Daylight Saving Time Policy and Energy Consumption

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Abstract. Daylight Saving Time is argued to be effective in saving energy. Turkey is one of the few countries that annulled the clock changes and remained in the summertime zone in 2016. This paper uses Multiple Linear Regression and Interrupted Time Series methods to study the impact of clock changes on energy consumption and load shift. We use historical energy consumption, electricity prices, and relevant atmospheric essential climate variables data in Turkey between the years 2012-2020. This paper shows that the Daylight Saving Time policy does not lead to a measurable amount of energy savings. Furthermore, it does not cause a noticeable continuous daily load shift throughout the year. We also claim that our findings should be applicable to those countries such as the United States, India, Japan, Australia or China and as well as continents of Africa and South America, whose latitudes are in between 42.0° north and south of the equator.

Keywords: Daylight Saving Time, energy, saving, time, zone

1. Introduction

Daylight Saving Time aims to take advantage of daylight through shifting an hour forward in the fall and backward in the spring. The concept of Daylight Saving Time was firstly introduced by Benjamin Franklin in 1784 [1]. Franklin's main objective of Daylight Saving Time (DST) was energy conservation since extending the sunlight hours in a day diminishes artificial light usage [2]. However, DST had become a considerable interest to a broader audience be adopted more than a century later. The first implementation of DST was done during World War I in 1916 by German Federal Council to increase war effort by decreasing the demand on coal for electrical lightning [1]. In those times, Frankfurter Zeitung enthusiastically noted the benefit of DST for Germany that the policy lengthened the amount of daylight about 150 hours [1]. Britain, France, the United States, and most other countries, including Turkey, had adopted DST for wartime purposes. Even though DST enabled countries to conserve energy during wartime, the continuation of the implementation of this policy had been questioned after the war with justification for diminishing productiveness of farmers [1]. The policy has been found controversial for many other reasons. One of the main questions is whether it caused more electricity consumption or saved more energy considering other economic activities linked to electricity other than just lighting. Some countries ceased the policy's implementation and reintroduced it again, and some of them ceased the application permanently.

In the literature, daylight saving time was addressed by numerous studies. The study [2] investigate the effects of daylight-saving time, and they conducted a Difference in Difference (DID) methodology. The study [3] conducted research about daylight saving time in Slovakia with hypothetical scenarios, and they also used DID method. They suggest that DST policy decrease 1% of annual electricity consumption. The study from Australia [4] examined how the daylight-saving time policy influenced electricity demand. The difference in difference method was used with detailed panelled data. They indicated that there is no effect on the DST policy on electricity consumption by showing that there is a decrease in energy consumption in the evening, yet a demand increase in the morning compensates it.

The research was not only conducted for measuring the energy conservation on daylight saving time. Studies inspect the effects of the biannual clock change on human behaviour, the life of satisfaction and welfare effects. The work [5] presents a comprehensive study that measures the welfare effects of the time change policy on people in the UK and Germany. Also, they used a regression discontinuity design to estimate the impact of the daylight-saving policy on life satisfaction. This study showed that the workers in the UK and Germany considerably affected by the transition to DST; this effect revealed in the society as an efficiency loss. The reference [6] shows the change in individuals' time usage behaviours with a shift in the daylight.

Turkey was one of the countries that stopped implementing DST between 1923 and 1940 [7]. After a few periods that the policy was suspended again, the DST policy was abolished entirely in 2016 and Turkey remained permanently in the summertime zone. The Official Gazette of Ministers dated September 8, 2016, published decree of No. 2016/9154 of Cabinet enacted summertime to become the country's permanent status [8].In 1991 China, in 2009, Pakistan, in 2010, Russia, in 2015 Azerbaijan and 2019 Brazil abolished DST policy [9]. Moreover, the European Parliament voted to repeal the practice of DST in 2021. The member states will choose to remain either in the summer or in the wintertime permanently [10]. However, there is still an ambiguity in many places for which time zone to choose. Table 1 shows a summary of the existing literature and presents the contradicting findings of the studies worldwide.

Table 1. Existing Literature for the Impact of DST on Energy Consumption

Reference	Year	Country	Method	DST impact of Energy Consumption	Remarks
[11]	2010	UK	Literature review	Review	This paper conducts a literature review of the effect of DST on energy consumption.
[12]	1997	US	Simulation with 224 residential loads	energy consumption increases	The study focuses on residential HVAC and lighting for typical US houses.
[13]	2009	Jordan	Comparison of the average daily load curves and Survey study	energy consumption increases between 0.5% - 1.7%	This paper focuses on the impact of daylight saving time on Jordan's energy consumption.
[14]	2011	Kuwait	Simulation	energy consumption increases by 0.07%	This paper examines the DST effect on the building sector's energy consumption.
[2]	2011	US	Difference in Differences and Regression Model	energy consumption increases	This paper conducted a natural experiment in Indiana for estimating DST effects on energy consumption.
[15]	2015	Chile	Heuristic Approach and econometric model	energy consumption increases by 3.18%	This paper focuses on the impact of daylight saving time on the Chilean residential consumption
[16]	2019	Argentina	Difference in difference	energy consumption increases between 0.4% and 0.6%	They used a natural experiment from Argentina to provide empirical estimates of DST's effects.
[17]	2020	Europe	Simulation with 11 different cities	energy consumption increases	The study focuses on DST on energy consumption for illumination at the office.
[18]	2008	US	Four methods were conducted (Regression model, Heuristic, Comparison of differences, before and after analysis)	energy consumption decreases	This report provides a comprehensive study with the result, data, and analytical methods used in the DOE Report to Congress
[19]	2011	Norway & Sweden	Difference in difference	energy consumption decreases at least 1%.	In this paper, DST effect was examined on the energy consumption in Norway and Sweden
[20]	2020	Spain	Simulation and mathematical model	energy consumption decreases	This paper examines the variations of sunrise and sunset times' effect on the electricity demand daily profile.

				between 0.22%-0.34%	
[4]	2008	Australia	Simulation and Difference-in-difference	No effect on energy consumption	This paper focuses on the daylight saving time extension on energy consumption in Australia
[21]	2018	Czech Republic	Literature review	No evidence found	They examined 44 studies which are research articles, government papers, and energy company reports.

The impact of DST on energy consumption is still a debatable topic. Even though this policy's beginning was driven with energy-saving purposes, we cannot find concrete evidence whether or not this is the case. In the literature, there are controversial papers which propose just the opposite. For instance, whilst studies [21] suggest that the DST policy has no effect on energy consumption,[19] claims the country would save 1% of electricity consumption, [14] argues that the DST policy causes an increase in energy consumption. These 3 different results showed us, DST policy is complicated and hard to clarify the proper solution.

This paper presents an analysis to investigate the Daylight Saving Time policy's impact by adopting two widely acknowledged methodologies, namely Multi Linear Regression and Interrupted Time Series approaches. Since Turkey abolished this policy in 2016, we will be using actual historical data rather than simulations or hypothetical scenarios. This paper takes Turkey as a case study and examines the electricity consumption, price, and relevant atmospheric essential climate variables datasets from 2012 to 2020.

2. Factors Affecting Electricity Consumption

Besides the utilised atmospheric essential climate variables data: temperature, wind, humidity, barometer, and visibility, in this article, to determine the influence of DST on electricity consumption, numerous important factors should also be considered. Factors that affect electricity consumption can be grouped under the following headings; social, economic, socio-economic, socio-demographic, behavioural, the character of dwelling, and appliances variables. A detailed list of these factors is given in Table 2.

