UNIVERSIDADE FEDERAL DO RIO DE JANEIRO

INSTITUTO COPPEAD DE ADMINISTRAÇÃO

DANIEL MARIANO DA CUNHA PAZ

THE IMPACT OF DAYLIGHT SAVING TIME ON ELECTRICITY CONSUMPTION IN SOUTHERN BRAZIL

Rio de Janeiro

2019

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Master’s dissertation presented to the COPPEAD Graduate School of Business, Universidade Federal do Rio de Janeiro, as part of the mandatory requirements in order to obtain the title of Master in Business Administration (M.Sc.).

Supervisor: Prof. Otavio Figueiredo, D.Sc.

Rio de Janeiro

2019

CIP - Catalogação na Publicação

```
        Paz, Daniel Mariano da Cunha
P348t      The impact of daylight saving time on
        electricity consumption in southern Brazil / Daniel
        Mariano da Cunha Paz. -- Rio de Janeiro, 2019.
           46 f.

           Orientador: Otavio Henrique dos Santos
        Figueiredo.
           Dissertação (mestrado) - Universidade Federal do
        Rio de Janeiro, Instituto COPPEAD de Administração,
        Programa de Pós-Graduação em Administração, 2019.

           1. Horário de Verão. 2. Modelo Econométrico. 3.
        Energia. 4. Política Pública. 5. Brasil. I.
        Figueiredo, Otavio Henrique dos Santos, orient. II.
        Título.
```

Elaborado pelo Sistema de Geração Automática da UFRJ com os dados fornecidos pelo(a) autor(a), sob a responsabilidade de Miguel Romeu Amorim Neto - CRB-7/6283.

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Approved on December 04th, 2019.

Otavio Henrique dos Santos Figueiredo, D.Sc - Advisor
COPPEAD

Peter Fernandes Wanke
COPPEAD

Jéfferson Augusto Colombo
FGV/EAESP

Rio de Janeiro

2019

ACKNOWLEDGMENTS

I would first like to thank my thesis advisor D. Sc. Otavio Figueiredo of COPPEAD at UFRJ. He consistently gave me the freedom to elaborate on my thesis as I saw it, guiding me in the right direction.

Secondly, I would like to thank my family and friends for the unconditional love and support throughout this part of my life. They helped me make the best decisions so far.

Thirdly, I would like to thank CAPES for the scholarship support given to me during this Master's Course at the COPPEAD business school at UFRJ.

RESUMO

MARIANO DA CUNHA PAZ, Daniel. **The Impact of Daylight Saving Time on Electricity Consumption in Southern Brazil**. Rio de Janeiro, 2019. pp. [46] Dissertation (Master's Degree in Business Administration) - COPPEAD Graduate School of Business, Federal University of Rio de Janeiro, Rio de Janeiro, 2019.

O Horário de Verão (HV) foi implementado pela primeira vez no Brasil em 1931, com o objetivo de reduzir o consumo elétrico doméstico. Desde então, o Horário de Verão mudou muitas vezes a abrangência geográfica e o período de duração no Brasil, mas sempre desempenhando um papel importante nos períodos de verão. Mudanças recentes na maneira como geramos e consumimos energia elétrica lançam dúvidas sobre as reais economias de energia propostas por esta política pública. O presente estudo analisa o consumo de eletricidade de 2016 a 2018 do Sul do Brasil, usando a abordagem econométrica Differences-in-Differences (DID). Os resultados do estudo sugerem que o impacto do Horário de Verão não é homogêneo ao longo do dia e, apesar de reduzir o consumo de eletricidade durante o horário de pico (18h - 21h) em cerca de 3,17%, no geral, há um aumento na demanda total de energia em 0,139% para primeiro período analisado e 0,141% para o segundo período. Nossas estimativas também mostram que o Horário de Verão causa um aumento nos custos de geração de energia na região em torno de 0,106% no primeiro período e 0,092% no segundo período analisado. Dada a heterogeneidade do impacto do Horário de Verão em grandes territórios como o Brasil, esse estudo também esclarece a importância da análise local do impacto do HV para própria mensuração do seu efeito.

Palavras-Chave: Horário de Verão, Brasil, Differences-in-Differences, Modelo Econométrico, Consumo Elétrico, Energia Elétrica, Política Pública

ABSTRACT

MARIANO DA CUNHA PAZ, Daniel. **The Impact of Daylight Saving Time on Electricity Consumption in Southern Brazil**. Rio de Janeiro, 2019. pp. [46] Dissertation (Master's Degree in Business Administration) - COPPEAD Graduate School of Business, Federal University of Rio de Janeiro, Rio de Janeiro, 2019.

Daylight Saving Time (DST) was firstly implemented in Brazil in 1931, with the objective of reduction on household electricity consumption. Since then, DST has changed many times the geographic coverage and duration in Brazil, but always playing an important role during summer periods. Recent changes in the way we generate and consume electricity have cast doubt on DST promises of energy savings. This present study analyzes electricity consumption from 2016 to 2018 from Southern Brazil, using the Difference-in-Differences (DID) econometric approach. Results for the study suggest that DST impact is not homogeneous along the day and, despite reducing electricity consumption during the peak hour (18h – 21h) in around 3,17%, overall, there is a net increase of energy demand by 0,139% for the first period analyzed and 0,141% for the second period. Our estimations also show that DST causes an increase in energy costs generation for the region of around 0,106% for the first period and 0,092% for the second period analyzed. This study also sheds light on the importance of local analysis of DST impact. Given the heterogeneity of DST impact on large territories like Brazil, proper assessments must analyze small areas to achieve more reliable conclusions.

Keywords: Daylight Saving Time, Summer Time, Brazil, Differences-in-Differences, Econometric Model, Energy Consumption, Public Policy

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LIST OF ABBREVIATIONS

ST	Summer Time
DST	Daylight Saving Time
ONS	Operador Nacional do Sistema Elétrico
WT	Winter Time
SADT	Standard Time
SIN	Sistema Interligado Nacional
GMT	Greenwich Mean Time

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1. INTRODUCTION

The main objective of the public policy known, in Latin America, as Summer Time (or Daylight Savings Time, internationally)[1] is to promote the reduction on electricity consumption during certain hours of the day by replacing artificial illumination for natural sunlight, using the effect of clock adjustment on people's lives. The basic mechanism works by forwarding the clock time in one hour close to summer periods when daylight periods are usually longer. This allows people to better fit sunlight hours of the day to waken hours, reducing the unnecessary use of electricity in households, especially during the early evening hours of the day. The first application of this policy tracks back to the XX century in Germany and Canada and nowadays more than 77 countries have Summer Time on their policy portfolio (Time and Date, 2019).

For many years, Summer Time was seen as an electric efficiency certainty. However, recent changes in the way we generate and consume electricity have challenged this certainty. Climate change, local energy efficiency policies, greater access to appliances – like air conditioning and heaters – new technologies and change in people's habits are all responsible for altering our consumption pattern (Verdejo *et al.*, 2016) in a way that, the magnitude for Summer Time energy savings expected two decades ago may not be as intense nowadays. Facing this new reality, researchers have made an effort to analyze locally the impact of the Summer Time clock adjustment to electricity efficiency, using the most varied methods.

The proper efficiency analysis for this public policy is highly significant as energy production and distribution, in Brazil, is a matter of increasing concern. First, Brazil has a vast history of energy supply crisis, from 2001 when oil prices forced electricity rationing, until 2016 when a drought on the Southeast region jeopardized energy supply from hydropower plants. Second, Brazilian electricity consumption per capita is still in developing country levels (2,23MWh/person) much far from developed countries levels (5MWh/person to 24MWh/person), showing clear signs that next decades may display a fast growth in demand per capita of electricity (Villareal and Moreira, 2016). As some articles about Brazilian household consumption have shown, Brazil is in an ascendant electricity demand pattern. Recent government reports from Brazilian Energy Research

[1] From now on Summer Time (ST) and Daylight Saving Time (DST) will be used as synonyms, meaning the periods where there is clock adjustment whilst Winter Time (WT) and Standard Time (SADT) are the periods without policy interference.

Enterprise states that the energy sector will grow on average between 2,2% and 2,3% per year until 2050 (Empresa de Pesquisa Energética, 2018).

This paper gains extra motivation as, in April 2019, elected president Jair Bolsonaro revoked the decree that institutionalizes the Summer Time, automatically canceling the next ST period, that was supposed to take place in 2019/2020. The cancelation measure was based upon a report from the Ministry of Mines and Energy (Operador Nacional do Sistema Elétrico, 2018) which has shown none significant statistical results.

In this context, this academic research aims to provide a consistent even tough geographic limited analysis of Summer Time impact in Southern Brazil's electricity efficiency. The geographic limitation of the study to the South Region lies in Brazil's continental proportion and data availability. As other international researches have shown, the best data set to analyze DST impact are local ones, using city or states electricity consumption and correlating them with local variables. Unfortunately, hourly data for electricity consumption, in Brazil, is only retrieved and made available by the government for two regions with Summer Time implementation. One of them is the Southern, the other region comprises Midwestern and Southeastern all together, encompassing a physical region so big it is impossible to make statistic valid local conclusions for the public policy.

The contribution we propose to the academy is answering important questions to the Southern Brazilian energy grid while shedding light to the fact that more detailed research on the matter should be carried by the government:

(I) "How Summer Time policy impacts the different periods of the day? Can we estimate different magnitudes for different hours?"

(II) "Does the Summer Time implementation cause a reduction in electricity consumption in both MWh and monetary cost terms? Can we estimate the magnitude of this reduction for the whole period?"

