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Article

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Factors Associated with Electricity Theft in Mexico

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ABSTRACT

The objective of this research is uncover some of the factors associated with electricity theft in Mexico. Econometric models of ordinary least squares with state and metropolitan information are carried out in order to know the determinants of energy theft. The models showed that there is a significant and positive relationship between electricity's theft and crime, government inefficiency, population, and population density.

Keywords: Electricity Theft, Electricity Losses, Non-technical Losses, Government Inefficiency, Crime
JEL Classifications: Q40, Q48, O13, K32

1. INTRODUCTION

Increasing efficiency in the generation, transmission, and distribution of electricity must be a goal of permanent improvement in the different cities of the world in order to reduce emissions and achieve more sustainability; undoubtedly, part of these improvements should be the decrease in electricity losses.

Electricity losses can be of two types: technical or non-technical losses (NTL's). "Technical losses occur naturally and are caused because of power dissipation in transmission lines, transformers, and other power system components" (Depuru et al., 2011. p. 1007). Obafemi and Ifere (2013) indicate that NTL's are generated by man and include theft, illegal connections, alteration of meters and inadequate measurements. Jamil (2018) notes that electricity theft is the major part of NTL's and is carried out by dishonest consumers who take it directly from the distribution network or with the complicity of some employees of the utility. "Electricity theft and corruption are illegal and combating these crimes are difficult as the monitors are frequently facilitating the crime" (Jamil, 2018, p. 148). According to Smith (2004), "the financial impacts of theft are reduced income from the sale of electricity and the necessity to charge more to consumers" (p. 2067). Even if the stolen energy is low in terms of the percentage of production, the monetary impact is usually significant due to the quantity of energy that could be sold (Smith, 2004).

Electricity losses have costs. Chirwa (2016) provides evidence that in Malawi there is a significant positive relationship between the increase in system losses and the increase in electricity tariffs; and Daví-Arderius et al. (2017) point out that the impact of energy losses with CO_2 emissions is significant. Among others, some benefits of reducing electricity losses are financial savings for energy companies, reduction of harmful emissions to the environment, reduced need for additional infrastructure for power generation and the possibility of lower electricity rates for consumers (Averbukh et al., 2019).

Losses in the generation of electricity are around 2% to 6% (Smith, 2004). However, in the transmission and distribution (T&D) phases, where the electricity can be measured and sold, losses also occur (Smith, 2004). "Very efficient power systems have <6% T&D losses —theft may be 1-2%. Less efficient systems may have 9-12% T&D loss and inefficient systems have line losses of over 15%" (Smith, 2004. p. 2070). The following section contains a literature review of the main factors that influence electricity theft.

2. DRIVERS OF ELECTRICITY LOSSES

Smith (2004) analyzes electricity theft in 102 countries in a period of twenty years and shows evidence that electricity theft is increasing over time; and that there is a high negative and significant correlation with indicators of good governance. Yurtseven (2015) develops econometric models using instrumental variables with the generalized method of moments approach (IV-GMM) and three-stage least squares method (3SLS) with data of the provinces of Turkey during the years 2002-2010, in order to estimate the socio-economic factors that impact in electricity theft. The results show that, in at least some of the models, the following variables were significant: percentage of rural population, price, temperature, dummy for the provinces in Southeastern Anatolia region, and percentage of agricultural production, in a positive sense; and education, income, net migration rate, referendum participation rate and trend, in a negative direction (Yurtseven, 2015).

Gaur and Gupta (2016) develop a Feasible Generalized Least Squares (FGLS) model with data from 28 states of India (2005 to 2009), and demonstrate that electricity theft is positively associated with poverty, urbanization, corruption, the percentage of electrified homes and populism. While there is a significant negative relationship with literacy, the participation of the industrial sector in the state GDP, taxes to GDP ratio, collective efficiency, presence of private capacity and line length (Gaur and Gupta, 2016). Jamil (2018) develops a model to explain electricity theft with data of a survey applied to consumers in Rawalpindi and Islamabad, Pakistan. The variables monitoring and good conduct of utility employees have a significant negative relationship with electricity theft, while monthly expenses have a significant positive association (Jamil, 2018).

