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Factors Associated with Electricity Losses: A Panel Data Perspective

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ABSTRACT

Electricity losses are an important problem worldwide that should be mitigated, since they generate an impact on CO_2 emissions and drive a possible rate increase. The benefits of the reduction of such losses are savings, a better environment and less infrastructure needs, amongst others. However, in order to generate reductions, it is imperative to measure the factors associated with such losses. Thus, the objective of this study is to explore the factors associated with electricity losses in the world. A database of 91 countries and 10 years of available data, from 2005 to 2014, was built, with variables taken according to our literature review and obtaind from different publicly available sources. A panel data model with international information was then tested in order to find the determinants of power losses. The model with the best fit was one with random effects. Our results show that the variables unemployment and crime were significant and positive at one percent, while urbanization and education were significant and negative also at one percent. Finally, we provide some policy implications on the evidence of how electricity losses are associated with low education, high unemployment, high homicide rates, and less urbanization.

Keywords: Electricity Losses, T&D Losses, Electricity Theft, Non-technical Losses, Power Losses, Random Effects.
JEL Classifications: L94, N70, Q41

1. INTRODUCTION

Electricity losses are an important problem that should be mitigated. They generate an impact on CO_2 emissions (Daví-Arderius et al., 2017) and drive a possible rate increase (Chirwa, 2016). Reducing losses can have benefits such as savings, improvement in the environment, and reduction of infrastructure needs for the generation (Averbukh et al., 2019).

There are losses of electricity in the Generation, Transmission, and Distribution that can be technical or non-technical (Depuru et al., 2011). While it is true that in Generation the losses can be clearly defined technically, the same does not happen in the Transmission and Distribution (T&D) because there are also non-technical factors that are usually external (Depuru et al., 2011). These non-technical losses can occur due to illegal connections, theft or manipulation of the meters (Obafemi and Ifere, 2013). Losses may vary from system to system. They can be <6% in very efficient systems, and more than 15% in very inefficient systems (Smith, 2004).

It is considered that theft is the most significant part of the non-technical losses (Jamil, 2018), and what generates significant economic distortions because no money is received for the sale of this electricity, charging captive consumers with the cost (Smith, 2004). In (Briseño and Rojas, 2020), some of the factors associated with electricity theft, for the particular case of Mexico, where studied, while in (Jawad and Ayyash, 2020), an analysis of electricity loss and theft is done for the case of Palestine and in (Jamil, 2018). Furthermore, the problem of electricity theft was studied from the point of view of the principal-agent model in (Jamil and Ahmad, 2019).

Measuring electricity theft is not a simple task. There are many approaches in order to do so, see (Tariq and Poor, 2016; Zheng et al., 2018). Howerver, we do not focus on the measurement itself but on the proxies for measurement and therefore their economic impact. In previous studies, it was measured through proxy variable T&D losses (Gaur and Gupta, 2016; Razavi and Fleury, 2019; Smith, 2004). In the present research, the factors that influence T&D losses will be explored. However, since the variable T&D losses is used as an approximation to electricity theft, the drivers of both variables will be similar. Indeed, few articles deal with the issue of electricity losses. The greatest focus in the literature is to study theft even if it is not measured directly. For this reason, researchers that will be cited in this research will deal more with the issue of electricity theft.

The structure of the paper is as follows: Section 2 presents results from the literature in order to find the best proxies for drivers of electricity losses. Section 3 presents some statistics about the economic impact of electricity losses in the world. Section 4 presents the variables and data used for the econometric model. Section 5 gives the results of the panel data econometric model. Finally, Section 6 concludes and gives some policy implications.

2. DRIVERS OF ELECTRICITY LOSSES

As mentioned, in the studies on electricity losses and their types, different variables are used as dependents or explained. Some of them try to explain the causes of T&D losses (Gaur and Gupta, 2016; Razavi and Fleury, 2019; Smith, 2004). In other studies, the electricity theft measured directly is explored (Yurtseven, 2015), or with an estimate of the extent of this activity (Jamil, 2018), an analysis of its theoretical causes (Jamil and Ahmad, 2019), or a ranking of its possible determinants (Yakubu et al., 2018).