To perform the desired study, we chose an econometric approach using hourly data. This helps us create a model taking into consideration possible variations on the electricity consumption due to hourly changes in temperature, sunlight presence, and individual hours of the day, as we will deepen on the methodology section.

2. CONTEXTUAL SETTINGS

Summer Time was instituted in Brazil by a decree-law in May 1931 and made permanent in September 2008 (Operador Nacional do Sistema Elétrico, 2018). The objective has always been to reduce maximal electricity demand on the National Integrated System[2] by postponing electric illumination use by one hour on the clock, allowing people to benefit from sunlight, especially during peak hours which in Brazil are, in general terms, from 18h to 21h during working days.

Since its implementation, Summer Time has faced much change regarding periods of the year and regions enrolling in the policy, which can be explained by Brazilian continental measures. From 1931 to 1933 and 1949 to 1953, Summer Time was applied to all Brazilian territory. After 10 years without ST, it was reinstated to all territory from 1963 to 1968 and back again from 1985 to 1988. From 1988 onwards, Summer Time was left out of the North region and, starting in 1990, Northeast region was not mandatorily included in the policy, leaving for local governments the decision to take part in clock change (Ministério da Ciência e Tecnologia, 2019).

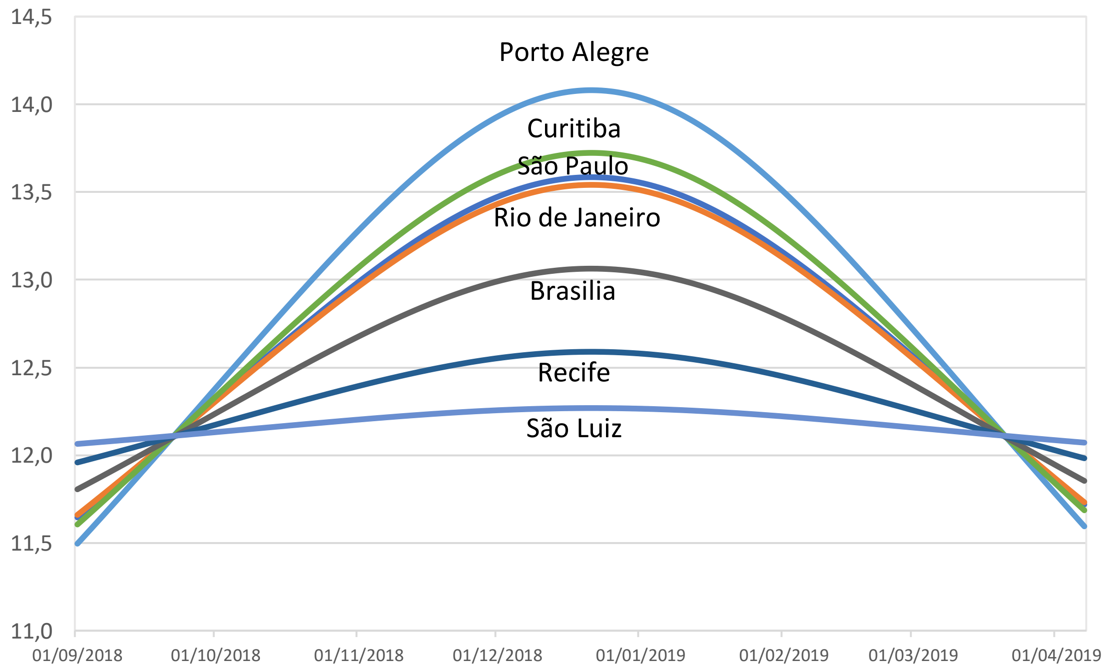

Figure 1 - Sunlight duration in hours for selected capital in Brazil, from September to April

ST benefits are closely related to latitude levels, meaning that places located more distant to the Ecuador line will face sharper inclination to the Earth axis during summer, thus

[2] *Sistema Interligado Nacional*

providing longer daylight periods. Longer sunlight hours in a day, if properly adjusted to the population schedule, have the opportunity to save electricity during peak evening hours. But Brazil territory extends from the Ecuador Meridian until the -30º of Latitude, and many capitals simply don't have enough change on summer days to justify DST implementation as we can see in Figure 1. That's why, after 1990, only South, Southeast, and Midwest regions have mandatorily adopted Summer Time, (with eventual independent adoption of Bahia state, due to recent energy crisis). North and Northeast have opted out of this public policy. As a consequence, during Summer Time, Brazil covers up to 4 different time zones: from GMT-2 (at regions using Summer Time) to GMT-5 (in Northern Region).

Since Summer Time implementation, the policy has been of great importance in trying to make per capita use of electricity more efficient, in particular as energy consumption in Brazil has been, since the 1970s, increasing significantly more than the GDP (Empresa de Pesquisa Energética, 2017), showing an unbalance in investments needed on the electric sector.

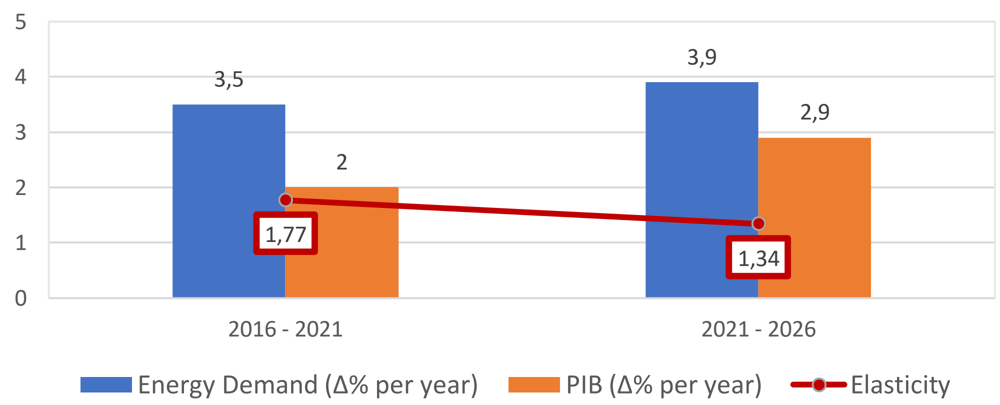

Figure 2 – Expected average yearly growth rate per period (%)

However, what once was guaranteed electricity savings, nowadays raises more questions than answers. Following international studies, Brazil has been conducting annual research to ensure that Summer Time is still beneficial for national territory. This concern is associated with many recent studies that shed light on the fact that DST has been theoretically responsible for increasing electricity demand rather than reducing (Kellogg and Wolff, 2007; Kotchen and Grant, 2008).

Those findings are related to the fact that the behavior that guides our way of using electricity has been changing for the past years. New appliances and their applications, different times for sleeping and waking up, together with new lifestyles have changed the intensity and duration of use of electricity (Sexton and Beatty, 2014). Based on those new patterns, Summer Time needs new and constant revision to ensure the public policy is still helping the conscient use of energy.

This debate gains importance in 2019 as elected president Jair Bolsonaro decides that for the 2019/2020 summer, Brazil won’t have Summer Time adjustment on clocks, following government reports that quest doubt on real reduction on electricity demand. Despite that, the president has made clear that next year’s position on DST still depends on further analysis.

3. LITERATURE REVIEW

The interest in studying the impacts of Daylight Saving Time on society is not globally recent. Many researchers have focused energy on understanding how people change their behavior and consumption patterns according to changes in sunlight and how countries may take advantage of that.

The concept of Summer Time was first presented by Benjamin Franklin in 1784, when he made calculations of how much wax and tallow could be saved during summer if people woke up earlier in the morning and went earlier to bed, optimizing daylight use (Franklin, 1784).

Centuries after that, many researchers have focused on clarifying if the main objective of the DST implementation, reducing energy consumption, is being fulfilled. Studies from Europe, Asia and America have used simulations and econometric approaches to answer this question without reaching an overall consensus.

The two pioneer empirical studies involving efficiency analysis of electricity consumption were performed in the UK and the US. In 1970, Her Majesty's Stationery Office (HMSO) performed a study to evaluate the British Standard Time (BST) trial which lasted from 1968 to 1971 and consisted of a Year-Round DST, where the Standard Time is forwarded one hour for the whole year. The conclusion for the study was that, despite findings of reduction of electricity consumption on the evening peak of 3% and increase on the morning peak of 2,5%, HMSO could not properly quantify the net impact for the implementation of the DST, discontinuing the public policy (Her Majesty's Stationery Office, 1970).

In 1974, the Department of Transportation (DOT) was in charge of evaluating the impact of the US Uniform Time Act, which consisted of a DST implemented in 1966. The DOT identified total electricity savings in the order of 1% and a decrease of 0,75% on daily peak loads. It worth mentioning that the study was considered of low reliability because of "the nature of the data". Results were considered "probable" rather than conclusive (Ebersole *et al*., 1974). Future studies from the National Bureau Standards also refuted the significance of the 1% electricity savings finding due to lack of reliability on the technique applied and the database used (Filliben, 1976).

Another Summer Time study took place in California. Kandel and Sheridan (2007) used daily electricity demand in California to assemble a regression model to identify the impact of the Summer Time three weeks extension on the energy consumption in the state. They concluded that ST extension had little or no significant impact on electricity demand in California.