Table 2. Factors Affect the Consumption of Electricity

Categories	**Variables**	**References**
Social	Daily Calendar Holidays	[22], [23], [24]
	Special Occasional Days	
	Natural Disasters,	
	Medical Emergency Landings	
	Climate Change	

Economic	Gross Domestic Product	[25], [26], [27], [28], [24]
	Household income	
	Employment Rate	
	State policy programs	
	The industrial production index,	
	Exchange rate,	
	Household consumption,	
	System marginal price,	
	Capacity utilisation rate	
	The use of fossil fuel sources,	
	The oil price,	
	The capital stock,	
	Agricultural area	
	Environmental taxes	
Socio-economic	Urbanisation Rate	[29], [30], [31]
	No. of working residents	
	No. of Full-time servant	
	No. of Part-time servant	
	No. of servant works at home	
	Building Ownership	
	Technological Developments	
Socio-demographics	Population	[32], [31]
	No. of Household	
	No. of People in Household	
	Residential space per person	
	Age of People in Household	
	Employment Status	
Appliances Variables	No. of lights in each room	[32], [30], [31], [33]
	Type of Lights installed	
	No. of AC installed	
	No. of Electric geysers	
	No. of room coolers	
	No. of Fridges	
	No. of electric heaters	
	No. of TVs	
	No. of computers	
	No. of Electric Cooker	

	No of electric Irons No of Washing machines Number of vacuum cleaner	
Character of Dwelling	Type of home Location and household composition Building age The size of home Type of ceiling the heating system of the house insulation number of bedrooms The material used for roof Sides of the home exposed to the sun No. of windows in each room No. of stories	[34], [35],[36] , [32], [30], [37], [38], [39]
Behavioural	The educational level of individuals The traditions and beliefs No. of women in a leading position The utilisation of electric appliances Frequency of cooking The growth of Internet users	[40], [22], [30], [37], [41], [24]

Table 2 lists some of the parameters that affect electricity consumption. Probably there are many more factors than we reviewed and mentioned here. It is almost impossible to claim a precise list of impacts and tell these are the only parameters that affect electricity consumption in the world. However, the lack of available data on these factors causes it to be uncertain if DST is one of the main determinants of electricity consumption confidently. To measure DST's impact on electricity consumption, we only made use of atmospheric climate variables and electricity prices.

3. Methodology

In the literature, there are three prominent types of methodologies which are used to measure the effect of DST policy on the energy conversation. We studied these methods and highlighted the disadvantages and advantages in Table 3.

Table 3. Methodologies to be applied in DST research

Model	Description	Advantages	Disadvantages
Multiple Linear Regression [28]	A statistical method that estimates the relationship between continuous quantitative variables.	- It helps determine which factors matter most, which it can ignore through criterion value. - It gives information about the relevance of features - It uses data very efficiently and can make useful predictions.	- It assumes a straight-line relationship between the dependent and independent variables, which is incorrect many times. - It is not able to capture the information in the data. - It does not allow the introduction of all available variables since their effects would cancel each other out because of the lack of independence
Difference in Difference (DID) [42], [43]	A design that examines the comparison of differences in outcomes of a treated time series with an untreated series by referring controlled before-and-after an intervention.	- The method is intuitive and fairly flexible - It allows estimating the treatment effect. - It demonstrates a causal impact from observational data if the assumptions of design are consistent. - There is no need to assume that all differences between before and after intervention are measured.	- The only difference in DID should be exposure to intervention which may not be possible for time series. - The analysis may be biased if the trends between the two groups are significantly different, - DID does not explain unobservable variables that are not fixed over time

Interrupted Time Series (ITS) [44], [45]	A methodology which uses to evaluate multiple consecutive pre-and post-intervention observations in a single population and incorporates time by comparing slopes of trend lines before and after the intervention	- This method uses standard regression techniques, and hence easy to implement. - It can determine whether the alteration is permanent or temporary. - It represents circumstances in real life and is easy to recreate in practice. - It allows both observation of change and the nature and timing of occurrence. - ITS can detect intermittent changes.	- There is an issue with determining whether a change noted is due to the intervention or to other factors. - It is incapable of assessing the assumption of comparability and thus, overall results might be suboptimal if pre-and post-intervention are not comparable. - It is unable to control for possible contemporaneous and imperative for future research

We did not use DID in our study because the DID method is not suitable for time series and analysis may be biased if the trends between the two groups are significantly different. For the implementation of DID, we need to provide a parallel trend assumption. However, there are no parallel trends in our data.

3.1 Multiple Linear Regression Analysis

Multiple Linear Regression (MLR) is a method used to predict the dependent variable with independent variables. The purpose of this method is to measure a linear relationship between the independent variables and dependent variables. Since we want to understand the correlation between electricity consumption and the daylight saving time, we decided to use multiple regression analysis as one of our methods. We aimed to measure the impact of DST on the hourly electricity consumption data. We constructed a multiple regression model whose dependent variable is the hourly electricity consumption, and the independent variables are the atmospheric essential climate parameters. Eight independent variables were defined for our model. There are dozens, maybe hundreds, of parameters that have an impact on the consumption of electricity. It is hard to consider all these parameters from the real world due to a lack of data and hard to reach specific data.

Harnessing daylight is prominent, especially in lighting and heating. Therefore, we narrowed down our independent variables, or the parameters of relevance, to essential climate variables, or merely weather data such as temperature, wind speed, humidity, weather condition, and visibility. Also, we took into account the hourly electricity price because the consumption of a product or a service is directly and quickly affected by its price. We used temperature as an independent variable because people might use air conditioners and heaters to make sudden air temperature changes. Therefore, it might affect the consumption of electricity with the usage of heaters or air conditioners. The humidity change could also affect the air conditioners' electricity consumption due to the condensation of the water vapour in the air. Especially in the summer, while the air conditioner cools the indoors, because of the water vapour's condensation, consumption of the electricity will increase [46]. When the weather is cloudy or rainy, we need more electric energy to illuminate houses, streets, and cities. Weather condition is a categorical variable, and it consists of 71 subcategories which are shown in Table 4.

Table 4. Weather Condition Subcategories

Weather Conditions		
Passing clouds.	Clear.	Light fog.
Partly cloudy.	Partly sunny.	Drizzle. Broken clouds.
Snow showers. Fog.	Rain showers. Passing clouds.	Light rain. Passing clouds.
Snow flurries. Broken clouds.	Sprinkles. Partly sunny.	Light rain. Partly cloudy.
Snow showers. Partly sunny.	Sprinkles. Fog.	Light rain. Broken clouds.
Broken clouds.	Rain showers. Partly sunny.	Light rain. Partly sunny.
Snow flurries. Fog.	Cool.	Light rain. More clouds than sun.
Snow flurries. Partly sunny.	Thunderstorms. Passing clouds.	Light rain. Mostly cloudy.
Snow flurries. Passing clouds.	Thunderstorms. Partly cloudy.	Rain. Mostly cloudy.
Snow flurries. Partly cloudy.	Rain showers. Broken clouds.	Rain. Partly cloudy.
Scattered clouds.	Thunderstorms. Partly sunny.	More clouds than sun.
Sunny.	Thundershowers. Partly sunny.	Drizzle. Fog.
Sprinkles. Partly cloudy.	Ice fog.	Light rain. Overcast.
Sprinkles. Broken clouds.	Overcast.	Drizzle. More clouds than sun.
Thunderstorms. Broken clouds.	Sprinkles.	Drizzle. Mostly cloudy.
Sprinkles. Passing clouds.	Rain showers. Partly cloudy.	Thundershowers. Passing clouds.
Fog.	Rain showers. Fog.	Haze.
Light rain. Clear.	Rain. Overcast.	Sprinkles. Mostly cloudy.
Snow. Overcast.	Mostly cloudy.	Thundershowers. Partly cloudy.

Dense fog.	Snow flurries. Mostly cloudy.	Light rain. Cloudy.
Quite cool.	Rain. Cloudy.	Cloudy.
Light rain. Fog.	Rain. Scattered clouds.	Drizzle. Dense fog.
Rain. Partly sunny.	Low clouds.	Thundershowers. Broken clouds.
Mild.	Drizzle. Partly sunny.	

We fed these 71 subcategories in our regression model as different weather parameters. In addition to weather conditions, we propose several other variables related to daylight saving. One of them is the intersection factor. We add the intersection variable that measures the intersection of work hours and the day's sunlight duration. With the intersection variable, we estimate what percentage of the daylight is being made use of workers. The other one is the Daylight Saving Time (DST) variable. DST variable is a categorical variable, and it represents which time zone are the country uses officially in that period.) Visibility is another variable that we added to the model to measure its effect primarily on illumination.