The information used in the researches comes from various sources. Some of the international organizations such as the World Bank (Smith, 2004), others of government agencies at the country or region level (Gaur and Gupta, 2016; Razavi and Fleury, 2019), and in some cases citizens are interviewed directly (Jamil, 2018; Yakubu et al., 2018).

The methodologies used for the study of electrical losses are varied. For example theoretical analysis under the principal-agent perspective, correlations, rankings, regression, generalized method of moments, generalized minimum squares feasible, and machine learning, between others. Table 1 shows some of the main studies done in recent years, a brief description of its methodology, and the enumeration of the explanatory variables that were significant.

As mentioned, the main variables that impact on electricity theft in a positive sense are price (Yakubu et al., 2018; Yurtseven, 2015), temperature (Yurtseven, 2015), rural population (Yurtseven, 2015), agricultural production (Yurtseven, 2015), poverty (Gaur and Gupta, 2016), corruption (Gaur and Gupta, 2016; Yakubu et al., 2018), expenses on electricity (Jamil, 2018), low quality of energy supplied (Yakubu et al., 2018), weak compliance with the law (Yakubu et al., 2018), crime (Razavi and Fleury, 2019), and consumption per person (Razavi and Fleury, 2019). On the other hand, the factors that reduce electricity theft are good governance (Smith, 2004), education (Yurtseven, 2015), income (Razavi and Fleury, 2019; Yurtseven, 2015), net migration (Yurtseven, 2015), participation in referendum (Yurtseven, 2015), literacy (Gaur and Gupta, 2016; Razavi and Fleury, 2019), participation of the industrial sector (Gaur and Gupta, 2016), government efficiency in tax collection (Gaur and

Table 1: Variables associated with electricity losses

Research	Method	Dependent variable	Positive relationship	Negative relationship
(Smith, 2004)	Correlations between transmission and distribution losses and indicators of governance. Information from 102 countries for two decades (1980-2000)	T&D losses	Time	Good governance
(Yurtseven, 2015)	Instrumental variables (IV) with generalized methods-of-moments (GMM) and three-stage least squares method (3SLS). Data of Provinces of Turkey from 2002 to 2010.	Percentage of electricity consumed illegally	Rural population. Price. Temperature Agricultural production	Education. Income. Net migration rate. Referendum participation rate. Trend
(Gaur and Gupta, 2016)	Feasible Generalized Least Squares (FGLS) model with data from 28 states of India for 5 years (2005-2009)	T&D losse	Poverty. Urbanization. Corruption. Percentage of electrified homes	Literacy. Industrial sector participation. Taxes to GDP ratio. Collective efficiency. Private capacity. Line length
(Jamil, 2018)	Questionnaires applied to rural and urban consumers in Rawalpindi and Islamabad. Regression Analysis	Perception of extend of electricity theft	Expenses on electricity.	Monitoring. Proper behavior of utility employee.
(Yakubu et al., 2018)	1523 questionnaires to customers of the Ashanti Region in India. Ranking of factors.	Electricity theft.	Prices. Low quality. Corruption. Low law enforcement	
(Jamil and Ahmad, 2019)	Principal-agent-client theoretical model. Costs and profits of theft, as well as the probability of being convicted.	Electricity theft	Economic benefits of stealing	Stealing costs: pecuniary and moral
(Razavi and Fleury, 2019)	Information from districts of Uttar Pradesh, India. Seven years, from 2006 to 2012. Machine learning models – Random forest.	T&D losse	Crime. Electricity consumption per person	Urbanization. Literacy. Income

Source: Authors

Gupta, 2016), the length of the line (Gaur and Gupta, 2016), the monitoring (Jamil, 2018), the ethical behavior of the employees of the utilities (Jamil, 2018), and the cost of crime (Jamil and Ahmad, 2019).