But not only government entities performed studies regarding the efficiency of Daylight Saving Time policies. One of the most quoted papers takes a different approach to evaluate the electricity effect of DST implementation on US territory. Running a simulation model (DOE-2.1 E), Rock (1997) tries to quantify the energy and energy cost impact of the use of DST in a typical US residence. The model is prepared using a standard house structure that is applied to 224 different US locations. The study concludes that, with the standard residence as a parameter, total energy demand is, on average, slightly increased by 0.147% when DST is used, although a small portion of sites was proved to have lower total costs and demand. Based on this study, Krarti and Hajiah (2011) used the upgraded simulation model (DOE-2.2) to estimate the impact of DST implementation in annual electric usage and peak demand for different buildings in Kuwait. They used parameters of peak demand and energy use from 2005 (OAPEC, 2006), which allowed them to simulated behaviors and patterns for distinct construction types (commercial, governmental, residential). The authors concluded that, despite beneficial for commercial and governmental buildings, when the overall is considered, a slight increase in energy use of 0,07% is observed, with a small reduction in peak demand of 0,14%.

Fong *et al.* (2007) also follow predecessors' steps in the attempt of using mathematical models to estimate DST electricity impact on households. This study sheds light on the theoretical gain that DST would have in Japan, which, by the time of the study, had no DST implementation. They conclude that the best time frame for ST implementation is from April to September and that Double Summer Time (two-hour adjustment on the clock) would generally bring more savings than regular Summer Time, but the values for each one of them vary a lot among different cities.

Another highly quoted research with a distinct approach was conducted in Australia, exploiting the benefits of a quasi-experiment scenario (Kellogg and Wolff, 2007). In the year of 2000, driven by the Olympics in Sydney, an extension of two months on the ongoing DST was proposed, creating the perfect scenario to empirically test the electric efficiency caused by the one hour plus adjustment on the clock. An econometric model was assembled using half-hourly panel data on electricity demand and other variables from Victoria State and South Australia State. After applying a triple-differences treatment model, researchers concluded that, although reducing electricity consumption in the evening peak, it increases the morning peak in a way that the benefits are canceled out, statistically rejecting savings of 1% or more.

Kotchen and Grant (2008) also take advantage of a natural experiment that took place in Indiana, US, 2006. This research used 2004 to 2006 monthly bills from households to estimate the residential impact of DST implementation, which, from 2006 on, became mandatory for all counties. Temperature for the days within the month was also measured. To perform the analysis, the authors applied the “equivalent day normalization technique” which compares hours of the day that are influenced by DST with hours that may not be influenced by DST. On one hand, this allows for a comparison with a control group of hours, on the other hand, there is a strong premise that some hours are unaffected by DST (e.g. noon and midnight). The experiment allowed for the control group to be compared to the treated group using the Difference-in-Differences method, to estimate the exact impact of DST. The statistical work concluded that there is, on average, an increase in electricity demand of 1%, highly significant, with greater increases happening during the fall period, where it reaches values between 2% and 4%.

Another recent study also uses a natural experiment in Ontario, Canada, to measure DST impact on electricity demand (Rivers, 2017). Across years, DST implementation period occurred in different calendars days, providing quasi-random variation, which can be used to provide a statistical measurement of its impact on energy demand. The author uses two different statistical approaches (Fixed Effects Approach and Regression Discontinuity Approach) producing similar results on both, implying that DST reduces electricity demand by around 1,5%.

Mirza and Bergland (2011) also follow the same statistical approach to measure DST electricity efficiency as a pioneer study in Scandinavian countries. They apply the Difference-in-Differences approach using data from 2003 to 2009. The econometric model relates energy demand with temperature in capitals, seasonality on the year and price for electricity. They also made use of the “equivalent day normalization technique” (Kotchen and Grant, 2008). The study concludes that DST causes both a slight reduction in the morning electricity consumption and a sharp decline during evening demand, securing at least a 1% reduction in overall electricity consumption.

As has been shown by the literature review so far, DST electric conservation benefits are not a certainty as they are highly dependent on the geographic and behavior characteristics of the locations involved (Aries and Newsham, 2008). Many studies propose to simulate adverse parameters to estimate possible savings on electricity consumption. Hill *et al.* (2010) use nonlinear regression, and half-hourly data from the UK National Grid system from 2001 to 2008 to predict the impact of DST application during winter times. Among other conclusions, having British Summer Time year-around would lead to savings on the order of at least 0,3% in the months the UK currently applies GMT. They also predict the equivalent savings of 450.000 tons of carbon dioxide due to the reduction of fossil fuel use.

In Latin America, studies gain importance as they shed light on electricity efficiency where DST implementation could help countries deal with the growing need for energy supply. In Chile, Verdejo *et al.* (2016) develop an econometric model to evaluate four different cities on the territory. On average there is a reduction of 3,18% in electricity consumption, reaching up to 7,76% on the evening peak. But savings were not even across Chilean territory, proving the geographic influence on DST impact. While Santiago, Punta Arenas e Arica reduced energy consumption, Concepcion showed the opposite effect.

Hancevic and Margulis (2017) took advantage of a natural experiment in Argentina from 2007 and 2008, using a Difference-in-Differences approach and the “equivalent day normalization technique”. The authors have segregated provinces and collected data from 2005 to 2010. The study concluded that on one hand, the DST implementation increases electricity consumption between 0,4% and 0,6%, while, on the other hand, peak hour demand is significantly reduced between 2,4% and 2,9%. Both aspects should be considered when evaluating public policy as they have distinct short-term and long-term impacts.

Apart from the electric sector, many studies involving DST try to find a correlation between the one-hour clock change and other human conditions, health situations or economic activities. Some researchers have studied the relationship between acute myocardial infarction and DST (Sandhu, Seth, and Gurm, 2014). Other researchers have performed statistical approaches to relate stock market prices, volatility and return, during DST in the US, concluding that lower returns during DST are explained by lower pricing of volatility during this time (Berument and Dogan, 2011). Furthermore, the DST spring transition phase has been proven to increase the number of fatal injuries resulted from road traffic collision with pedestrians, especially during sunset times (Alsousoua *et al.*, 2009).

In terms of Brazil, no academic institution has entered this exact field of study. Despite that, The Electric System National Operator releases an annual evaluation report of the previous year's Summer Time impact (Operador Nacional do Sistema Elétrico, 2018). The study uses daily electricity demand values applied in a dynamic regression model, taking into account other variables that may impact energy demand like temperature, weekends, holidays, and others. Findings indicate that the study was not significant in finding the effects of DST in both subsystems analyzed (South/Midwest and Southeast). The lack of significance may be related to the magnitude of the database used. As we have seen from the previous literature, DST proper evaluation requires local analysis rather than macro-region studies. Consequently, this controversial manner of study evaluation may be leading to inconclusive results that can drive to wrong decisions regarding the policy nationwide.

Given the abundant international literature and the inconclusive national research scenario on the problem, this study makes an effort on testing if the Summer Time policy has an impact on electricity consumption in Southern Brazil.

Tables 1 to 3 resume the main literature review so far on the matter separating studies with findings of increase, decrease or no significance on the impact of ST policies on energy demand.

Table 1 - Evidence that ST policy increases overall electricity demand

Authors	Country	Findings
Rock (1997)	*US*	*Used a simulation model to conclude that overall, ST generates an increase of 0,147% in energy consumption*
Kellogg and Wolf (2007)	*Australia*	*Use the quasi-experimental setting from the 2000 Olympics to conclude that a reduction in evening peak and increase in the morning peak caused by ST cancel each other out.*
Kotchen and Grant (2008)	*US*	*Used electricity monthly bills to conclude that ST increases energy demand by 1% on average, with high statistical significance*
Krarti and Hajiah (2011)	*Kuwait*	*Used a simulation model to conclude that ST causes a net increase of 0,07% in energy demand*
Hancevic and Margulis (2017)	*Argentina*	*Used an econometric approach to conclude that, despite reducing peak demand in 2,4%-2,9%, overall energy demand increases 0,4%-0,6%.*

Table 2 - Evidence that ST policy decreases overall electricity demand

Authors	Country	Findings
HMSO (1970)	*UK*	*Reduces demand on evening peak and increases on morning peak, but overall couldn't be quantified.*
Ebersole et al. (1974)	*US*	*Uniform Time Act evaluation registered 1% overall electricity demand savings and 0,75% reduction on daily peak load, even though the low study reliability*
Fong et al. (2007)	*Japan*	*Uses mathematical simulations to conclude that double ST from April to September would bring electricity savings*
Hill et al. (2010)	*UK*	*Apply nonlinear regression to conclude that all year ST would bring at least 0,3% reduction in energy demand during the months with previous standard time*
Mirza and Bergland (2011)	*Norway & Sweden*	*Apply econometric models to conclude that ST causes a reduction in both morning and evening peaks, securing at least 1% reduction in overall energy demand*
Verdejo et al. (2016)	*Chile*	*Apply econometric models to conclude that reduction in energy demand due to ST can vary from 3,18% to 7,76%, despite uneven across the national territory*
Rivers (2017)	*Canada*	*Uses statistical approaches to conclude that ST reduces electricity demand by around 1,5%*

Table 3 - No statistical relevance that ST policy changes overall electricity demand

Authors	Country	Findings
Filliben (1976)	*US*	*Refuted the significance of the 1% electricity savings finding of the Uniform Time Act study due to lack of reliability on the technique applied and the database used*
Kandel and Sheridan (2007)	*US*	*Using daily values for electricity demand and a regression model, they concluded that the Summer Time extension of four weeks in California had no significant impact on energy demand*
Operador Nacional do Sistema Elétrico (2018)	*Brazil*	*ST statistical analysis for two regions of Brazil was not significant, nothing could be concluded according to the study*

4. METHODOLOGY

From the literature review, the main research question emerges: "Is Summer Time policy still energy and cost-saving measure for the Southern Brazilian population?". For statistical purposes, two hypotheses derived from this question:

(I) H_0: Summer Time does not affect electricity demand

(II) H_a: Summer Time reduces electricity demand

As the main purpose of this study is to analyze the causal effect of Summer Time to Southern Brazilian electricity grid efficiency, the Difference-in-Differences causal approach was selected, following international literature (Kellogg and Wolff, 2007; Verdejo *et al.*, 2016; Hancevic and Margulis, 2017). This instrument is used to test the hypothesis that Summer Time does not affect changing the electric demand against the hypothesis that it may reduce energy consumption.