Our MLR model for the measurement of DST on electricity consumption is shown in Equation 1.

$$y = a + ß_{Temp}X_1 + ß_{wind}X_2 + ß_{Electricity\ price}X_3 + ß_{Intersection}X_4 + ß_{Humidity}X_5 + ß_{Weather}X_6 + ß_{Visibility}X_7 + ß_{DST}X_8 \quad (1)$$

Where,

y: dependent variable, which represents the electricity consumption.

a: the constant (y-intercept)

$ß_{Temp}$: the coefficient of temperature and X_1: the independent variable temperature,

$ß_{wind}$: the coefficient of the wind and X_2: the independent variable wind,

$ß_{Electricity\ price}$: the coefficient of the electricity price and X_3: the independent electricity price variable wind,

$ß_{Intersection}$: the coefficient of the intersection factor and X_4: the independent intersection variable,

$ß_{Humidity}$ refers to the coefficient of the humidity and X_5: independent humidity variable,

$ß_{Weather}$: the coefficient of the weather and X_6: independent weather variable,

$ß_{Visibility}$: the coefficient of the visibility and X_7: independent visibility variable,

$ß_{DST}$: the coefficient of the DST and X_8: independent DST variable.

3.2 Interrupted Time Series Analysis

A continuous sequence of observations over time is called as Time Series. Interrupted Time Series (ITS) analysis measures the interventions within the time series. ITS analysis reveals the changing trend in outcome with specific intervention in a time series. Changing the time zone in 2016 is an intervention to the DTS policy in Turkey. Using the ITS method, we wanted to show the impact of this decision on electricity consumption. Therefore, according to ITS methodology, we defined the required three variables. These are listed as:

i. Time elapsed: This variable measures the elapsed time since the start of the study by a unit of frequency of the observations; in our case, it is hourly data.
ii. Intervention: It is a dummy variable that coded as pre-intervention period and post-intervention period at time t.
iii. y: Dependent variable as an outcome of the interventions at time t.

We constructed an interrupted time series analysis model to measure electricity consumption's effect with the policy change intervention with these three variables. We also used the same independent variables with the multiple linear regression with the additional three variables, as shown in Equation 1. The ITS model is shown below. Also, we added the interaction effect of the intervention variable and time elapsed variable

The intersection factor is calculated as follows:

$ß_{Intersection} =$ the coefficient of the intersection variable $X_9 * X_{10}$

$$y = a + ß_{Temp}X_1 + ß_{wind}X_2 + ß_{Electricity\ price}X_3 + ß_{Intersection}X_4 + ß_{Humidity}X_5 + ß_{Weather}X_6 + ß_{Visibility}X_7 + ß_{DST}X_8 + ß_{Time\_elapsed}X_9 + ß_{intervention}X_{10} + ß_{interaction\ effect}X_9 * X_{10} \quad (2)$$

4. Results

To measure the effect of DST on electricity consumption, we believe the intersection factor ($ß_{Intersection}$) plays a key role. Thus, we developed two scenarios that are related to working hours. Turkey's typical working hours start at 8 am and ends by 5 pm (public sector) or 6 pm (private sector) in the evening. However, we should keep in mind that the workers need to wake up early to prepare for the day and make the necessary commute, especially in a crowded city like Istanbul. We define the working hour in the first scenario as 8:00-17:00 o'clock, which is the typical civil service work routine. However, we considered the preparation and commuting period for the second scenario and defined the working hour as 6:00-20:00

o'clock. We calculated the intersection of the daylight and working hours in two scenarios. Therefore, the only difference between the two scenarios is the intersection variables values.

Many parameters affect electricity consumption, and we only examined the meteorological variables and price of electricity. Due to lack of data, it is hard to take account of all of them. In Regression analysis, R-square and adjusted R-square results are generated. R-square is an indicator that shows the percentage of variation in the dependent variable, which is electricity consumption in our model. R-square is a tool to measure the overall goodness of fit of the model. The values range from 0 to 1. An R-square of 0 means that the explanatory variables explain none (0 per cent) of the variations of the dependent variable; whereas an R-square of 1 means that the explanatory variables explain the variation in the dependent variable perfectly (100 per cent).

For the multiple linear regression model when we added a new independent variable to the model, the R square will be increased by its formula. Due to prevent that increase in R square, we provided an adjusted R square of all scenarios. Thus, the adjusted R square provides the eliminate a spuriously increase in R square.

Table 5 shows the R-square and adjusted R-square results of our modelling without electricity price as a parameter, and Table 6 presents the same results with the electricity price parameter.

Table 5. R-Square results for MLR and ITS Analysis without Electricity Price

Without Electricity price	**Multiple Linear Regression**		**Interrupted Time Series**	
	8.00-17.00 Scenario	**6.00-20.00 Scenario**	**8.00-17.00 Scenario**	**6.00-20.00 Scenario**
R-Square	0.3785	0.3685	0.379	0.3733
Adjusted R-Square	0.3728	0.3628	0.3733	0.3675

Table 6. R-Square results for MLR and ITS Analysis with Electricity Price

With Electricity price	**Multiple Linear Regression**		**Interrupted Time Series**	
	8.00-17.00 Scenario	**6.00-20.00 Scenario**	**8.00-17.00 Scenario**	**6.00-20.00 Scenario**
R-Square	0.4434	0.4429	0.4883	0.488
Adjusted R-Square	0.4384	0.4379	0.4835	0.4832

R-square values show us the explainability of the dependent variable with independent variables. There is no specific R-square value that tells us that dependent variable (in our case the electricity consumption) is explained by the independent variables (in our case the weather conditions and thus the DTS policy). However, in the literature, some claim that the R-square value higher than 0.90 provides an acceptable prediction for the dependent variable [47]. In our case, we see that weather conditions, and thus DTS policy, fails to explain an observable impact on electricity consumption. When we add the electricity price as a parameter to the model, we see roughly a 20% increase in R-square values. However, it is still less than 50%. If we add all the parameters that we listed in Table 2 to the regression models, the R-square will indeed approach 100%. Nevertheless, we can conclude that measuring the impact of DST policy on electricity consumption seems impossible. Figure 1 shows the one-month energy consumptions and trends during the time change in the years when DST was applied.