3. ELECTRICITY LOSSES IN THE WORLD

The average electricity loss from 2005 to 2010 in 141 countries with data is 14.37%. On average there is no clear trend in the period studied, the losses vary in a range of 13.22% to 14.74%. The countries with the highest average losses in the period studied are Benin (66%), Togo (61%), Congo (60%), Haiti (53%), and Iraq (40%). Those countries with the lowest electricity losses are Singapore, Israel, Gibraltar, Trinidad and Tobago, and Iceland, with <3% on average.

While it is true that on average there is not much change in losses year to year, some countries had strong increases or decreases during the period studied. The countries with the highest increase in losses, and that exceed the 15% threshold to be considered inefficient (Smith, 2004) are Libya (456%, from 13 to 30%), Jamaica (132%, from 12 to 20%), Cambodia (111%, of 11 to 19%), and Albania (105%, from 12 to 30%).

On the other hand, those countries that had significant improvements and went from the category of "inefficient" to "moderately efficient" were Botswana (−63%, 30 to 11%), Georgia (−63%, 16 to 12%), Uruguay (−59%, from 23 to 13%), Bosnia and Herzegovina (−54%, from 18 to 13%) and Angola (−53%, from 24 to 13%). Table 2 shows the evolution of losses on average and in some atypical cases.

In the following section, the description of the database is carried out with the explanatory variables of the electricity losses in the countries.

4. DATA DESCRIPTION

In order to find the factors that explain electricity losses in the world, a database of 91 countries was built as units of measurement and 10 years as units of time (2005 – 2014). Information about the explained variable *electricity losses* was collected, measured through the T&D Losses indicator. Likewise, some explanatory variables mentioned in the literature were integrated. The criteria for choosing these variables was that these were relevant in previous studies, and that data were available for most of the countries in the sample. The variables, as well as their explanation and sources, are shown in Table 3.

Table 4 shows the descriptive statistics for the last year of the sample (2014) of the variables studied. Countries with information during that year were considered. The average of T&D losses is 13.7% and the median is 10.9%. Countries with more losses are Togo, Libya, and Haiti with 71, 69 and 60% respectively; and those with losses <3% are Singapore, Trinidad and Tobago, Slovak Republic, Iceland, and Israel. Regarding access to electricity (ACCESS), the average is 83% and the median is 99.7%. Many countries have 100% coverage, while there are still several with low levels such as the cases of Burundi (7%), Chad (8.5%), Liberia (9.4%), Malawi (11.9%), and Congo (13.5 %), to name a few. Figure 1. shows some of the countries that have experienced an increase in losses over time, whereas Figure 2 presents some of the countries with a significant decline in losses over the period under study.

The average electric power consumption is 4270 kWh per capita, and the median is 2620. The countries with the highest per capita consumption are Iceland (53,832), Norway (22,999.9), and Bahrain (19,596.9). The average percentage of people over 25 years old with at least secondary school completed is 55.55% and the median is 62.1%. The countries with the highest percentage are Georgia, Uzbekistan, Estonia, and the Czech Republic, with more than 89%. Those with the lowest percentage in this area are Burkina Faso

Table 2: Electricity losses in percentage rounded by year, average and percentage change