Yakubu et al. (2018) apply a survey to 1532 people asking them in what grade they agree with some factors like determinants of electricity theft on a scale of 1 (strongly agree)-5 (strongly disagree). The factors that result with more influence (between 1 and 3) were higher electricity prices, poor quality of power supplied, corruption, poor enforcement of the law against electricity theft and that the PURC[1] doesn't fight for the interest of consumers (Yakubu et al., 2018).

Under the principal-agent-client perspective, Jamil and Ahmad (2019) propose an analysis framework whose underlying essence is that a person weighs the benefits of stealing electricity over the costs of being sanctioned. In this sense, if the benefits of stealing are greater than the costs (pecuniary, moral satisfaction and reputation), NTLs of electricity will tend to increase (Jamil and Ahmad, 2019). Razavi and Fleury (2019), through a random forest regression model using district data from Ultra Pradesh, India from 2006 to 2012, suggest that 87% of variability in electricity losses could be explained by "crime rate, literacy rate, income, urbanization and average electricity consumption per capita" (p. 1). Table 1 shows some relevant studies about electricity theft and its possible determinants.

Derived from the findings found in the literature review and shown in Table 1, we can conclude that electricity theft does not only depend on the price of it or the efficiency of the systems. Other socio-economic factors also have a significant impact. In the following pages, the information available in Mexico will be analyzed and an econometric model will be carried out to know which variables influence the theft of electric energy in the Mexican case.

3. MEXICAN ELECTRICITY CONTEXT

The national electricity system is divided into 7 interconnected regions (96.4% of consumption) and 3 isolated systems (SENER, 2018). Most of the electricity consumption is in the industrial sector (more than 55%), followed by the residential sector (around 25%); the commercial, agricultural and services sector accumulate around 16% (SENER, 2018). Consumption by region is distributed as follows (SENER, 2018): western (21.9%), northwest (18.1%), central (17.9%), eastern (15.3%), north (8.7%),

1 Public Utilities Regulatory Commission.

Table 1: Variables associated with electricity theft*

Study	Methodology	Relevant variables
Smith (2004)	Comparative analysis. Correlations. 102 countries (1980-2000)	Time (+). Indicators of good governance (−)
Yurtseven (2015)	IV-GMM and 3SLS. Provinces of Turkey (2002-2010)	Rural population (+), price (+), temperature (+), agricultural production (+), education (−), income (−), net migration rate (−), referendum participation rate (-), trend (-)
Gaur and Gupta (2016)	FGLS model with data from 28 states of India (2005 to 2009)	Poverty (+), urbanization (+), corruption (+), the percentage of electrified homes (+), populism (+), literacy (−), industrial sector participation (−), taxes to GDP ratio (−), collective efficiency (−), presence of private capacity (−), line length (−)
Jamil (2018)	Survey applied to consumers. Rawalpindi and Islamabad, Pakistan	Monitoring (−), the good conduct of utility employee (−), monthly expenses on electricity (+)
Yakubu et al. (2018)	Survey to 1532 people. Ghana	Higher prices (+), poor quality (+), corruption (+), weak law enforcement (+)
Jamil and Ahmad (2019)	Theoretical model	Benefits of stealing (+), pecuniary, moral and reputation costs (−)
Razavi and Fleury (2019)	District data from Ultra Pradesh, India (2006-2012). Random forest regression model	Crime rate (+), literacy rate (−), income (−), urbanization (−), electricity consumption per capita (+)

Source: Authors own elaboration. *Positive relationship (+), negative relationship (−)

northwest (8%), Baja California (4.8%), peninsular (4.8%), Baja California Sur (0.9%), and Mulegé (0.05%). The maximum demand for Mexico in 2017 was 46,025 MWh/h[2] (SENER, 2018).

In order to provide electricity to the population, the National Electricity System has 797 plants, of which 526 are of conventional technologies and 271 of clean technologies (SENER, 2018). The total installed capacity is divided into the following technologies: combined cycle (37.1%), hydroelectric (16.7%), conventional thermoelectric (16.6%), carboelectric (7.1%), turbo gas (6.8%), wind (5.5%), and others (SENER, 2018). With regard to the electricity producers, the largest installed capacity is that of the Federal Electricity Commission (CFE) with 56.7%, followed by independent producers (17.5%), self-supply (13.2%), cogeneration (5.3%) and others (SENER, 2018).