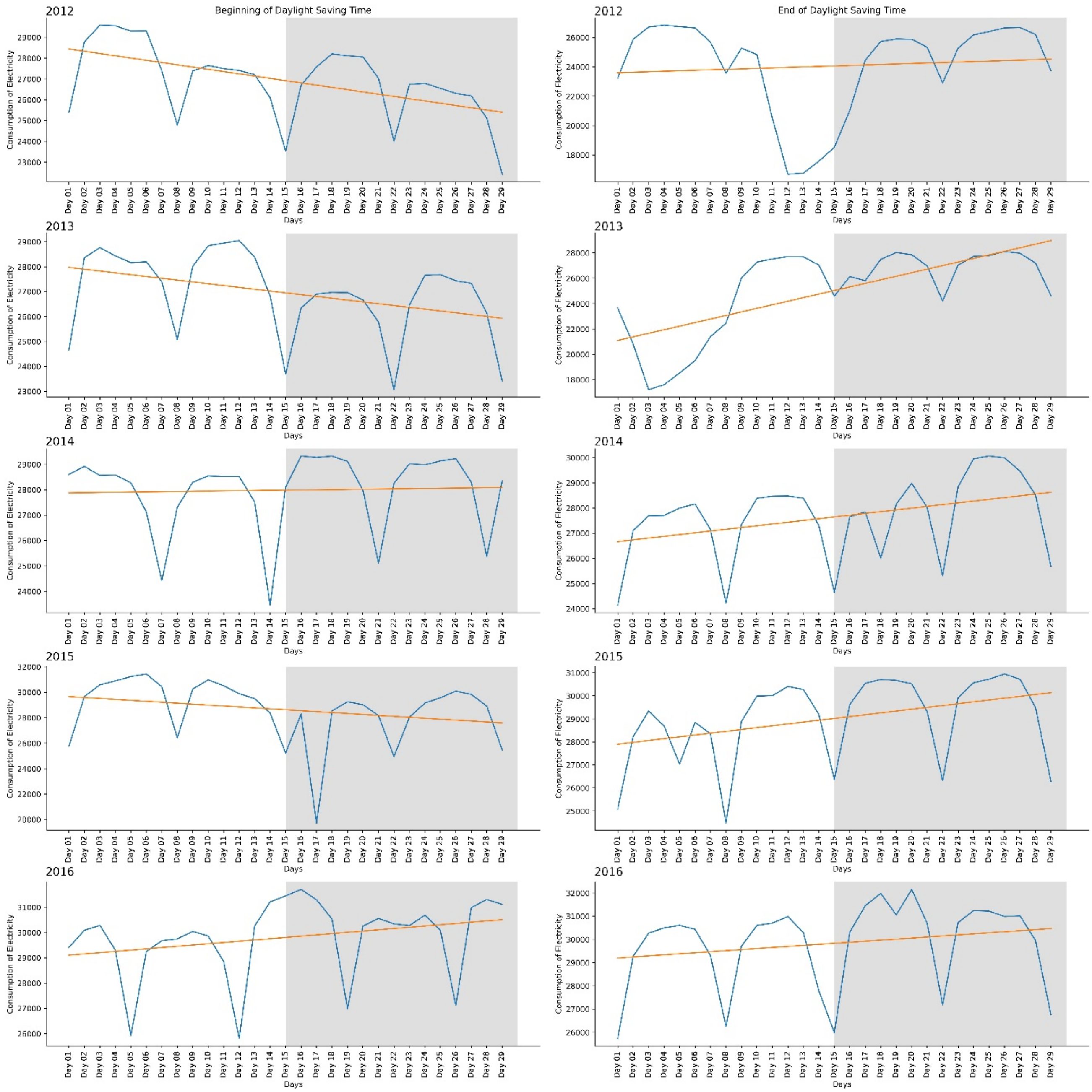

Figure 1 Monthly Electricity Consumption

Figure 1 illustrates the electricity consumption for two weeks before and after the beginning and end of DST for the last five years (2012-2016) when Turkey decided to abolish DST in 2016. Coloured parts on the graphs represent the first two weeks after the time-zone change. According to these graphs, electricity consumption creates an almost weekly repetitive pattern by making a dip during the weekends and holidays. While there is no particular trend line pattern at the beginning of DST, a positively sloping trend line pattern is seen at the end of DST. This is understandable since, in autumn, heating naturally increases electric energy consumption in Turkey. During autumn 2016, Turkey did not enter the wintertime zone. However, we see a similar trend line with the previous years when the country changed clocks. When Turkey entered the summertime zones during springs, we see a decrease in electricity consumption (except for 2014 and 2016). However, we cannot claim that this was due to the DST policy since the warming weather means less heating and the decreasing trend is observed weeks before the changing of the clocks dates. To compare the trend of electricity consumption with other years when DST was not applied, we depict Figure 2 which shows one-month energy consumption trends during the time change between 2012 and 2020 where day 15 designates the clock change date.

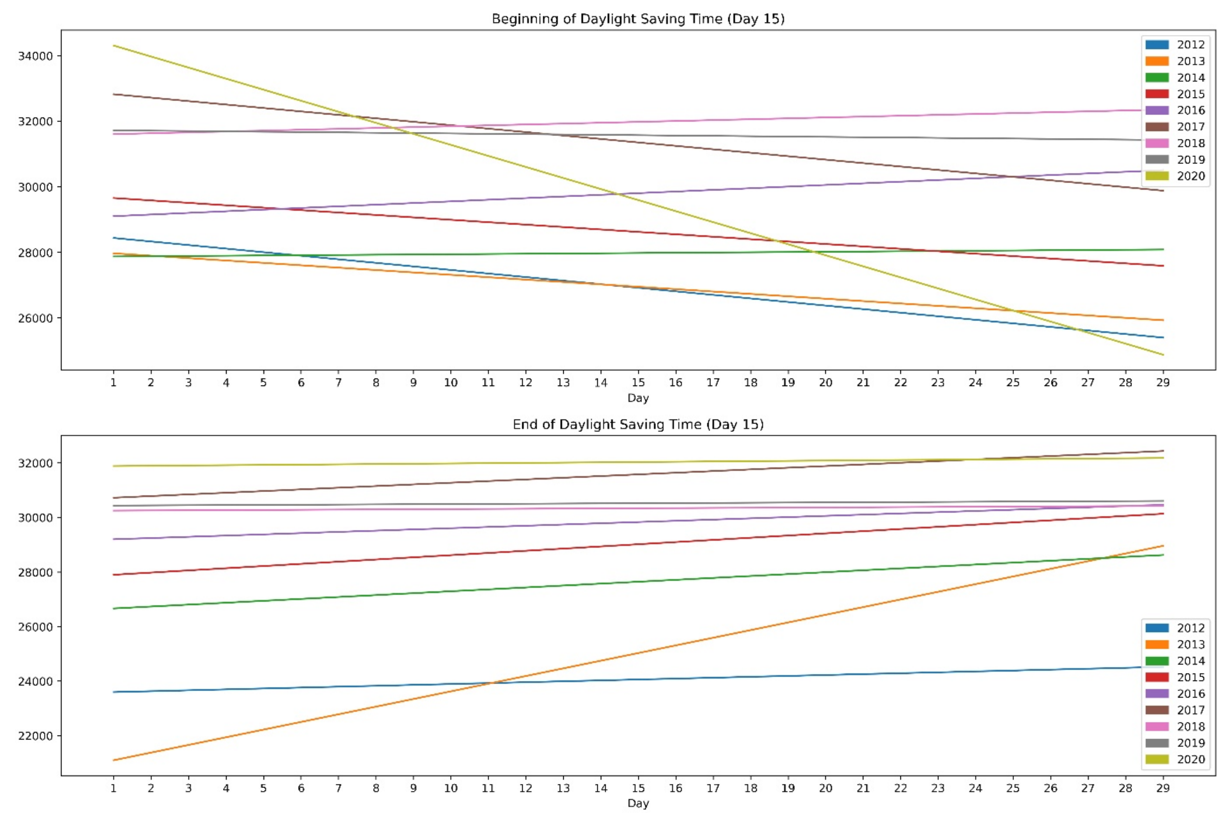

Figure 2 Trend line of Energy Consumption between 2012-2020 before and after DST is applied

Figure 2 further supports our argument that DST's impact on electricity consumption is neither observable nor measurable. Whether or not DST is applied, there is a trend downwards during springs, and during autumn, the trend is upwards. In conclusion, we claim that we cannot measure DST's impact by observing R-square values, and we cannot follow the effect with trend lines.

This brings us to the next argument about the shift of energy consumption, or in other words, time-zone change results in a shift in the daily load curve of electricity. Some studies might claim that DST results in peak demand or peak load-shift in energy consumption [4], [13]. To examine this claim, we depicted Figure 3 to show daily load curves during and the day before the clock changes between 2012 and 2016.