The preference for this methodology can be explained as DiD tests for causal inference by calculating the difference of control and a treated group using longitudinal data for comparison. This methodology is suited when there is a natural experiment involved, caused by an exogenous factor like the application of a governmental policy, which changes the way people, companies and cities function (Wooldridge, 2002; Gujarati, 2003). Like other studies, we have considered the implementation period of the Summer Time as a crucial aspect for characterizing this as a quasi-experiment, as every year people have to adjust clocks at a nonstandardized day of the calendar which can change due to elections or carnival.

The DiD's purpose is to identify timely differences in conjunction with the differences caused by the treatment. to properly estimate the real effect of the desired event on the treated group. First, the difference of means of treated and untreated groups is evaluated before the governmental policy application (first difference) then, after the implementation of the Summer Time policy, another of means is calculated between both groups (second difference), expecting some change due to the effect of the policy. The third step consists of making the difference between the two differences to find the real causal effect of the treatment or, in other words, to find the *Average Treatment Effect on the Treated* (ATT) from the *Average Treatment Effect* (ATE). This has been vastly used in DST research to check for electricity efficiency impacts literature (Kellogg and Wolff, 2007; Mirza and Bergland, 2011; Verdejo *et al.*, 2016; Rivers, 2017).

In Brazil, the methodology had to be adapted for two reasons:

(I) **First, geographic selection for the analysis had to be simplified**. Summer Time's impact on electricity is known to be a local matter, highly dependent on temperature, latitude, longitude, social habits, and other regional variables. As a consequence, in the same country, ST can cause positive and negative impacts on different regions during the same period (Rock, 1997; Verdejo *et al.*, 2016). Therefore, a whole country analysis for ST should be a sum of many local studies, taking into account local information for all desired variables, including the dependent one (electricity consumption). However, the data available for the hourly electricity consumption analysis is not presented as detailed as needed for a national evaluation. The Electric System National Operator ('*Operador Nacional do Sistema"*) provides the hourly demand only for Brazilian Regions, and two out of three of the regions where DST is applicable (Southeastern and Midwestern) are numerically merged in the National Operator's panel data, accounting for more than 50% of all national electricity consumption. For a sense of comparison, those two regions of Brazil, have approximately the same geographic area of France, Spain, Germany, Sweden and Norway, all together, making it difficult for local statistical conclusions. **So, we decided to focus our evaluation on the Southern region**, where geographic area and variation on climate and habits are far reduced if compared to the entire country, increasing the internal validity of the study.

(II) Second, the proper application of DiD methodology implies the use of a control group that acts as a counterfactual for the treated group, allowing to measure only the effect of the desired treatment. In the Brazilian scenario, due to the country continental proportions, regions and even states can experience large variations on economic, geography and demographic characteristics in a way that, comparing a Southern state that enrolls on the DST with a Northern state that does not may account for much more differences that only the DST effect, like climate divergences, local holidays, specific economic moments, contrasting habits and others. **In this way, the counterfactual chosen for this study follows researches on the same matter and uses the "Equivalent**

Day Normalization Technique" (Kotchen and Grant, 2008; Mirza and Bergland, 2011; Hancevic and Margulis, 2017). The "Equivalent Day Normalization Technique" segregates the day into 24 hours to be analyzed separately. The important assumption behind this method is that there are hours in the day in which the application of ST would not interfere with electricity efficiency, especially because sunlight presence would not change in those periods. This allows **hours** to be subdivided into two groups: **affected** and **unaffected** by the policy, creating the perfect set of data to be counterfactual.

By selecting two years, we follow international standard research (U.S. Department of Energy, 2008; Verdejo *et al.*, 2016), which allows analysis of four changes on the clock, two implementations of the Summer Time, October the 16th of 2016 and October 15th of 2017, together with two returns to the Winter Time, February 19th of 2017 and February 18st 2018. This interval was considered suitable as the data does not get influenced by the impact in hydropower plants due to the Brazilian hydric crises from 2014 to early 2016. For this period, besides electricity consumption, other variables like temperature, economic activity and sunrise and sunset hours were collected.

4.1. THE COUNTERFACTUAL

An important task in the Difference-in-Differences is to properly define the control group, which differs from the treated group only by the treatment. As there is no region, similar or close enough to Southern Brazil without the application of ST, we have to resort to another method to find the control, using the hours of the day and the Summer Time functionality.

The only physical change that happens with the ST implementation is the clock adjustment in one hour forward. In terms of sunlight impact, it causes a displacement in the sunrise and sunset times, meaning that hours around these moments will experience major illumination changes and consequently change people's behavior during these periods. By default, other hours of the day (e.g. after sunrise or afternoon) won't have considerable sunlight alteration and should not cause perceptive changes in people's electricity consumption, as one hour is not enough to alter illumination patterns for those periods, regardless the policy. According to this premise, early morning and evening hours should respond to the treatment (characterized as a treated group) and the rest of the day should behave inertly (characterized as a control group)

Next, we perform the "*Equivalent day normalization technique*" (*EDNT*) to check this assumption and correctly define the hours for control and treatment groups.

To identify those groups using the *EDNT* we have to plot and compare the hourly demand curves before and after Summer Time implementation to observe changes within the hours of the day. The following steps were taken:

(I) After defining region and period, hourly electricity demands curves were obtained for both before and after each of the two ST starts (October 16th of 2016 and October 15th of 2017) and ends (February 19th of 2017 and February 18th of 2018)

(II) A duration of **10 working** days was set for each period before and after the start and the end of the ST. As a result, we have eight equally sized curves, four with the Summer Time and four with the Winter Time. We also make sure that we have the same number of observations for each curve, avoiding selection bias for holidays and weekends.

(III) An equivalent curve for electricity demand was gathered by averaging the hourly curve for each day in each period. As a result, we have two curves that represent the hourly average energy consumption during Summer Time and Winter Time (Figure 3)

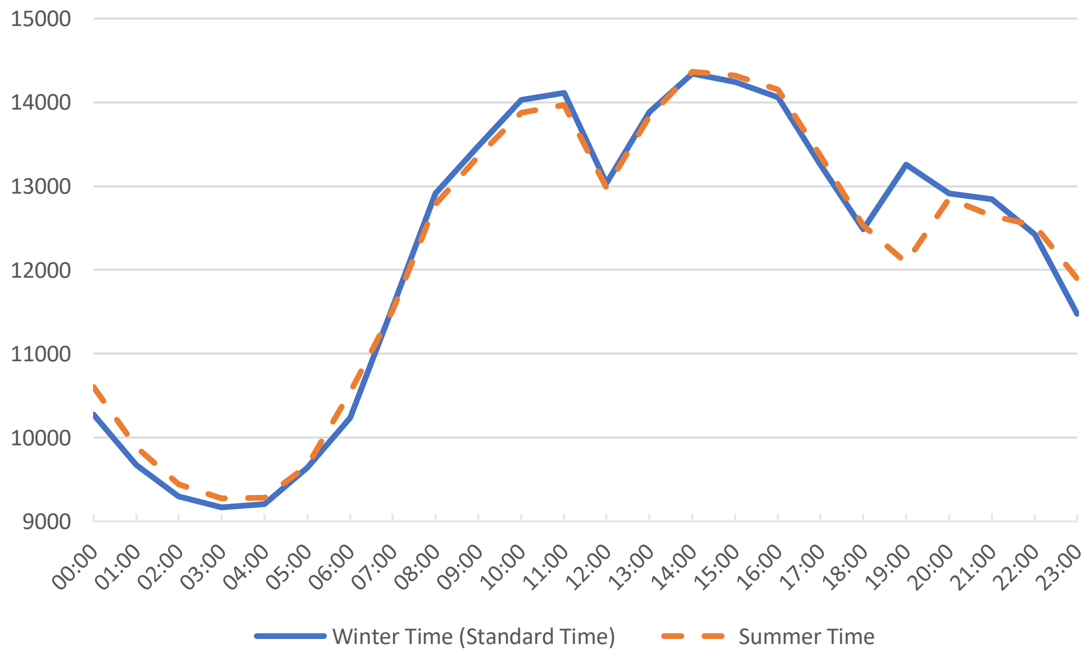

Figure 3 – Electricity Consumption Mean Hourly Curve for Summer Time and Winter Time (in MW)

(IV) To help us identify the control hours in the day, we can calculate the hourly ratio between Summer Time and Winter Time curves, allowing us to distinguish which hours of the day are influenced by the government policy and which remain relatively inert.