However, the percentages of installed capacity do not match with the actual generation. Practically half of the energy produced is through combined cycle technology, and almost 80% of the generation is through conventional technologies that are more polluting (SENER, 2018). There is a large area of opportunity for increasing the installed capacity of clean technologies and their use. Regarding the type of producer, 51.8% of the electricity is generated by CFE, 26.7% by independents, 11.4% self-supply, 5% cogeneration, and others (SENER, 2018). In the transmission, CFE Transmission is the only company responsible for carrying out this important activity in the country through 53 regions with 107,042 kilometers of transmission lines (SENER, 2018). The distribution to 42.2 million users is carried out through 1,469,458 distribution transformers (SENER, 2018).

2 It includes user requirements, transmission losses, and own uses for generation (SENER, 2018).

4. DESCRIPTION OF DATA

In order to demonstrate what factors have an impact on the electricity theft in Mexico, it was necessary to build a database with the percentage of electricity theft by state and with the variables that were mentioned in the literature review. As there is redundant and highly correlated information, it was necessary to select only some variables and in other cases create indexes. The observations of electricity theft were the 32 States of the Mexican Republican during the year 2018. It is important to note that this research focuses only on one year because it is difficult to collect information from a longer period because there are gaps in the data, and sometimes there are estimates by imputation that could bias the analysis. Although there are only data about electricity theft by state, two models were carried out. One with state data in the explanatory variables and the other with data from metropolitan areas (in order to obtain more observations). The variables with the greatest impact (in a state and metropolitan levels), their explanation and their sources are presented in Table 2.

Table 2: Variables and sources

Variable	Explanation	Measurement units	Source
Energy losses (*losses*)	Energy losses by State	Kilowatts	Transparency request number
Percentage of energy losses (*plosses*)	Percentage of energy losses by State	%	SAIP-19-1131 (Transparency unit-CFE)
Percentage of technical losses (*ptloss*)	Percentage of technical losses by State	%	
Percentage of non-technical losses (*pntloss*)	Percentage of non-technical losses by State	%	
Percentage of electricity Theft (*petheft*)	Estimated percentage of energy theft by State	%	
Normalized electricity theft (*petheft_norm*)	*petheft* in a scale of 0-100 where 0 is the State white minus losses and 100 is the one with the most	Scale (0-100)	Authors elaboration with transparency data
Energy losses per capita (*losses_percapita*)	Energy losses by State	Kilowatts	
Electricity theft (*etheft*)	Electricity theft by State	Kilowatts	
Electricity theft per capita (*etheft_percapita*)	Electricity theft by State per capita	Kilowatts	
Murders (*mur*)	Murders by each one hundred thousand people (state and by metropolitan area)	Per 100 thousand inhabitants	IMCO (2018; 2018a) Executive secretariat of the national public security
Kidnappings (*kidnap*)	Kidnappings by each one hundred thousand people (state and metropolitan area)	Per 100 thousand inhabitants	system (SESNSP) in IMCO (2018; 2018a)-2016 data
Crime (*crime*)	Average of murders and kidnappings in a 0-100 scale	Scale (0-100)	
Difficulty opening a business (*opening*)	It measures what is required to open a company based on procedures, time and costs	Average percentile	Doing Business, Doing Business in Mexico in IMCO (2018; 2018a)-2016 data
Property registration (*reg_prop*)	It measures what is required to property registration based on procedures, time and costs	Average percentile	
Government inefficiency (*gov_ineff*)	Average of *opening* and *reg_prop* in a 0-100 scale	Scale (0-100)	
Population	Number of people		National population council (CONAPO)
Population density (*pop_dens*)	Numbers of inhabitants in a given area	People per hectare	National Institute of Statistic and Geography (INEGI) in IMCO (2018a)