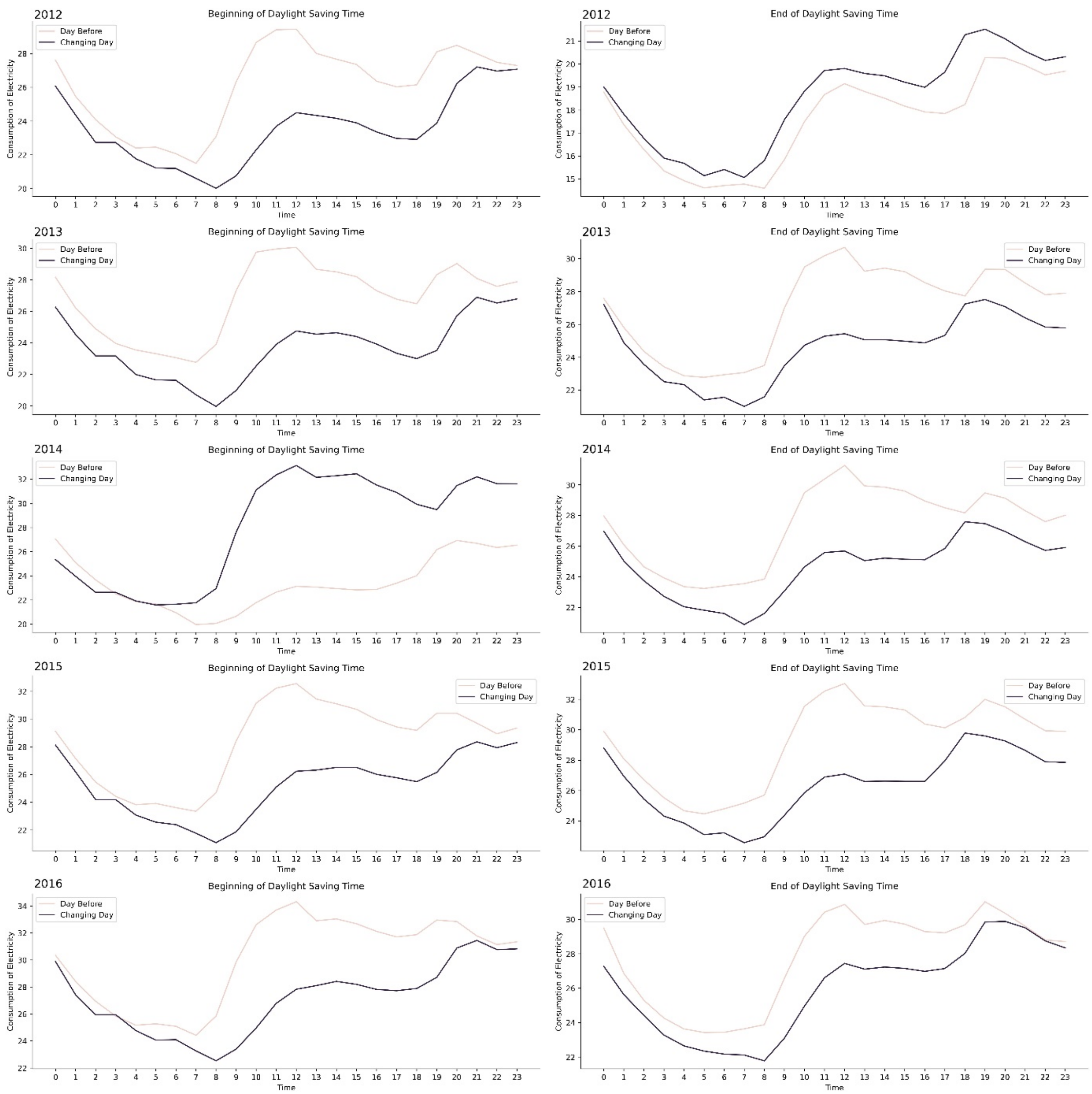

Figure 3 Energy consumptions of the time change day and the previous day

When passing to the wintertime zone in autumns, we see only a one-hour load shift in Turkey in 2012. In the rest of the years, we observe no load shift. On the other hand, there are apparent one-hour load shifts in springs right after the DST. Nevertheless, we should highlight that in the clock change time at the beginning of daylight saving time, the empty time zone (3 – 4 am) is filled with the previous hour's value. Naturally, this will end up with a virtual load shift in the daily load curve. To investigate whether DST actually causes a load shit or not, we illustrated the daily load curves on the day of the clock change, a week ago and a week after the same day. Figure 4 shows the daily load curves of these three days.

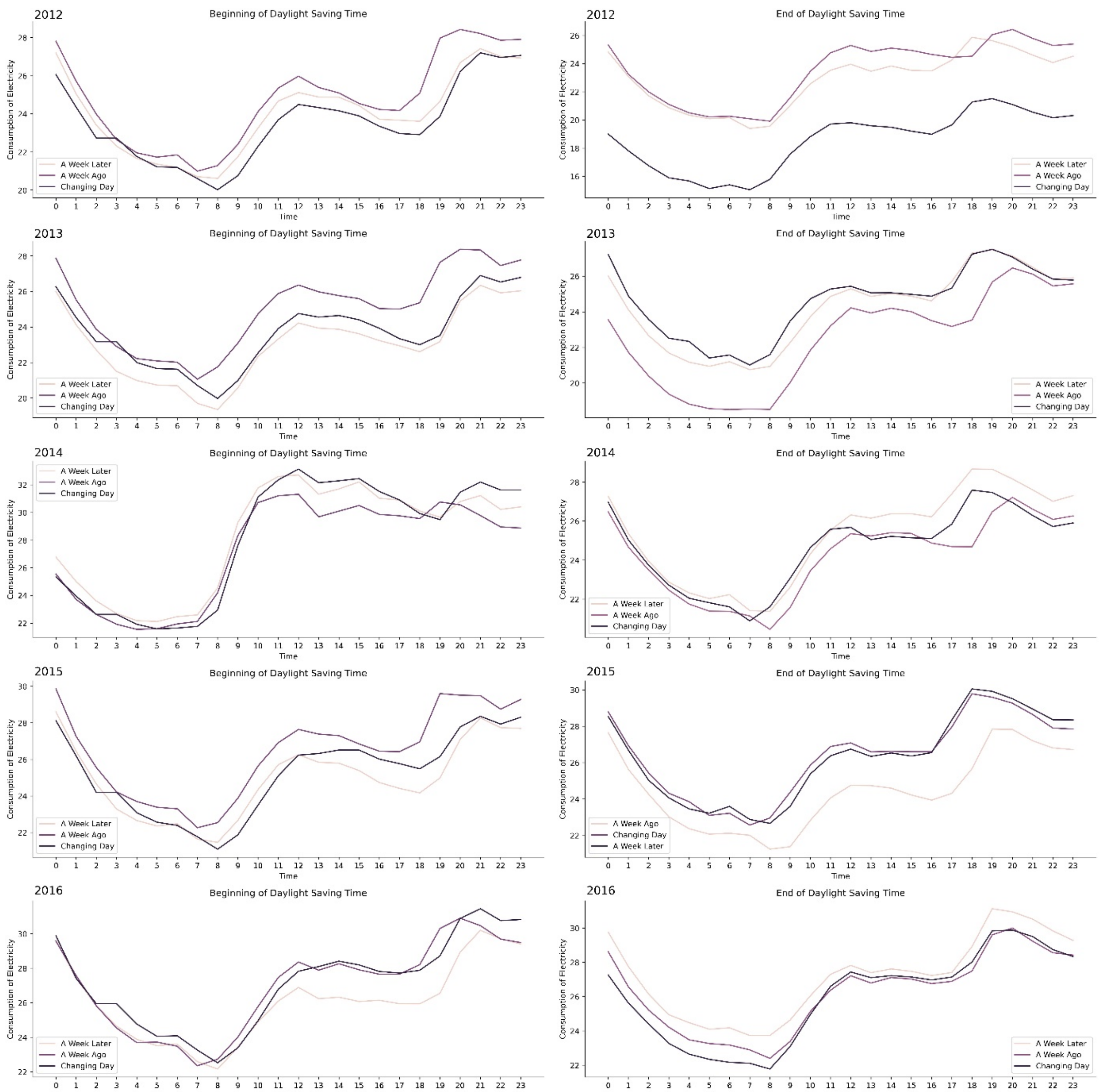

Figure 4 Energy consumptions of the time change day, the same day a week ago and the same day a week later

When we check the beginning of DST in springs between 2012 and 2016, we see a clear one-hour shift in the daily load curve (the dip generally shifts from 7 am to 8 am). However, we do not observe a consistent trend at the end of DST during autumns. Nonetheless, we should remind that the clock changes occur on the weekends, commonly on Sunday mornings. The energy consumption of the industry sector is minimal during weekends. Do we see a similar one-hour shift during weekdays when the working hours are fixed?

To answer this question, we depicted Figure 5 to show daily load curves on Mondays, one day after the clock change and one week before that Monday.