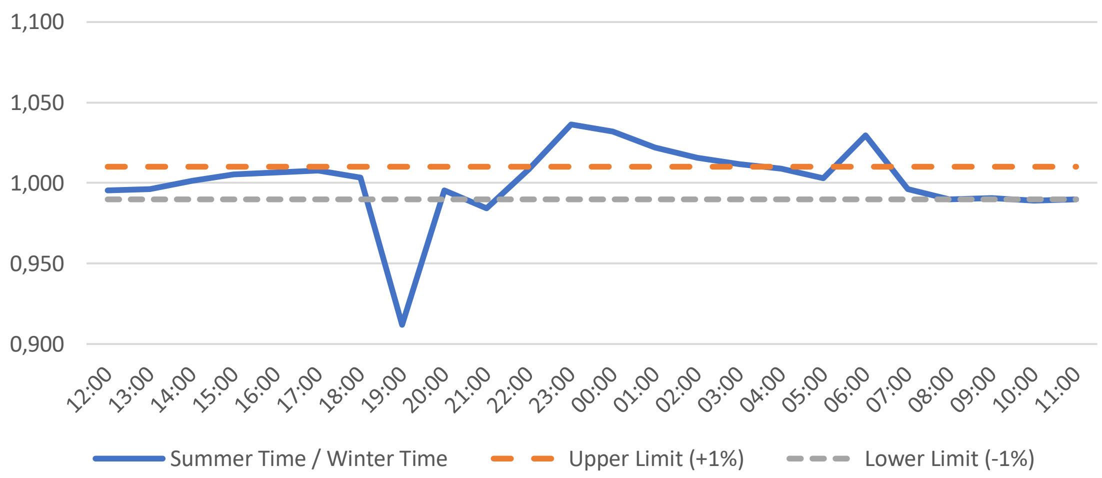

Figure 4 - Electricity Consumption Ratio (Winter Time / Summer Time) and upper and lower limits of 1%. Graph starts at 12:00 to facilitate insights

(V) Comparing both curves from Figure 3 we identify that the Southern electricity consumption curves have somehow an authentic shape, with three spaced peak hours: morning, afternoon and evening. ST policy has a clear negative effect on evening consumption, reducing and delaying the evening peak in one hour. After this, however, there is an opposite effect. From dawn till early morning, there is a slight increase in energy demand with Summer Time. The rest of the day remains mostly stable as one curve overlaps the other showing virtually no impact from the policy. We have chosen to focus on energy demand variations of 1% or greater. The Upper and Lower limits on Figure 4 help us identify the hours of the day with greater impact due to Summer Time. Those hours will be used to assemble the control and treatment groups.

(VI) Given the previous analysis, we could segregate three groups, comprising hours with the same effect together. The first group constitutes the period that suffers negative influence by ST (reduction on electricity demand) and comprises the hours 08h, 09h, 10h, 11h, 19h, 21h. The second group suffers a positive influence by ST (increasing electricity consumption) and comprises the hours 00h, 01h, 02h, 03h, 06h, 23h. By definition, those two groups are considered treated concerning the policy. The third group comprises the hours of the day that have less than 1% impact on energy demand, virtually inert to the policy implementation, thus considered the control group for the study. Groups are identified in Table 4.

Table 4 - Hours for control and treatment groups

Groups	***Hours***
Control	04:00 05:00 07:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 20:00 22:00
Treatment Reduction	08:00 09:00 10:00 11:00 19:00 21:00
Treatment Increase	00:00 01:00 02:00 03:00 06:00 23:00

Despite the representative change in electricity consumption during dawn hours in Southern Brazil, which is a peculiarity already highlighted by previous studies (Operador Nacional do Sistema Elétrico, 2018), preliminary findings for this part align with other international studies that found a reduction in electricity consumption for the evening period while the morning period observes an increase in energy demand (Kellogg and Wolff, 2007; Momani, Yatim and Ali, 2009; Hancevic and Margulis, 2017). The similarity of our study to other researches geographically close reinforces the importance of the location aspect to this type of research.

Before proceeding, an important assumption has to be guaranteed for the groups selected in this stage. The premise that the "Parallel Trend" for the selected groups has to hold, meaning that, we can only apply the DiD method if we can ensure that, before the treatment, all groups were "following the same trend". The average weekly electricity consumption was calculated for eleven weeks before the first ST implementation in (October 16th, 2016). The behavior for the three groups can be observed

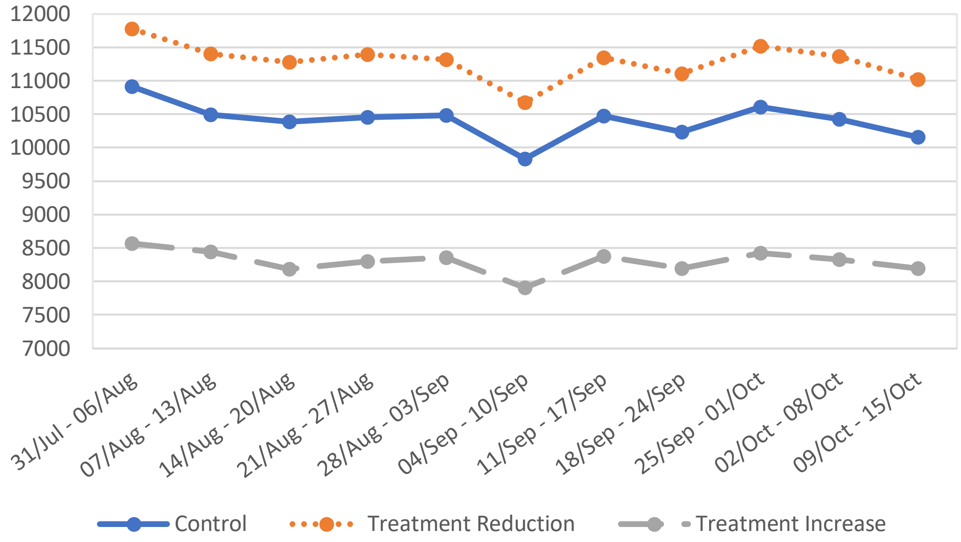

Figure 5 - Weekly average consumption for control and treatment groups (in MW)

The visual inspection from Figure 5, in addition to the correlation matrixes for the treatment and control groups (Appendix A), supports the fact that all groups follow a synchronized behavior pre-test, reinforcing the idea that differences *ex-post* the policy implementation should be attributed to the treatment.

4.2. THE ECONOMETRIC APPROACH

The regression model used to estimate the impact of the Summer Time policy on electricity consumption is not a consensus among international studies. Different explanatory variables are used to give more explanatory power to the econometric model. To find the best fit for the regression, different combinations of variables are used, but all will derive from the same complete equation as follows:

$$\begin{aligned} Ln\,(ElectCon)_h = {} & \delta_0 + \delta_1 Weekend_h + \delta_2 Holidays_h + \delta_3 ST_h \\ & + \delta_4 TreatIncrease_h + \delta_5 TreatReduction_h \\ & + \delta_6 ST * TreatIncrease_h + \delta_7 ST * TreatReduction_h + \\ & + \delta_8 IBCR.South_h \\ & + \delta_9 SunlightPR_h + \delta_{10} SunlightSC_h + \delta_{11} SunlightRS_h \\ & + \delta_{12} TempPR_h + \delta_{13} TempSC_h + \delta_{14} TempRS_h \\ & + \theta DummyHour_h + \alpha DummyMonth_h + \omega DummyYear_h \end{aligned}$$

The variable $Ln(ElectCon)_h$ accounts for the natural logarithm of the electricity consumption of the Southern Region of Brazil in MWh at each hour *h*.

$Weekend_h$ and $Holiday_h$ are both dichotomous variables. They are assigned respectively one if the hour is comprised in a weekend day, zero otherwise and one if the hour is comprised in a holiday, zero otherwise.

The dichotomous variable ST_h accounts for the presence of Summer Time (Daylight Saving Time). It assigns the value of one in the presence of ST and zero in the absence.

The dichotomous variable $TreatIncrease_h$ assigns the value of one to the hours of the day where electricity consumption is positively affected by the ST: 00:00, 01:00, 02:00, 03:00, 06:00, 23:00

The dichotomous variable *TreatReduction* assigns the value of one to the hours of the day where electricity consumption is negatively affected by the ST: 08:00, 09:00, 10:00, 11:00, 19:00, 21:00

The dummy variable vector $DummyYear_h$ controls for each of the years presented in the analysis. There are three categories, starting in 2016, which is the reference year. The second dummy variable vector $DummyHour_h$ controls for all the hours in the day. There are 24 categories with the 00:00 being the reference hour. The third dummy variable vector $DummyMonth_h$ control for all the months in the year. There are 12 categories for this vector and January is the reference month.

The $Sunlight_h$ dichotomous variables assign the value of one if that particular hour had the presence of the sunlight equal to or greater than 30 minutes. Sunlight intensity was not measured, only presence, due to sunrise and sunset variation times. These variables were measured considering each capital latitude and longitude, thus representing each state of the Region (Parana, Santa Catarina and Rio Grande do Sul)

The $Temp_h$ is a continuous variable that represents the hourly temperature in Celsius for the capital of each state of the region.

The $IBCR.South_h$ continuous variable is an index from the Brazilian Central Bank, responsible for measuring economic activity on a regional scale. Values are calculated and seasonally adjusted monthly for Southern Brazil.

The most important variables for this study arise from multiplying the presence of Summer Time (ST_h) with the two treatment periods separately ($TreatIncrease_h$, *TreatReduction)*. By doing so, we measure the impact of Summer Time policy on both treatment periods. From the interaction, we have two more dichotomous variables to analyze: $ST*TreatIncrease_h$ *and* $ST*TreatReduction_h$, which assign the value of one when values from both variables are also one.

As standard, to avoid multicollinearity problems, in this model control groups had no dummy variables associated with their values.