Source: Authors own elaboration

Table 3: Descriptive statistics

Variable	n*	Mean	Median	Standard deviation	Minimum	Maximum
Energy losses per capita (*losses_percapita*)	32	3,093	2,812	1,722	917.1	10,612
Electricity theft per capita (etheft_percapita)	32	1,014	749.9	1,042	40.47	5,839
Percentage of energy losses (*plosses*)	32	9.93	8.64	4.37	4.82	19.97
Percentage of technical losses (*ptloss*)	32	5.65	5.20	1.87	3.21	10.66
Percentage of non-technical losses (*pntloss*)	32	4.27	3.14	3.65	0.03	14.77
Percentage of electricity theft (*petheft*)	32	3.18	2.34	2.72	0.02	10.99
Normalized electricity theft (*petheft_norm*)	32	27.43	19.59	25.26	0	100
Murders (*mur*)	32	18.41	12.92	15.72	2.33	71.22
Kidnappings (*kidnap*)	32	0.87	0.52	1.00	0.00	4.33
Crime (*crime*)	32	21.79	14.65	17.50	0.54	66.26
Difficulty opening a business (*opening*)	32	0.27	0.27	0.13	0.06	0.60
Property registration (*reg_prop*)	32	0.46	0.44	0.15	0.17	0.88
Government inefficiency (*gov_ineff*)	32	40.56	38.15	17.15	10.80	88.64
Murders (*mur*)	73	22.24	12.55	23.36	2.87	120.5
Kidnappings (*kidnap*)	73	1.23	0.63	1.93	0.00	10.87
Crime (*crime*)	73	13.87	8.56	14.14	0.43	63.94
Difficulty opening a business (*opening*)	73	0.27	0.27	0.13	0.06	0.60
Property registration (*reg_prop*)	73	0.42	0.39	0.13	0.17	0.72
Government inefficiency (*gov_ineff*)	73	42.88	40.43	19.17	13.98	100

Source: Authors with data from IMCO (2018; 2018a). *n=32 means state data; n=73 means metropolitan data

The energy data were obtained through the transparency unit of the Federal Electricity Commission (CFE), and the information of the explanatory variables was extracted from the databases of the competitiveness indices prepared by the Mexican Institute for Competitiveness (IMCO). Table 3 shows the descriptive statistics of the aforementioned variables.

According to information provided by the CFE's transparency portal, 412,616 million kilowatts of energy were lost in 2018. Most of the energy was lost in the following states: State of Mexico (18.61%), Tamaulipas (9.23%), Mexico City (8.66%), Veracruz (6.08%), Jalisco (6.07%), Nuevo León (5.07%), and Chihuahua (4.71%). On average, the loss per month is 8.33%. In per capita terms, 3,093 kilowatts were lost per person in the country, reaching a maximum of 10,612 the state of Tamaulipas, followed by Chihuahua (5,208), State of Mexico (4,501), Sinaloa (4,217), Sonora (4,183) and Mexico City (3,954). With respect to energy theft per capita, the average was 1,014 kilowatts; with the first places being the states of Tamaulipas (5,839), Mexico (2,456), Mexico City (1,957), Chihuahua (1,589) and Sinaloa (1,522).

Regarding the percentage of energy produced, the states where energy is most stolen are Tamaulipas (10.99%), Mexico (10.75%) Guerrero (7.73%), Mexico City (7.54%) and Chiapas (5.31%). The average of electricity theft is 3.18% and the median is 2.34%. The states with the highest crime rate were Guerrero, Tamaulipas, Colima, Tabasco, Zacatecas, Morelos, and Veracruz. In addition, those that resulted in the highest level of inefficiency were Quintana Roo, Mexico City, Durango, Baja California, and Baja California Sur. The states whit the lowest crime rate were Yucatán, Aguascalientes, Nayarit, Tlaxcala, and Hidalgo; and those with the highest efficiency were Puebla, Colima, Veracruz, Guanajuato, and Michoacán.