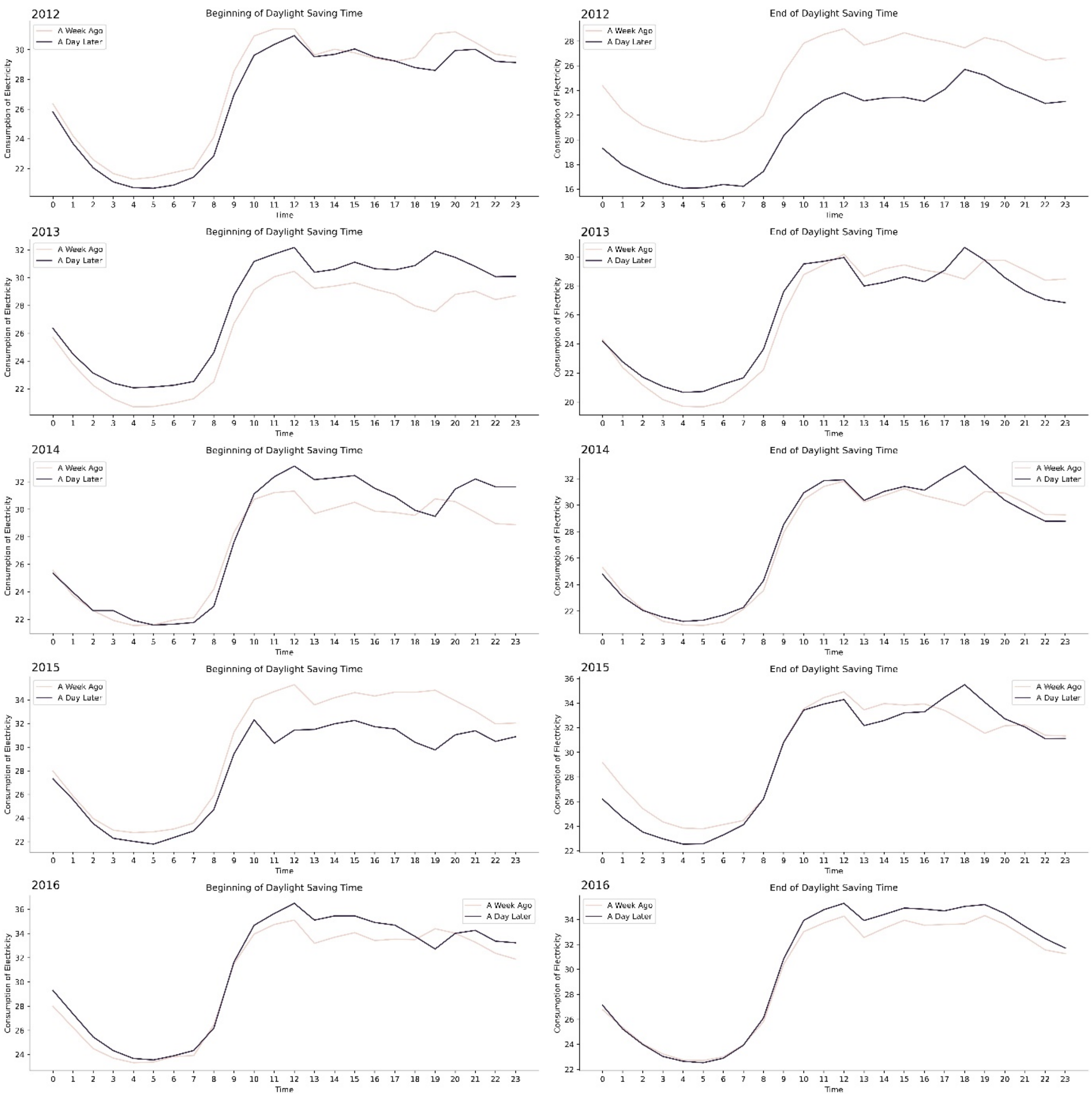

Figure 5 Energy consumptions of the one day after time change day and same day a week ago (on Mondays)

Figure 5 shows a typical working day, Monday, behaviour before and after the clock change. We see no time shift in the daily load curve. This is understandable since the industry and service sector do not change their working hours before and after the DST. Therefore, we conclude that a one-hour load shift was only observed during weekends when we passed to the summertime zone, and it is not observed during autumns when the DTS is ended and during weekdays throughout the year. One other observation from Figure 3 is that the energy consumption during the clock day's change is lower than the day before. To analyse whether the DST causes this or not, we depicted Figure 6 to show random for weeks of daily load curves throughout a year.

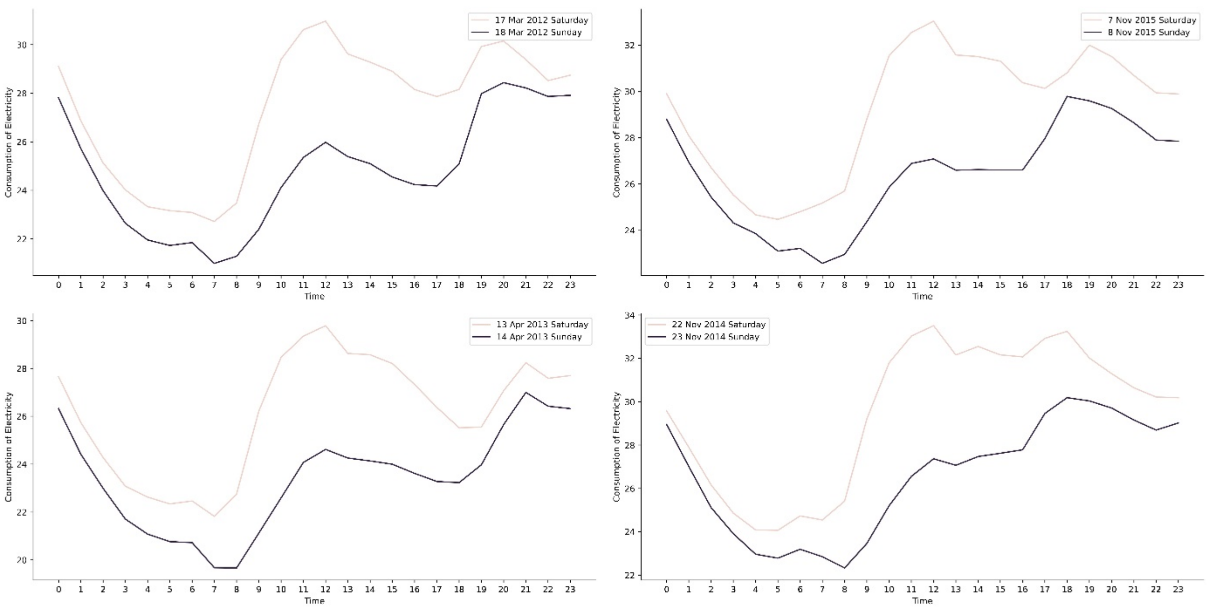

Figure 6 Energy consumptions of random four week's Saturdays and Sundays

Figure 6 shows the hourly electricity consumption for four random weekends (2012-2016). DST is generally applied in Sunday mornings. That means the day before is Saturday. As can be seen from the graphs, there was more energy consumption on Saturdays than on Sundays. So the decrease in energy consumption cannot be explained by DST; instead, it can be explained by the people's behaviours and habits during Sundays.

5. Discussion

DST effect on energy consumption is primarily and predominantly seen in illumination (lighting) and heating. In this study, we made use of the total electricity consumption of Turkey rather than the residential load. One reason is that the country does not share hourly residential load data. We only had access to hourly overall energy consumption. The other reason is that the Ministry of Energy of Turkey claimed overall energy savings if the DST policy was to be abolished in 2016.

The studies underline that impact of DST on energy consumption depends on the climate, geographical properties and mathematical location (longitudes and altitudes) of the country or the region [17], [48],[49]

.Moreover, the article [21] suggests that with increasing altitude, or as you go from equator to the north and south poles, the energy savings will increase.

Our findings in this study may not apply to those countries with totally different latitudes such as Northern Europe, Russia, or Canada. On the other hand, Turkey has similar mathematical location characteristics to Southern European countries, the United States, India and China. We believe that the MLR and ITS methodologies could be applied in other countries with similar latitudes to Turkey. Turkey's latitude is 36°-42° north. To illustrate the idea, we draw a world map with blue lines on 42.0° north and south of equator.

Figure 7. 42.0° north and south of equator

Since as input we use essential climate variables in our models, we argue that our modelling must be applicable and reproducible for the countries in between 42.0° north and 42.0° south. One crucial observation is that world's majority of population and Gross Domestic Product (GDP) fall in this region. Therefore, we claim that for a majority of the population and GDP of the world, DST policy does not lead to any significant outcomes in terms of energy consumption. Of course this claim needs to be proved by further similar studies to be conducted with the same methodology as we adopt here.

