brazil	2009	CERON	48.06	35.87	58.59	25.30
Brazil	2009	CLOSE	169.93	78.52	20.61	53.72
Brazil	2009	CFLO	3.93	5.21	5.58	5.11
Brazil	2009	CHESP	19.56	14.31	44.79	23.91
Brazil	2009	CNEE	6.32	7.70	9.03	9.67
Brazil	2009	COCEL	14.95	10.86	10.80	8.30
Brazil	2009	COELBA	16.71	20.88	9.45	8.51
Brazil	2009	COOPERALIANÇA	3.89	4.94	3.04	4.19
Brazil	2009	COPELDIS	14.30	11.24	13.36	7.73
Brazil	2009	COSERN	12.52	13.51	9.39	7.40
Brazil	2009	CPFLJaguari	6.96	6.40	6.30	5.30
Brazil	2009	CPFLLestePaulista	8.36	8.23	8.71	6.32
Brazil	2009	CPFLMococa	7.35	6.46	8.62	5.79
Brazil	2009	CPFLPAULISTA	6.40	6.94	5.54	4.86
Brazil	2009	CPFLPIRATININGA	7.18	6.85	5.37	4.40
Brazil	2009	CPFLSantaCruz	7.96	6.50	9.61	5.86
Brazil	2009	CPFLSulPaulista	10.32	10.36	9.26	8.03
Brazil	2009	DCELT	9.90	14.06	15.10	15.87
Brazil	2009	DEMEI	11.42	9.91	14.80	11.20
Brazil	2009	DMED	5.43	3.29	6.77	3.01
Brazil	2009	EBO	15.02	7.79	12.12	5.59
Brazil	2009	EDEVP	7.95	6.13	8.86	5.50
Brazil	2009	EDPES	11.73	9.21	8.96	5.67
Brazil	2009	EDPSP	9.77	8.60	7.16	5.48
Brazil	2009	EEB	9.45	12.72	11.58	9.49
Brazil	2009	EFLJC	12.35	3.55	8.03	3.38
Brazil	2009	EFLUL	15.31	7.15	15.59	7.04
Brazil	2009	ELECTRO	10.06	8.44	7.27	4.91
Brazil	2009	ELETROACRE	24.95	53.72	37.93	40.74
Brazil	2009	ELETROCAR	25.15	14.60	25.03	12.57
Brazil	2009	ELETROPAULO	10.25	11.89	6.84	5.46

Table A.1. SAIDI and SAIFI before and after quality regulation – continues.

Country	Year of Regulation	Business	SAIDI or equivalent		SAIFI or equivalent	
			No Regulation	With Regulation	No Regulation	With Regulation
Brazil	2009	ENF	19.07	8.58	16.75	6.82
Brazil	2009	EPB	35.49	19.46	17.49	9.54
Brazil	2009	EQUATORIALAL	25.18	31.61	19.25	17.86
Brazil	2009	EQUATORIALPA	44.43	56.84	37.43	31.36
Brazil	2009	EQUATORIALPI	49.03	30.88	38.44	21.08
Brazil	2009	ESE	14.47	15.09	10.82	9.01
Brazil	2009	ESS	6.95	7.68	7.97	7.08
Brazil	2009	ETO	44.17	34.14	35.14	17.58
Brazil	2009	FORCEL	2.28	1.89	5.42	3.63
Brazil	2009	HYDROPAN	13.00	8.00	18.15	10.88
Brazil	2009	LIGHT	9.20	13.36	6.65	6.80
Brazil	2009	MUXENERGY	19.43	4.11	18.09	3.81
Brazil	2009	RGE	19.75	15.36	13.52	8.44
Brazil	2009	RGESUL	19.68	16.30	13.72	8.16
Brazil	2009	SULGIPE	18.85	12.21	19.21	9.92
Brazil	2009	UHENPAL	23.80	16.23	28.12	10.04
Chile	2019	Enel	6.64		1.52	
Colombia	2008	CODENSA		12.61		13.24
Colombia	2008	ESSA		24.39		20.37
Colombia	2008	ELECTRICARIBE	130.00	96.91	83.70	90.20
Colombia	2008	EMCALI		18.77		23.90
Colombia	2008	EPM		15.11		22.59
Colombia	2008	EPSA(CELSIA)		17.07		20.35
Colombia	2008	CEDENAR		82.95		48.76
Colombia	2008	CENS		32.94		10.39
Colombia	2008	CETSA		5.18		14.34
Colombia	2008	CHEC		33.21		28.00
Colombia	2008	DESPAC		73.84		44.61
Colombia	2008	EDEQ		11.54		14.36
Colombia	2008	EMSA		18.72		31.81
Colombia	2008	ELECTROCAQUETA		63.08		66.47
Colombia	2008	CEO		18.72		31.56
Colombia	2008	EECC		82.48		
Colombia	2008	EBSA		12.29		56.68
Colombia	2008	EEP		15.45		12.10
Colombia	2008	ELECTROHUILA		51.40		43.37
Colombia	2008	ENELAR		94.16		66.69
Colombia	2008	ENERTO LIMA		60.28		112.12
Costa Rica	2015	CNFL	10.29	34.38	12.75	60.24
Costa Rica	2015	COOPEALFARO	29.90	5.37	47.00	6.55
Costa Rica	2015	COOPEGUANACASTE	4.80	6.75		8.40
Costa Rica	2015	COOPELESCA	7.90	9.85	11.00	9.65
Costa Rica	2015	COOPESANTOS	1.80	16.63		7.23
Costa Rica	2015	ESPH	5.30	15.65	5.00	7.63
Costa Rica	2015	ICE	14.00	10.22	11.74	8.68
Costa Rica	2015	JASEC	4.93	9.12	6.75	7.15