5. DATA

5.1. DATA GATHERING

This study complies hourly longitudinal data for Brazilian Southern region, from June 11th, 2016 to June 25th, 2018. The period selected takes into account the two-year standard time spam for analysis of this kind (Verdejo *et al.*, 2016) and the need to cover for intervals before and after DST periods (Table 5). Besides that, data from late 2016 was selected to avoid recent supply issues faced by Brazilian hydropower plants from 2013 until mid-2016 (Villareal and Moreira, 2016), which brought great energy generation unreliability to the National Integrated Electric System (Moreira *et al.*, 2015).

Table 5 - Periods of analysis separated in Summer Time and Winter Time

Period	***Start***	***End***	***ST***	***Running Days***
1	11/06/2016	15/10/2016	Off	126
2	16/10/2016	19/02/2017	On	126
3	20/02/2017	14/10/2017	Off	236
4	15/10/2017	18/02/2018	On	126
5	19/02/2018	25/06/2018	Off	126

Data for the hourly electricity consumption was extracted from “Hourly Load Curve” from the online platform from the Electric System National Operator (Operador Nacional do Sistema Elétrico, 2019). The historic for ST periods was extracted from decree legislations, kept in the Time Service Division from the National Observatory site (Time Service Division, 2019). Hourly temperature for each capital was provided by request from the SADMET, a data storage department inside the National Meteorology Institute (Instituto Nacional de Meterologia, 2019). Sunrise and sunset daily time for each capital were calculated using the day of the year, specific longitude and latitude for capitals, earth inclination and Coordinated Universal Time (UTC). The monthly IBCR index was extracted from the Brazilian Central Bank repository website (Banco Central do Brasil, 2019).

5.2. DATA LIMITATION

Because of the geographic large display, a national analysis for DST efficiency should be carried out by aggregating small local studies of cities/states in the country to achieve a conclusion on the DST effect in Brazil as a whole. Unfortunately, Brazilian research and regulation energy institutions do not search for this information at a local level, meaning that the DST assessments they produce are based on macro-regions hourly information.

To increase the internal validity, we limited our study to the smallest geographic region of Brazil, in which states share many characteristics like climate, population size, daylight period and others. We believe that, by analyzing the Southern region, despite the limitations, we can achieve conclusive results about DST impact.

5.3. STATIONARITY OF DATA

When dealing with temporal series, it is paramount to make sure that the analyzed data follows the principle of stationarity. Hidden trends can be deceiving and mask results for the econometric model. We follow international research on the matter and check both electricity consumption and its natural log for stationarity (Mirza and Bergland, 2011; Verdejo *et al.*, 2016; Hancevic and Margulis, 2017). The Augmented Dickey-Fuller (ADF) test was performed on both temporal series, using R software. The results are in Table 6.

Table 6 - Dickey-Fuller stationarity test for Electricity Consumption and Natural log for Electricity Consumption

Electricity Consumption		***Ln (Electricity Consumption)***	
Dickey-Fuller	-9,399	Dickey-Fuller	-10,217
p-value	<0,01	p-value	<0,01

The highly negative ADF value supported by the low p-value rejects the assumption of unit root for both time series. With a slightly more negative ADF estimate and enabling further comparison with other international studies, the natural logarithm time series was preferred for this analysis and will take part in the econometric equation as previously described in the methodology section.

6. RESULTS

With the econometric equation, the treatment groups and the time spam defined, we can estimate the regression. We chose to analyze the effects of the policy using three models (A, B and C).

The software R Studio was used to achieve the results, which are briefly displayed in Table 7 and completely displayed in Table 12 (Appendix). A 95% confidence interval is used.

Table 7 - Summary of the results for three econometric models

	Model A		**Model B**		**Model C**	
Predictors	*Estimates*	*std. Error*	*Estimates*	*std. Error*	*Estimates*	*std. Error*
Weekend	-0.2113 ***	0.0020	-0.2109 ***	0.0015	-0.2106 ***	0.0015
Holidays	-0.2036 ***	0.0051	-0.1997 ***	0.0039	-0.1983 ***	0.0040
ST	-0.0077 **	0.0029	-0.0014	0.0038	0.0004	0.0038
Treatment Increase	-0.1215 ***	0.0030	-0.1833 ***	0.0048	-0.1879 ***	0.0049
Treatment Reduction	0.0798 ***	0.0027	0.0478 ***	0.0048	0.0504 ***	0.0049
ST*Treatment Increase	**0.0606 *** **	**0.0047**	**0.0483 *** **	**0.0035**	**0.0481 *** **	**0.0036**
ST*Treatment Reduction	**-0.0392 *** **	**0.0047**	**-0.0317 *** **	**0.0035**	**-0.0322 *** **	**0.0036**
IBCR	0.0076 ***	0.0004	0.0021 ***	0.0006		
Sunlight - PR	0.1058 ***	0.0140	0.0431 ***	0.0110	0.0411 ***	0.0112
Sunlight - SC	-0.1382 ***	0.0103	-0.0998 ***	0.0082	-0.0945 ***	0.0084
Sunlight - RS	0.0922 ***	0.0102	-0.0072	0.0080	-0.0067	0.0082
Temp - PR	0.0037 ***	0.0004	0.0028 ***	0.0003		
Temp - SC	0.0063 ***	0.0005	0.0019 ***	0.0004		
Temp - RS	0.0053 ***	0.0003	0.0022 ***	0.0003		
Year Control	x		✓		✓	
Month Control	x		✓		✓	
Hour Control	x		✓		✓	
Observations	17878		17878		17878	
R^2 / R^2 adjusted	0.646 / 0.646		0.799 / 0.799		0.792 / 0.792	

* *p<0.05* ** *p<0.01* *** *p<0.001*

In all three models, the parameters of interest (ST*Treatment Increase and ST*Treatment Reduction) are highly significant and considerably constant in terms of magnitude and signals. For both models with higher explanatory power (Model B and Model C), coefficients have very similar values. To properly calculate the impact of ST in the electricity consumption we choose to proceed with Model B, with the higher explanatory power of (almost 80%).

According to Model B, hours from the Reduction Group influence energy demand in -3,17% while hours from the Increase Group increase in 4,83% the demand. Those numbers are not comparable by themselves as the different hours in which they take place have very distinct consumption magnitudes. To estimate the right impact we must calculate, for the ST period analyzed, which would have been the electricity consumption without the effects of Summer Time.

By extracting the effects of the ST during the treated hours, we estimate the theoretical electricity consumption that would occur in the absence of the Summer Time Policy and compare it with the real electricity demand. The results for both ST periods are in Table 8.

Table 8 - *Net impact on electricity consumption on each Summer Time period*

Summer Time Period	***1st ST Period 16 Oct 2016 - 19 Feb 2017***	***2nd ST Period 15 Oct 2017 - 18 Feb 2018***
Effective Consumption (MW)	34.180.847	34.183.771
Estimated Consumption without ST (MW)	34.133.413	34.135.675
Δ %	0,139%	0,141%

Results show that for both ST periods, the public policy generates a minor positive net impact in terms of absolute electricity consumption. The difference in magnitude, however, is far lower than if compared solely to the coefficients measured by our econometric model. This can be explained by the fact that the hours in which ST reduces consumption have a higher magnitude than the hours that suffer a positive effect.

This fact brings us another important aspect of energy generation. Different hours of the day require different intensities of energy supply due to variations in commercial, industrial and residential use. This supply has to be adjusted hourly to each Brazilian region electricity needs, which means changing considerably the energy supply matrix across the day to provide the correct amount of energy. To achieve that, the energy provided by thermoelectric, hydroelectric, solar and wind power plants has to be constantly recombined causing a change in the operational cost for energy supply. From a public policy point of view, analyzing the operational cost is even more important than measuring the net electricity consumption in an interval because it relates to building, maintaining and coordinating the national energy matrix.

To calculate the difference in the total operational cost caused by ST, we use the Marginal Cost of Operation (MCO), provided online by the Electric System National Operator (ONS - SINtegre, 2019). The MCO represents the cost to generate an extra MWh required in the short term by the electric system. It is released for each Brazilian region weekly and separated in three demand levels: low, medium and high. Each level is directly linked to the corresponding hours of the day. The hours for each level with and without Summer Time are in Table 9.

Table 9 - *Hours for each demand level with and without Summer Time for the Operating Marginal Cost*

Demand Level	Without Summer Time		With Summer Time	
	Mon - Sat	***Sun - Holidays***	***Mon - Sat***	***Sun - Holidays***
Low	00:00 to 06:59	00:00 to 16:59	00:00 to 06:59	00:00 to 17:59
		22:00 to 23:59		23:00 to 23:59
Medium	07:00 to 17:59	17:00 to 21:59	07:00 to 18:59	18:00 to 22:59
	21:00 to 23:59		22:00 to 23:59	
High	18:00 to 20:59		19:00 to 21:59	

Higher demand levels are expected to have higher marginal costs of operation as they require extra power plants to operate. In Brazil, it usually means to increase the supply from thermoelectric plants, which are more expensive than hydroelectric and other sustainable power plants.

By crossing the hourly electricity consumption achieved and the hypothetical consumption estimated with the Marginal Cost of Operation dataset provided by the government, we can calculate the total cost of operation with ST and estimate the total cost without ST, allowing for a net comparison. Table 10 breaks for each period how much should have been the cost without the ST policy, how much cost is reduced during the reduction treatment hours, how much is increased during the increase treatment hours and the effective operational cost that happened.