Country	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	AVG	Change
Libya	13	10	14	33	36	36	32	59	61	70	36	456%
Jamaica	12	13	11	24	22	21	22	26	27	27	20	132%
Cambodia	11	12	14	11	14	29	28	18	28	23	19	111%
Albania	12	45	73	39	24	13	25	24	28	24	30	105%
Angola	24	12	13	10	10	12	11	11	11	11	13	−53%
Bosnia and Herzegovina	18	17	19	13	12	9	10	11	8	8	13	−54%
Uruguay	23	18	12	12	13	11	12	12	11	10	13	−59%
Georgia	16	14	13	13	13	11	11	11	8	6	12	−63%
Botswana	30	30	41	47	61	63			37	11	40	−63%
Benin		82	57	61							67	−25%
Togo	46	46	53		66	49	72	83		71	61	56%
Congo, Rep.		87		77	70	59	52	45	45	45	60	−49%
Haiti	38	38	48	53	51	58	66	57	57	60	53	57%
Iraq	30	28	41	49	49	36	39	43	40	51	40	69%
Iceland	4	4	4	3	3	4	3	3	2	3	3	−37%
Trinidad and Tobago	6	4	3	3	4	3	3	3	2	2	3	−58%
Gibraltar	3	3	3	3	3	3	3	3	3	3	3	10%
Israel	3	3	3	2	3	3	3	3	4	3	3	0%
Singapore	3	3	3	3	2	3	3	2	2	2	2	−35%
Average	14	15	14	15	14	14	14	14	13	14	14	2%

Source: Authors with information from the World Bank and the International Energy Agency. Blank spaces correspond to years without information reported

Table 3: Variables and sources

Variable	Explanation	Units	Source
Electric losses (T&DLosses)	Percentage of transmission and distribution losses.	0-100 scale.	World Bank, International Energy Agency (IEA)
Access to electricity (ACCESS)	Percentage of population with access to electricity.	0-100 scale	World Bank, IEA Statistics, Energy Sector Management Assistance Program
Electric consumption (C)	Production minus losses and own use.	kWh per capita.	World Bank IEA Statistics
Education (EDU)	Percentage of the population of at least 25 years old with secondary finished.	0-100 scale	World Bank. UNESCO Institute for Statistics
Literacy rate (LIT)	Percentage of people with at least 15 years old.	0-100 scale	World Bank. UNESCO Institute for Statistics
Unemployment (UNEMPLOY)	Percentage of the total labor force without work.	0-100 scale	World Bank International Labour Organization, ILOSTAT database
CRIME	Intentional homicides	Per 100,000 people.	World Bank. UN Office on Drugs and Crime's International Homicide Statistics database
Urban population (URBAN)	Percentage of people living in urban areas.	0-100 scale	World Bank United Nations Population Division. World Urbanization Prospects: 2018 Revision.