Table A.1. SAIDI and SAIFI before and after quality regulation – continues.

Country	Year of Regulation	Business	SAIDI or equivalent		SAIFI or equivalent	
			No Regulation	With Regulation	No Regulation	With Regulation
Ecuador	2018	CNEL	84.19	11.14	75.71	8.71
Ecuador	2018	CNELGuayaquil	3.37	2.63	5.70	3.50
Ecuador	2018	CNELBolivar	167.43	17.58	111.31	8.84
Ecuador	2018	CNELElOro	104.99	12.79	118.74	14.84
Ecuador	2018	CNELEsmeraldas	181.58	18.14	111.94	13.91
Ecuador	2018	CNELGuayasLosRíos	69.70	14.52	73.82	11.04
Ecuador	2018	CNELLosRíos	157.40	25.45	200.77	14.96
Ecuador	2018	CNELManabí	177.49	8.21	149.52	7.51
Ecuador	2018	CNELMiracle	180.66	17.82	118.15	15.08
Ecuador	2018	CNELStElena	128.55	24.85	98.45	11.09
Ecuador	2018	CNELStoSunday	89.05	4.46	70.79	4.06
Ecuador	2018	CNELSucumbíos	285.14	36.62	207.06	18.52
Ecuador	2018	EEAmbato	53.68	7.18	50.90	5.53
Ecuador	2018	EEAzogues	38.55	7.60	31.19	4.96
Ecuador	2018	EECentrosur	44.28	9.41	27.00	4.48
Ecuador	2018	EECotopaxi	26.39	6.22	28.46	6.77
Ecuador	2018	EEGalapagos	105.31	29.77	71.35	13.03
Ecuador	2018	EENorth	92.04	10.84	60.67	8.56
Ecuador	2018	EEQuito	20.28	1.54	21.57	1.93
Ecuador	2018	EERiobamba	119.33	23.18	54.25	11.52
Ecuador	2018	EESur	53.07	6.70	31.17	5.62
Ecuador	2018	EEPdeGuayaquil	28.22	-	40.42	
El Salvador	2014	CAESS	21.82	8.63	9.87	3.67
El Salvador	2014	CLESA	21.95	11.08	8.13	3.93
El Salvador	2014	DEUSEM	20.21	5.97	10.38	2.38
El Salvador	2014	DELSUR	23.32	10.69	10.30	5.39
El Salvador	2014	EEO	27.17	11.08	14.29	3.88
El Salvador	2014	EDESAL	7.14	3.01	4.32	1.72
Panama	2013	ENSA	21.82	36.02	9.87	15.49
Panama	2013	EDEMET	21.95	51.55	8.13	19.56
Panama	2013	EDECHI	20.21	39.29	10.38	19.36

Table A.1. SAIDI and SAIFI before and after quality regulation – continuation.

Country	**Year of Regulation**	**Business**	**SAIDI or equivalent**		**SAIFI or equivalent**	
			No Regulation	**With Regulation**	**No Regulation**	**With Regulation**
Peru	2004	EnelDistributionPeru		8.65	2.87	2.86
Peru	2004	Hydrandine		48.17		20.26
Peru	2004	Southeast		35.14		18.32
Peru	2004	Electrosur		15.89		9.62
Peru	2004	electropuncture		20.32		12.98
Peru	2004	edelnor			4.46	3.94
Peru	2004	Electrodune		62.14		16.33
Peru	2004	ENOSA				28.03
Peru	2004	SEAL				15.28
Peru	2004	electronorthwest		43.20		43.20
Peru	2004	Electric Society of the South West		21.75		9.89
Peru	2004	Electrocenter		56.48		24.40
Peru	2004	ElectroOrient		23.76		23.76
Peru	2004	Electronorth		25.35		11.68
Peru	2004	ElectroUcayali		14.84		10.33
Dominican Republic	2012	Edenorte	158.62	92.82	46.47	27.17
Dominican Republic	2012	Edesur	161.94	125.27	46.11	32.91
Dominican Republic	2012	EDEEST	137.24	139.75	35.18	
Dominican Republic	2012	CEPM	79.69	124.29	17.55	12.25
Total			**40.75**	**24.08**	**29.75**	**16.15**

Source: Authors' elaboration based on companies' and regulators' website information.