Table 10 - Total Impact on Cost of Operation on each Summer Time period (in R$ Mi)

Summer Time Period	***1st ST Period 16 Oct 2016 - 19 Feb 2017***	***2nd ST Period 15 Oct 2017 - 18 Feb 2018***
Estimated Cost (Without ST)	4836,69	11245,45
Increase due to ST	47,78	110,13
Reduction due to ST	42,64	99,77
Effective Cost (With ST)	4841,83	11255,81
Δ %	0,106%	0,092%

For both ST periods, we estimate that the public policy increases not only the net consumption but also the total operational costs for energy generation. The increase in the operational cost is yet lower than the one in the net consumption. This can be explained as the ST policy is effective in reducing the hourly demand during peak hours of the day in which the marginal costs are higher. However, this effect is not enough to even the total operational costs for the electric grid.

7. CONCLUSION AND POLICY IMPLICATIONS

Results obtained from the econometric estimation allow us to make three main inferences on the Southern Brazil energy consumption scenario:

1. ST policy causes an increasing effect in terms of **net electricity consumption**, increasing **0,139% for the 1st ST** period and **0,141% for the 2nd ST** period.
2. ST policy causes a reduction effect in consumption during **peak hours of demand**, reducing on average **3,17%** on consumption
3. ST policy also causes an increasing effect in terms of **total operating costs** for energy generation in the Southern electric grid, increasing **0,106% for the 1st ST** period and **0,092% for the 2nd ST** period.

From those inferences, there are two main conclusions. Firstly, in an overall sense, the public policy, in terms of the region analyzed, seems to be functioning contrary to its main objective, increasing net consumption and costs. As a consequence, the absence of the ST policy, planned to start in October 2019, should create a reduction in net demand to what has been expected as electric consumption for this period. As this reduction is not even across the day, it requires recalculations on the hourly contribution of each power plant to the system, guaranteeing coordination to the energy allocation policy so there is no lack of waste of electricity generation.

On the other hand, there is one important outcome aligned with the ST policy plan. Electric consumption savings during peak hours of the day have a direct impact on the safety and installed capacity of the electric system. By reducing demand during hours of the day with higher magnitude, we reduce both chances of blackout and the installed power plant capacity required to fulfill energy needs, avoiding unnecessary spendings to expand the electric park. As a consequence, the absence of the ST policy shall create an increase in demand during peak hours, of 3,27% on average, which will probably impact the national policy regarding electric park dimensioning. This increase could also have a considerable environmental impact as an increase in demand during peak hours usually means an intensification of thermoelectrical usage, which carries more pollution emission. Estimations for the increase in pollution could be the theme for future studies on this matter.

Another finding from our research lies in the curious positive effect that ST has during dawn hours. All the increase registered in the daily demand curve is comprised between 23h and 06h, which was also observed in another study from the Brazilian government (Operador Nacional do Sistema Elétrico, 2018) but is drastically different from other international studies. The proper understanding of this effect is crucial for the effectiveness of the policy. If adjustments on the policy could be made to reduce or eliminate this effect, energy savings capacity would be much more significative.

As highlighted in this article, future studies on ST in Brazil must be guided using local analysis rather than macro-region datasets, because Summer Time impact is highly geographic heterogeneous (Verdejo *et al.*, 2016). Only in this way it is possible to account for every major city in the country and reach conclusions for Summer Time impact on a national basis. Also, the next period of Summer Time, which would start in October 2019 but has been canceled by the president, allows us to study the same period of the year, without the effects of the policy, checking if any change in the daily consumption curve still sustains. This would give a much broader perspective of the impact of ST Policy on the Brazilian framework.

Future studies should also cover other important impacts of ST policy on Brazilian society like: change in the economic environment, checking for commerce, services and industrial consequences; effects in traffic and local mobility; and body and mental health impacts on people.

APPENDIX A.

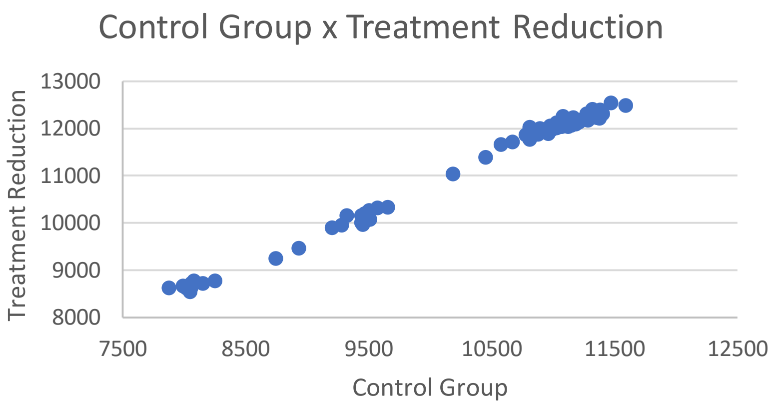

Figure 6 - A1 - Correlation between Control Group x Treatment Reduction

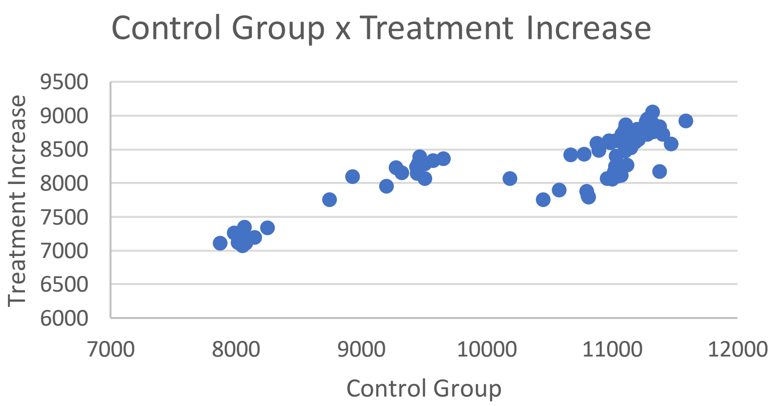

Figure 7 - A2 - Correlation between Control Group x Treatment Increase

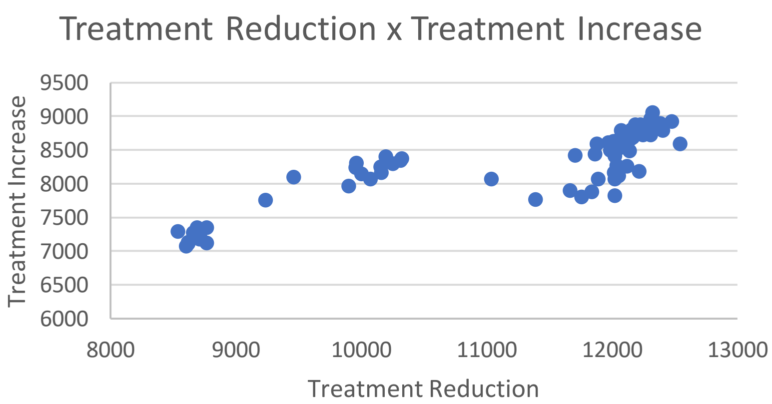

Figure 8 - A3 - Correlation between Treatment Reduction x Treatment Increase

Table 11 - Correlation between control and treatment groups

	Control Group	***Treatment reduction***	***Treatment Increase***
Control Group	1		
Treatment reduction	0,9971	1	
Treatment Increase	0,8559	0,8401	1

Table 12 - Complete results for three econometric models

	Model A		Model B		Model C	
Predictors	*Estimates*	*std. Error*	*Estimates*	*std. Error*	*Estimates*	*std. Error*
Weekend	-0.2113 ***	0.0020	-0.2109 ***	0.0015	-0.2106 ***	0.0015
Holidays	-0.2036 ***	0.0051	-0.1997 ***	0.0039	-0.1983 ***	0.0040
ST	-0.0077 **	0.0029	-0.0014	0.0038	0.0004	0.0038
Treatment Increase	-0.1215 ***	0.0030	-0.1833 ***	0.0048	-0.1879 ***	0.0049
Treatment Reduction	0.0798 ***	0.0027	0.0478 ***	0.0048	0.0504 ***	0.0049
ST*Treatment Increase	0.0606 ***	0.0047	0.0483 ***	0.0035	0.0481 ***	0.0036
ST*Treatment Reduction	-0.0392 ***	0.0047	-0.0317 ***	0.0035	-0.0322 ***	0.0036
IBCR	0.0076 ***	0.0004	0.0021 ***	0.0006	x	
Sunlight - PR	0.1058 ***	0.0140	0.0431 ***	0.0110	0.0411 ***	0.0112
Sunlight - SC	-0.1382 ***	0.0103	-0.0998 ***	0.0082	-0.0945 ***	0.0084
Sunlight - RS	0.0922 ***	0.0102	-0.0072	0.0080	-0.0067	0.0082
Temp - PR	0.0037 ***	0.0004	0.0028 ***	0.0003	x	
Temp - SC	0.0063 ***	0.0005	0.0019 ***	0.0004	x	
Temp - RS	0.0053 ***	0.0003	0.0022 ***	0.0003	x	
2017	x		0.0113 ***	0.0030	0.0289 ***	0.0018
2018	x		0.0288 ***	0.0036	0.0453 ***	0.0026
FEB	x		0.0469 ***	0.0041	0.0546 ***	0.0037
MAR	x		-0.0054	0.0052	-0.0050	0.0049
APR	x		-0.0517 ***	0.0051	-0.0648 ***	0.0049
MAY	x		-0.0995 ***	0.0053	-0.1399 ***	0.0049
JUN	x		-0.0679 ***	0.0054	-0.1220 ***	0.0049
JUL	x		-0.0671 ***	0.0055	-0.1178 ***	0.0051
AUG	x		-0.0730 ***	0.0053	-0.1171 ***	0.0051
SEP	x		-0.0725 ***	0.0052	-0.1027 ***	0.0051
OCT	x		-0.0819 ***	0.0041	-0.1083 ***	0.0040
NOV	x		-0.0469 ***	0.0038	-0.0648 ***	0.0037
DEC	x		-0.0160 ***	0.0037	-0.0157 ***	0.0036
1H	x		-0.0657 ***	0.0047	-0.0677 ***	0.0048
2H	x		-0.1071 ***	0.0047	-0.1109 ***	0.0048
3H	x		-0.1233 ***	0.0047	-0.1288 ***	0.0048
4H	x		-0.2887 ***	0.0047	-0.3003 ***	0.0048
5H	x		-0.2515 ***	0.0047	-0.2641 ***	0.0048
6H	x		-0.0178 ***	0.0047	-0.0264 ***	0.0048
7H	x		-0.0756 ***	0.0051	-0.0888 ***	0.0052
8H	x		0.0027	0.0064	-0.0063	0.0064
9H	x		0.0372 ***	0.0063	0.0388 ***	0.0064
10H	x		0.0692 ***	0.0064	0.0802 ***	0.0064
11H	x		0.0733 ***	0.0064	0.0915 ***	0.0064
12H	x		0.0380 ***	0.0065	0.0643 ***	0.0065
13H	x		0.0669 ***	0.0065	0.0971 ***	0.0065
14H	x		0.0865 ***	0.0065	0.1181 ***	0.0065
15H	x		0.0847 ***	0.0065	0.1158 ***	0.0065
16H	x		0.0895 ***	0.0065	0.1171 ***	0.0065
17H	x		0.0882 ***	0.0064	0.1093 ***	0.0065
18H	x		0.1040 ***	0.0064	0.1179 ***	0.0065
19H	x		0.0403 ***	0.0050	0.0470 ***	0.0051
20H	x		0.0665 ***	0.0049	0.0712 ***	0.0050
23H	x		0.0891 ***	0.0047	0.0913 ***	0.0048
Observations	17878		17878		17878	
R^2 / R^2 adjusted	0.646 / 0.646		0.799 / 0.799		0.792 / 0.792	