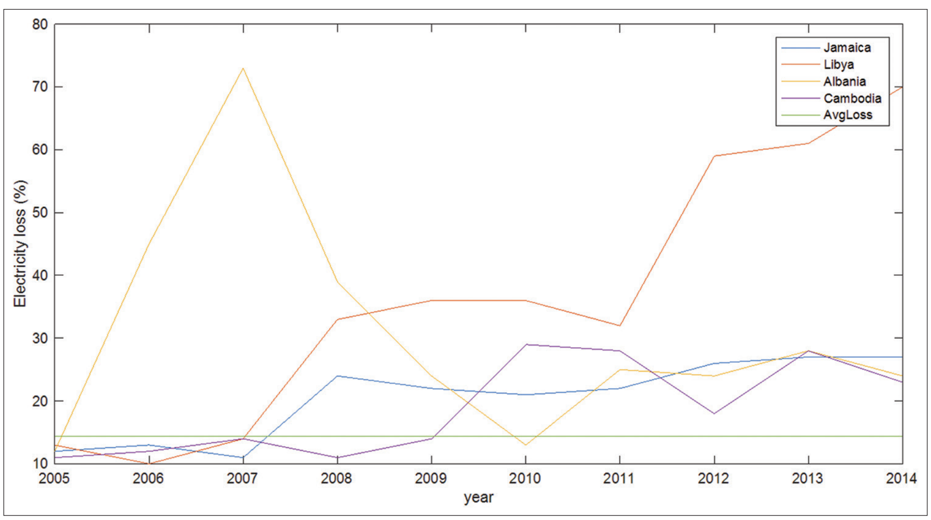
Source: Authors

Table 4: Descriptive statistics in 2014

Variable	n	Mean	Median	Standard Deviation	Minimum	Maximum
Electric losses (T&DLosses)	140	13.7	10.9	11.6	2	71
Access to electricity (ACCESS)	215	82.8	99.7	27.6	7	100
Electric consumption (C)	141	4270	2620	5941	39.1	53,832
Education (EDU)	70	55.5	62.1	26.1	2.8	92.1
Literacy rate (LIT)	54	85.7	93.1	17.5	32	100
Unemployment (UNEMPLOY)	126	8.4	6.6	6.3	0.2	35.2
CRIME	134	7.4	2.9	11.7	0	66.9
Urban population (URBAN)	214	59.7	60.4	24.2	11.8	100

Source: Authors

Figure 1: Some countries with the most electricity losses in the period under study



(2.8%), Burundi (3.3%) and Guinea (6.7%). Regarding literacy, the average is 85.7% and the median is 93.1%. The average unemployment rate is 8.4% and the median is 6.6%. The countries with the most unemployment are Kosovo with 35%, Bosnia and Herzegovina with 27.5% and Greece with 26.49%. The ones with the lowest unemployment are Qatar (0.2%) and Belarus (0.5%).

With respect to crime, the average of intentional murders per 100,000 inhabitants is 7.4 and the median is 2.9. The countries with the highest numbers in this ruble are Honduras, El Salvador, and Venezuela, with more than 60. The average of the urban population is 59.7% and the median is 60.4%.

5. EMPIRICAL RESULTS

With the aforementioned variables, some data panel models were carried out to find one that would better explain the electricity

Figure 2: Some countries with a significant decline in electricity losses in the period under study

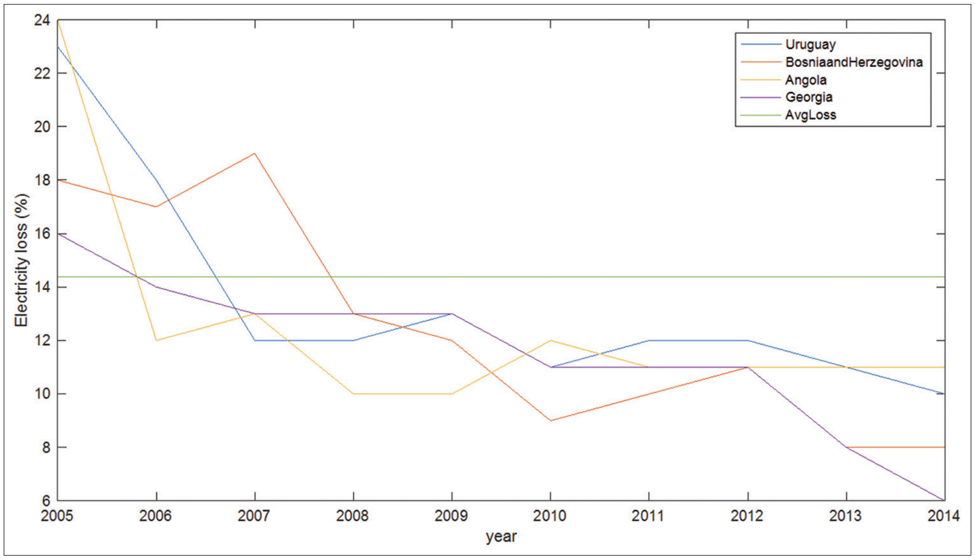


Table 5: Random effects model about factors associated with electricity losses (l_T&Dlosses)

	Coefficient	Statistic	P-value
Const	3.01419	15.59	0.0000
EDU	−0.00598028	−3.506	0.0005
UNEMPLOY	0.0111213	3.157	0.0016
CRIME	0.00780744	3.310	0.0009
URBAN	−0.00903925	−3.277	0.0011

Source: Authors

losses. The model with the best performance and that accomplish with the respective validation tests is the one shown in Table 5. It was necessary to log the dependent variable to achieve a better fit.