5. EMPIRICAL RESULTS

With the aforementioned variables, different models of ordinary least squares both at state and metropolitan level were tested. In the state level, the model with the best fit and that accomplish with the assumptions is presented in Table 4. It was necessary to eliminate the observation of Tamaulipas because it generated high squared errors (outliers), remaining 31 observations in the state model. Constant and crime index (*Crime*) were statistically significant at 5%. While government inefficiency (*Gov_Ineff*) and the population at 1%. The null hypotheses of the normality tests (P = 0.96), Reset of Ramsey (P = 0.097), White (P = 0.41) and Breusch-Pagan (P = 0.51) were accepted, so we can conclude that the model has normality in the residuals, correct specification and homoscedasticity. The model is considered to have no multicollinearity because the correlation between independent variable pairs is <0.51. The coefficient of determination R^2 is 0.67, which means that 67% of the changes in electricity theft are determined by changes in crime, inefficiency, and population.

Table 4: Factors associated with electricity theft (*petheft_norm*)-state level

	Coefficient	t statistic	P
const.	−21.8166	−2.636	0.0137
crime	0.353286	2.357	0.0260
gov_ineff	0.489459	3.455	0.0018
Population	0.000005	6.869	0.0000

Source: Authors own elaboration

Table 5: Factors associated with electricity theft (*petheft_norm*) - metropolitan level

	Coefficient	t statistic	P
const	−17.3764	−1.812	0.0747
crime	0.5248	2.362	0.0212
gov_Ineff	0.3238	2.940	0.0046
pop_dens	0.3315	3.037	0.0035

Source: Authors own elaboration

The negative value of the constant means that without crime, inefficiencies, and population, electricity theft does not exist. The crime coefficient means that due to a change of a unit in the crime indicator the normalized electricity theft is increased by 0.35 units.

On the other hand, an increase of one in government inefficiency increases the theft of electricity by 0.48. An increase of one million in the population increases the theft of electricity by five.

Regarding the model with explanatory metropolitan variables, although with a state dependent variable, the one that presented the best fit is shown in Table 5. In order to achieve normality in the residuals, it was necessary to eliminate the outliers Toluca, Tampico - Pánuco, Matamoros, Nuevo Laredo, and Reynosa - Río Bravo; remaining 68 observations in the metropolitan model. Constant was statistically significant at 10%. Crime index (*Crime*) was statistically significant at 5%. While government inefficiency (*Gov_Ineff*) and population density (*pop_dens*) at 1%. The null hypotheses of the normality tests (P = 0.12) and Reset of Ramsey (P = 0.058) were accepted, so we can conclude that the model has normality in the residuals and correct specification. It was necessary to use robust typical deviations in the presence of heteroscedasticity.

The model does not have multicollinearity because the correlation between pairs of explanatory variables is less than 0.5. The coefficient of determination R^2 is 0.28, which means that 28% of the changes in electricity theft are determined by changes in crime, inefficiency, and population.

In the metropolitan model, the crime coefficient means that due to a change of a unit in the crime indicator the normalized electricity theft is increased by 0.52 units; on the other hand, an increase of one in government inefficiency increases the theft of electricity by 0.32. An increase of one person per hectare rises the theft of electricity in 0.33.

6. POLICY IMPLICATION AND CONCLUSIONS

As mentioned in this article, both losses and theft of electricity have financial and environmental costs that are important to try to avoid. According to the literature review, several factors are associated with the theft of electric power. In this article, several variables were tested. However, the ones that proved most significant and showed a better fit model are crime and government inefficiency variables. In line with Razavi and Fleury (2019), crime generates crime. In this work, an index composed of high-impact crimes (homicide and kidnapping) was explored as an explanation of electricity theft. This proposal suggests that high-impact crimes may encourage, or not see as serious, minor crimes such as theft of electricity. The econometric models shown shows evidence of this suggestion, with a statistical significance of 5%. On the other hand, government inefficiency is measured through an index composed of the difficulty of opening a company and registering a property. This variable was statistically significant at 1%.

The results mentioned above imply that the decrease in high-impact crimes, as well as an increase in government efficiency, can help mitigate the theft of electricity. In addition to trying to improve on these two objectives, it is important that the government sends a signal to the public that stealing electricity has negative consequences for society. Emphasize that electricity theft generates damage to the environment and economic problems because it drives the increase in tariffs in addition to the need for more infrastructure to provide the service satisfactorily. Another possible strategy is to seek to generate the perception of an efficient government because if people observe a government with this quality they recognize a State that can solve problems and punish when is necessary. A perception of this kind increases the cost of crime and reduces electricity theft.

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