* *p<0.05* ** *p<0.01* *** *p<0.001*

REFERENCES

Alsousoua, J., Jenks, T., Bouamra, O., Lecky, F., & Willett, K. (2009, October). Daylight savings time (DST) transition: The effect on serious or fatal road traffic collision-related injuries. *Injury Extra*, pp. 211-212.

Aries, M. B., & Newsham, G. R. (2008, March 19). Effect of daylight saving time on lighting energy use: A literature review. *Energy Policy*, pp. 1858-1866.

Banco Central do Brasil. (2019, September 10). *Time Series Management System - v2.1*. Retrieved from BCB: https://www3.bcb.gov.br/sgspub/localizarseries/localizarSeries.do?method=prepararTelaLocalizarSeries

Berument, H., & Dogan, N. (2011). Effects of Daylight Saving Time Changes on Stock Market Volatility: A Reply. *Psychological Reports, 3*, pp. 863-878. doi: 10.2466/13.17.PR0.109.6.863-878

Ebersole, N., D, R., W, H., E, D., L, F., D, P., & K, S. (1974). *The Year-Round Daylight Saving Time Study, vol. I. Interim Report on the Operation and Effects of Year-Round Daylight Saving Time.* Cambridge, MA, USA: US Department of Transportation, Transportation Systems Center.

Empresa de Pesquisa Energética. (2017). *Projeção da demanda de energia elétrica para os próximos 10 anos (2017-2026).* Ministério de Minas e Energia. Rio de Janeiro: Ministério de Minas e Energia. Retrieved from http://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-245/topico-261/DEA%20001_2017%20-%20Proje%C3%A7%C3%B5es%20da%20Demanda%20de%20Energia%20El%C3%A9trica%202017-2026_VF[1].pdf

Empresa de Pesquisa Energética. (2018, December). Cenários de Demanda para Plano Nacional de Energia 2050. Rio de Janeiro, RJ, Brazil: Ministério de Minas e Energia.

Filliben, J. J. (1976). *Review and technical evaluation of the DOT daylight saving time study.* Technical Report KF27.I5589, US House of Representatives, US National Bureau of Standards.

Fong, W.-K., Matzumoto, H., Lun, Y.-F., & Kimura, R. (2007, November). Energy Savings Potential of the Summer Time Concept in Different Regions of Japan From the Perspective of Household Lightning. *Journal of Asian Architecture and Building Engineering*, pp. 371-378.

Franklin, B. (1784, April 26). Journal de Paris. *Letter to the Editor of the Journal of Paris*. Paris, France.

Gujarati, D. N. (2003). *Basic Econometrics.* New York: McGraw-Hill.

Hancevic, P., & Margulis, D. (2017, August 2). Daylight saving time and energy consumption: The case of Argentina. *Munich Personal RePEc Archive*, p. 80481.

Her Majesty's Stationery Office. (1970). Review of British Standard Time. *Command Paper Cmnd*, 4512.

Hill, S., Desobry, F., Garnsey, E., & Chong, Y.-F. (2010, May 10). The impact on energy consumption of daylight saving clock changes. *Energy Policy*, pp. 4955-4965.

Instituto Nacional de Meterologia. (2019, June 10). *Central de Serviços*. Retrieved from Inmet: http://www.inmet.gov.br/portal/index.php?r=home/page&page=central_servicos

Kandel, A., & Sheridan, M. (2007). *The effect of early daylight saving time on California electricity consumption: a statistical analysis.* California: Energy Commission.

Kellogg, R., & Wolff, H. (2007, Janurary). Does Extending Daylight Saving Time Save Energy? Evidence from an Austrlian Experiment. *CSEM WP - Center for the Study of Energy Markets*, 163.

Kotchen, M. J., & Grant, L. E. (2008, October). Does Daylight Saving Time Save Energy? Evidence from a Natural Experiment in Indiana. *National Bureau of Economic Research*, p. 14429.

Krarti, M., & Hajiah, A. (2011, January 11). Analysis of Impact of Daylight Time Savings on Energy Use of Buildings in Kuwait. *Energy Policy*, pp. 2319-2329.

Ministério da Ciência e Tecnologia. (2019, June 24). *Divisão Serviço da Hora (DSHO) do Observatório Nacional (ON)*. Retrieved from Decretos sobre o Horário de Verão no Brasil: http://pcdsh01.on.br/DecHV.html

Mirza, F. M., & Bergland, O. (2011, April 16). The impact of daylight saving time on electricity consumption: Evidence from southern Norway and Sweden. *Energy Policy*, pp. 3558-3571.

Momani, M. A., Yatim, B., & Ali, M. A. (2009, March 14). The impact of the daylight saving time on electricity consumption — A case study from Jordan. *Energy Policy*, pp. 2042-2051.

Moreira, J. M., Cesaretti, M. A., Carajilescov, P., & Maiorino, J. R. (2015, September 29). Sustainability deterioration of electricity generation in Brazil. *Energy Policy*, pp. 334-346.

OAPEC. (2006). *The Secretary's General 33rd Report for the Organization for Arab Petroleum Countries.* Safat, Kuwait: OAPEC. Retrieved from https://www.opec.org/opec_web/en/

ONS - SINtegre. (2019, September 12). *SINtegre*. Retrieved from Custo Marginal de Operação (CMO): http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/cmo.aspx

Operador Nacional do Sistema Elétrico. (2018). *Avaliação do Efeito do horário de Verão 2017/2018 nos Subsistemas Sudeste/Centro-Oeste e Sul do Brasil.* Rio de Janeiro: ONS.

Operador Nacional do Sistema Elétrico. (2019, June 10). *Curva de Carga Horária*. Retrieved from ONS: http://www.ons.org.br/Paginas/resultados-da-operacao/historico-da-operacao/curva_carga_horaria.aspx

Rivers, N. (2017, March 21). Does Daylight Savings Time Save Energy? Evidence from Ontario. *Environmental and Resource Economics*, pp. 517-543.

Rock, B. A. (1997). Impact of daylight saving time on residential energy consumption and cost. *Energy and Buildings*, pp. 63-68.

Sandhu, A., Seth, M., & Gurm, H. S. (2014, March 30). Daylight savings time and myocardial infarction. *Open Heart*, p. 019.

Sexton, A. L., & Beatty, T. K. (2014, March 28). Behavioral responses to Daylight Savings Time. *Journal of Economic Behavior & Organization*, pp. 290-307.

Time and Date. (2019). *Time and Date*. Retrieved July 23, 2019, from Timeanddate.com: https://www.timeanddate.com/time/dst/

Time Service Division. (2019, June 30). *Divisão Serviço da Hora*. Retrieved from Observatório Nacional: http://pcdsh01.on.br/

U.S. Department of Energy. (2008). *Impact of Extended Daylight Saving Time on National Energy Consumption.* Washington D.C., October: Office of Energy Efficiency and Renewable Energy.

Verdejo, H., Becker, C., Echiburu, D., Escudero, W., & Fucks, E. (2016, January). Impact of daylight saving time on the Chilean residential consumption. *Energy Policy*, pp. 456-464.

Villareal, M. J., & Moreira, J. M. (2016, June 10). Household consumption of electricity in Brazil between 1985 and 2013. *Energy Policy*, pp. 251-259.

Wooldridge, J. M. (2002). *Introductory economics - A modern Approach - 2nd Edition.* Australia: Thomson.