The model accomplishes with normality in errors (P = 0.69). Likewise, the null hypothesis of the Hausman test is accepted (P = 0.86), so it is chosen to use random effects in the data panel model. Correlation between the dependent variable and its forecast is 0.34. The variance between the variables (0.22) is greater than within time (0.02). The correlation between the explanatory variables is <0.5, so it is assumed that there is no multicollinearity. Since the explained variable was logarithmized and the explanatory ones are in level form, it is important to interpret the results taking care of this situation. The coefficients of variables are interpreted in the following paragraphs.

The education variable (EDU) was significant negative at one percent as mentioned in the literature. As the coefficient points out, an increase in a unit in education decreases 0.59% electricity losses. In other words, when the percentage of people 25 years or older who finish high school increases in a unit, the theft of electricity decreases by 0.59%. Unemployment (UNEMPLOY) was significant positive at one percent. The coefficient indicates that an increment in one unit in the unemployment rate, like a percentage of the total labor force (0-100 scale), increase in 1.11% electricity losses. CRIME resulted significant positive at one percent too. The coefficient associated with this variable shows that an increment in one unit in intentional homicides per 100,000 people increases in 0.78% electricity losses. The variable urban population (URBAN) was significant negative at one percent. Its coefficient shows that an increment of one unit in the percentage (0-100 base) of the population that is urban decrease in 0.59% electricity losses. Below are some conclusions or implications that are derived from the results of the econometric model.

6. CONCLUSION AND POLICY IMPLICATIONS

This document presents a review of the literature on the main findings on electricity losses. Likewise, it shows evidence of how electricity losses are associated with low education, high unemployment, high homicide rates, and less urbanization. Education is extremely necessary for the development of society. Provide technical capabilities to the citizens in order to they can exercise a job and are more prepared to have a family and financially support it. The lack of education, in addition to reducing the likelihood of citizens receiving civic and ethical values, makes them economically vulnerable and prone to engage in criminal or illegal activities. It is important that the state promote quality education so that its inhabitants have technical skills but also civic principles. Unemployment generates vulnerability in individuals due to social exclusion and the impossibility of achieving economic benefits. Higher levels of unemployment generate incentives for theft in general; and, in this case, for the theft of electric power. It is relevant that the state generates conditions for the development of companies that create jobs, or the possibility of assuring citizens who are unable to find one occupation. High impact crime, such as homicides, creates an environment of tolerance for minor crimes such as electricity theft. As some authors mention, crime creates crime (Razavi and Fleury, 2019). Regardless of the level of crime, always undesirable, it is important that the authority show the citizen the inconvenience of electricity theft in terms of its economic, environmental and social impacts. Likewise, punishing this crime with more important penalties would decrease its frequency. As some authors point out, a crime decreases if the cost and the probability of being penalized increases (Jamil and Ahmad, 2019).

Regarding urbanization, in this article, the result of the coefficient is negative although in previous studies it is ambiguous. Since this study is at the country level, it is understood that there are undeveloped populations that may be more prone to theft because they do not have adequate infrastructure. Regardless of the level of study, it is considered important that governments provide the electric power service, with reasonable quality and prices, for the population's well-being and to prevent theft. As a general conclusion, to combat electricity theft, governments can increase the average level of schooling of their inhabitants, generate opportunities or conditions for job creation, reduce high-impact crimes, increase the penalties for electricity theft, and generate infrastructure that allows citizens access to energy at reasonable prices. Likewise, it is also convenient to explore the use of technologies in vogue such as neural networks (Nazmul et al., 2019) and deep learning (Lu et al., 2019) for the effective detection of energy losses and their subsequent sanction.

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