One other crucial matter is the reliability of the results. The studies claims that thanks to the decrease in lighting load, the energy consumption is decreased by 0.5% in the overall electricity consumption in the US [49], 0.5% in Slovakia [3] and about 0.3% in Great Britain [11]. However, the US Energy Information Agency reports that only residential lighting load comprises only 1.7% of the total US electricity consumption in 2019 [50]. When we consider the share of residential lighting in total consumption, 1.7% in the US case, these saving estimations do not seem credible. We believe this observation further supports our claim that DST's impact on the total energy consumption is not measurable, meaning that it is not at a considerable level.

6. Conclusions

The impact of Daylight Saving Time (DST) on energy consumption has been a controversial matter since more than a century. Turkey repealed the DST policy in 2016 and decided to remain in the summertime zone claiming that the country would make significant energy savings. In this study, we applied two methodologies, Multiple Linear Regression (MLR) and Interrupted Time Series (ITS), to model the impact of Daylight Saving Time policy on electricity consumption. In the modelling, we made use of historical electric energy consumption, electricity prices and relevant atmospheric essential climate variables data in Turkey from 2012 to 2020.

MLR and ITS are modelled with Equations 1 and 2, respectively. When we check Tables 5 and 6, ITS yields slightly higher R-squared values, almost 1%, more than MLR. The results indicate that including the electricity prices as an input to the analysis increases the R-squared values almost by 20%. However, the overall figures, which are less than 50%, falls below the expected threshold, which is 90%, for a reliable and acceptable conclusion. On the other hand, Figures 1 and 2 shows the trend lines of energy consumption two weeks before and after the clock change dates. From these figures, we cannot observe that there is an energy-saving, or a decrease in consumption, due to the DST policy. Therefore, we argue that switching time zones does not have a measurable or observable impact on energy savings.

One other crucial finding was about a possible one-hour load shift due to the DST. Indeed, Figures 3, 4 and 5 show us that there is a one-hour load shift during the springs' weekends. However, there is no load shift during weekends of autumn and the weekdays through the year. Therefore, we claim that the argument for the one-hour load shift due to the DST is quite limited and cannot be observed continually.

To sum up, there are dozens, or perhaps hundreds, of parameters that affect energy consumption. Using historical datasets in Turkey in two different methodologies, we conclude that time-zone switching neither increases nor decreases energy consumption at a measurable amount. Furthermore, the one-hour load shift is not observable throughout the year. Saving energy by time zone switching needs further evidence and clarification. We claim that our findings are applicable to countries such as the United States, India, Japan, Australia or China, whose latitudes are in between 42.0° north and south of equator.

Conflict of Interest: The authors declare that there is no conflict of interest.

References

[1] D. S. Prerau, *Seize the daylight : the curious and contentious story of daylight saving time*. 2005.

[2] M. J. Kotchen and L. E. Grant, “Does Daylight Saving Time Save Energy? Evidence From A Natural Experiment In Indiana,” 2011. doi: 10.1162/REST_a_00131.

[3] P. Kudela, T. Havranek, D. Herman, and Z. Irsova, “Does daylight saving time save electricity? Evidence from Slovakia,” *Energy Policy*, vol. 137, Feb. 2020, doi: 10.1016/j.enpol.2019.111146.

[4] R. Kellogg and H. Wolff, “Daylight time and energy: Evidence from an Australian experiment,” *J. Environ. Econ. Manage.*, vol. 56, no. 3, pp. 207–220, Nov. 2008, doi: 10.1016/j.jeem.2008.02.003.

[5] D. Kuehnle and C. Wunder, “Using the Life Satisfaction Approach to Value Daylight Savings Time Transitions: Evidence from Britain and Germany,” *J. Happiness Stud.*, vol. 17, no. 6, pp. 2293–2323, Dec. 2016, doi: 10.1007/s10902-015-9695-8.

[6] A. L. Sexton and T. K. M. Beatty, “Behavioral responses to Daylight Savings Time,” *J. Econ. Behav. Organ.*, vol. 107, no. PA, pp. 290–307, Nov. 2014, doi: 10.1016/j.jebo.2014.03.012.

[7] Servet KARASU, “Yaz Saati Uygulamasinin Binalarda Aydinlatma İçin Kullanilan Elektrik Tüketimine Etkileri,” 2010, Accessed: Jan. 29, 2021. [Online]. Available: https://www.researchgate.net/publication/308903648_YAZ_SAATI_UYGULAMASININ_BINALARDA_AYDINLATMA_ICIN_KULLANILAN_ELEKTRIK_TUKETIMINE_ETKILERI.

[8] R. Tayyip *et al.*, “Karar Sayısı : 2016/9154 Yönetmelik Adı-7.”

[9] “The World Clock — Worldwide.” https://www.timeanddate.com/worldclock/ (accessed Jan. 16, 2021).

[10] “State of the Union 2018: Q&A on the Commission’s proposal to put an end to seasonal clock changes.” https://ec.europa.eu/commission/presscorner/detail/en/MEMO_18_5641 (accessed Jan. 26, 2021).

[11] S. I. Hill, F. Desobry, E. W. Garnsey, and Y. F. Chong, “The impact on energy consumption of daylight saving clock changes,” *Energy Policy*, vol. 38, no. 9, pp. 4955–4965, Sep. 2010, doi: 10.1016/j.enpol.2010.03.079.

[12] B. A. Rock, “Impact of daylight saving time on residential energy consumption and cost,” *Energy Build.*, vol. 25, no. 1, pp. 63–68, Feb. 1997, doi: 10.1016/s0378-7788(96)00990-5.

[13] M. Awad Momani, B. Yatim, and M. A. M. Ali, “The impact of the daylight saving time on electricity consumption-A case study from Jordan,” *Energy Policy*, vol. 37, no. 5, pp. 2042–2051, May 2009, doi: 10.1016/j.enpol.2009.02.009.

[14] M. Krarti and A. Hajiah, “Analysis of impact of daylight time savings on energy use of buildings in Kuwait,” *Energy Policy*, vol. 39, no. 5, pp. 2319–2329, May 2011, doi: 10.1016/j.enpol.2011.01.046.

[15] H. Verdejo, C. Becker, D. Echiburu, W. Escudero, E. Fucks, and M. Jose Reveco, “Impact of daylight saving time on the Chilean residential consumption,” *Energy Policy*, vol. 88, pp. 456–464, Jan. 2016, doi: 10.1016/j.enpol.2015.10.051.

[16] P. Hancevic and D. Margulis, “Daylight saving time and energy consumption: The case of Argentina,” 2016.

[17] L. Bellia, I. Acosta, M. Á. Campano, and F. Fragliasso, “Impact of daylight saving time on lighting energy

consumption and on the biological clock for occupants in office buildings," *Sol. Energy*, vol. 211, pp. 1347–1364, Nov. 2020, doi: 10.1016/j.solener.2020.10.072.

[18] D. B. Belzer, S. W. Hadley, and S.-M. Chin, "Impact of Extended Daylight Saving Time on National Energy Consumption Report to Congress," Oct. 2008. doi: 10.2172/949762.

[19] F. M. Mirza and O. Bergland, "The impact of daylight saving time on electricity consumption: Evidence from southern Norway and Sweden," *Energy Policy*, vol. 39, no. 6, pp. 3558–3571, Jun. 2011, doi: 10.1016/j.enpol.2011.03.057.

[20] M. López, "Daylight effect on the electricity demand in Spain and assessment of Daylight Saving Time policies," *Energy Policy*, vol. 140, p. 111419, May 2020, doi: 10.1016/j.enpol.2020.111419.

[21] T. Havranek, D. Herman, and Z. Irsova, "Does Daylight Saving Save Electricity? A Meta-Analysis," *Energy J.*, vol. 39, no. 2, pp. 63–86, 2018, doi: 10.5547/01956574.39.2.thav.

[22] B. Gatama and M. Njeri, "FACTORS INFLUENCING HOUSEHOLD ENERGY CONSUMPTION: THE CASE OF BIOMASS FUELS IN KIKUYU DISTRICT OF KIAMBU COUNTY, KENYA A RESEARCH PROJECT, SUBMITTED IN 3PARTIAL FULFILLMENT, OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF ARTS IN ENVIRONMENTAL PLANNING AND MANAGEMENT OF THE UNIVERSITY OF NAIROBI. DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES," 2014.

[23] A. Cihat, O. Korkmaz, and A. Enerji, "TÜRKİYE KISA SÜRELİ ELEKTRİK TALEBİNİN SAATLİK OLARAK TAHMİN EDİLMESİ."

[24] A. Zaharia, M. C. Diaconeasa, L. Brad, G.-R. Lădaru, and C. Ioanăș, "Factors Influencing Energy Consumption in the Context of Sustainable Development," *Sustainability*, vol. 11, no. 15, p. 4147, Aug. 2019, doi: 10.3390/su11154147.

[25] E. Y. Haliloğlu and Y. Tutu, "TÜRKİYE İÇİN KISA VADELİ ELEKTRİK ENERJİSİ TALEP TAHMİNİ SHORT-TERM ELECTRICITY POWER DEMAND FORECASTING FOR TURKEY," Jul. 2018. Accessed: Jan. 16, 2021. [Online]. Available: https://dergipark.org.tr/en/pub/jyasar/285007.

[26] M. J. Kim, "Characteristics and determinants by electricity consumption level of households in Korea," *Energy Reports*, vol. 4, pp. 70–76, Nov. 2018, doi: 10.1016/j.egyr.2017.12.001.

[27] M. Sakai and Mihoko, "The effect of economic factors and energy efficiency programs on residential electricity consumption," *PhDT*, 2013, Accessed: Jan. 16, 2021. [Online]. Available: https://ui.adsabs.harvard.edu/abs/2013PhDT........59S/abstract.

[28] D. Weedmark, "The advantages & disadvantages of a multiple regression model," *Sciencing*, 2018. https://sciencing.com/advantages-disadvantages-multiple-regression-model-12070171.html (accessed Jan. 16, 2021).

[29] R. Ghedamsi *et al.*, "Modeling and forecasting energy consumption for residential buildings in Algeria using bottom-up approach," *Energy Build.*, vol. 121, pp. 309–317, Jun. 2016, doi: 10.1016/j.enbuild.2015.12.030.

[30] R. V. Jones, A. Fuertes, and K. J. Lomas, "The socio-economic, dwelling and appliance related factors affecting electricity consumption in domestic buildings," *Renewable and Sustainable Energy Reviews*, vol.

43. Elsevier Ltd, pp. 901–917, Mar. 01, 2015, doi: 10.1016/j.rser.2014.11.084.

[31] K. P. Amber, M. U. Saeed, M. W. Aslam, I. Hussain, and M. S. Khan, "Effect of different factors on the electricity consumption and electricity usage intensity (EUI) of residential buildings in Pakistan," *Rev. la Constr.*, vol. 17, no. 3, pp. 473–483, 2019, doi: 10.7764/RDLC.17.3.473.

[32] G. Huebner, D. Shipworth, I. Hamilton, Z. Chalabi, and T. Oreszczyn, "Understanding electricity consumption: A comparative contribution of building factors, socio-demographics, appliances, behaviours and attitudes," *Appl. Energy*, vol. 177, pp. 692–702, Sep. 2016, doi: 10.1016/j.apenergy.2016.04.075.

[33] G. K. F. Tso and K. K. W. Yau, "A study of domestic energy usage patterns in Hong Kong," *Energy*, vol. 28, no. 15, pp. 1671–1682, Dec. 2003, doi: 10.1016/S0360-5442(03)00153-1.

[34] F. H. Abanda and L. Byers, "An investigation of the impact of building orientation on energy consumption in a domestic building using emerging BIM (Building Information Modelling)," *Energy*, vol. 97, pp. 517–527, Feb. 2016, doi: 10.1016/j.energy.2015.12.135.

[35] K. J. Baker and R. M. Rylatt, "Improving the prediction of UK domestic energy-demand using annual consumption-data," *Appl. Energy*, vol. 85, no. 6, pp. 475–482, Jun. 2008, doi: 10.1016/j.apenergy.2007.09.004.

[36] A. Druckman and T. Jackson, "Household energy consumption in the UK: A highly geographically and socio-economically disaggregated model," *Energy Policy*, vol. 36, no. 8, pp. 3177–3192, Aug. 2008, doi: 10.1016/j.enpol.2008.03.021.

[37] A. Kavousian, R. Rajagopal, and M. Fischer, "Determinants of residential electricity consumption: Using smart meter data to examine the effect of climate, building characteristics, appliance stock, and occupants' behavior," *Energy*, vol. 55, pp. 184–194, Jun. 2013, doi: 10.1016/j.energy.2013.03.086.

[38] P. P. Shrestha and P. Kulkarni, "Identifying Factors that Affect the Energy Consumption of Residential Buildings," in *Construction Research Congress 2010*, May 2010, pp. 1437–1446, doi: 10.1061/41109(373)144.

[39] V. Shabunko, C. M. Lim, S. Brahim, and S. Mathew, "Developing building benchmarking for Brunei Darussalam," *Energy Build.*, vol. 85, pp. 79–85, Dec. 2014, doi: 10.1016/j.enbuild.2014.08.047.

[40] G. Çalmaşur and K. İnan, "Hanehalkı Elektrik Talebini Etkileyen Faktörler: Türkiye Üzerine Bir Uygulama," *Erciyes Üniversitesi İktisadi ve İdari Bilim. Fakültesi Derg.*, no. 52, pp. 71–92, Dec. 2018, doi: 10.18070/erciyesiibd.435627.

[41] Y. T. Chen, "The factors affecting electricity consumption and the consumption characteristics in the residential sector—a case example of Taiwan," *Sustain.*, vol. 9, no. 8, Aug. 2017, doi: 10.3390/su9081484.

[42] U. C. Priva and C. Sanker, "Limitations of difference-in-difference for measuring convergence," *Lab. Phonol.*, vol. 10, no. 1, 2019, doi: 10.5334/labphon.200.

[43] H. Zhou, C. Taber, S. Arcona, and Y. Li, "Difference-in-Differences Method in Comparative Effectiveness Research: Utility with Unbalanced Groups," *Appl. Health Econ. Health Policy*, vol. 14, no. 4, 2016, doi: 10.1007/s40258-016-0249-y.

[44] J. Lopez Bernal, S. Cummins, and A. Gasparrini, "Difference in difference, controlled interrupted time

series and synthetic controls," *Int. J. Epidemiol.*, vol. 48, no. 6, pp. 2062–2063, Dec. 2019, doi: 10.1093/ije/dyz050.

[45] J. E. Ewusie, C. Soobiah, E. Blondal, J. Beyene, L. Thabane, and J. S. Hamid, "Methods, applications and challenges in the analysis of interrupted time series data: A scoping review," *Journal of Multidisciplinary Healthcare*, vol. 13. 2020, doi: 10.2147/JMDH.S241085.

[46] H. Guan, S. Beecham, H. Xu, and G. Ingleton, "Incorporating residual temperature and specific humidity in predicting weather-dependent warm-season electricity consumption," *Environ. Res. Lett.*, vol. 12, no. 2, p. 024021, Feb. 2017, doi: 10.1088/1748-9326/aa57a9.

[47] G. K. Uyanık and N. Güler, "A Study on Multiple Linear Regression Analysis," *Procedia - Soc. Behav. Sci.*, vol. 106, pp. 234–240, Dec. 2013, doi: 10.1016/j.sbspro.2013.12.027.

[48] O. Bergland, F. M. Mirza, O. Bergland, and F. Mirza, "Latitudinal Effect on Energy Savings from Daylight Savings Time," Dec. 2017, Accessed: Jan. 29, 2021. [Online]. Available: https://econpapers.repec.org/RePEc:hhs:nlsseb:2017_008.

[49] M. B. C. Aries and G. R. Newsham, "Effect of daylight saving time on lighting energy use: A literature review," *Energy Policy*, vol. 36, no. 6, pp. 1858–1866, Jun. 2008, doi: 10.1016/j.enpol.2007.05.021.

[50] "Frequently Asked Questions (FAQs) - U.S. Energy Information Administration (EIA)." https://www.eia.gov/tools/faqs/faq.php?id=99&t=3 (accessed Jan. 26, 2021).