Smart meter consumption time-series forecasting

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Thesis submitted for the degree of Master of Science in Artificial Intelligence, eg

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Preface

I would like to thank everybody who kept me busy the last year, especially my promoter and my assistants. I would also like to thank the jury for reading the text. My sincere gratitude also goes to my wive and the rest of my family.

Ir. Stijn Staring

Contents

Abstract

The `abstract` environment contains a more extensive overview of the work. But it should be limited to one page.
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Abstract

In dit `abstract` environment wordt een al dan niet uitgebreide Nederlandse samenvatting van het werk gegeven. Wanneer de tekst voor een Nederlandstalige master in het Engels wordt geschreven, wordt hier normaal een uitgebreide samenvatting verwacht, bijvoorbeeld een tiental bladzijden.
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List of Figures and Tables

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List of Abbreviations and Symbols

Abbreviations

LoG	Laplacian-of-Gaussian
MSE	Mean Square error
PSNR	Peak Signal-to-Noise ratio

Symbols

42	“The Answer to the Ultimate Question of Life, the Universe, and Everything” according to [**?**]
c	Speed of light
E	Energy
m	Mass
π	The number pi

Chapter 1

Introduction

The first contains a general introduction to the work. The goals are defined and the modus operandi is explained.

1.1 Importance of topic

1.2 Problem formulation and link with previous studies

blablabla

1.3 Thesis objective and structure

The goal of this thesis is to do short-term load forecasting for individual households. A forecast of the electrical load of a household for 24 hours.

Chapter 2

Data analysis

In this chapter details of the dataset are introduced and a basic analysis is performed. This includes assessing missing data, seasonality, influence of temperature and household data, comparing weekdays and weekends, applying an ARIMA model for forecasting.

2.1 Introduction to dataset

update pictures The data that is used in this thesis is made available for the IEEE-CIS technical challenge on energy prediction from smart data. It consists out of data from smart meters about the 1/2 hour granulated electricity consumption of 3248 households located in the United Kingdom in the year 2017. The definition of a household are all the people who occupy a single housing unit, regardless of their relationship to one another. Each smart meter collected thus a total of 17520 measurements that are performed by the the leading international energy provider, E.ON UK plc. Not all the 3248 smart meters consist of full data as can be seen in Figure A.1 in appendix A. It can be clearly seen that there are 12 steps in the amount of missing values. This is because the available data ranges from one month (only December) to a full year of data. This acknowledges that customers may have joined at different times during the year. Additionally, missing values are introduced due to errors in sending/receiving from smart meters.
Next to the electricity consumption of the different households, also information is available about the average, minimum and maximum temperature of the day on the location of the smart meter. This data is available at a daily resolution. Also, through voluntary surveys, incomplete information is collected about 2143 smart meters. This concerns e.g. dwelling type, number of occupants, number of bedrooms etc. Table A.1 displays all the attributes in appendix A.

Because of the additional information about the attributes that are summed up in Table A.1, it can be better understood what kind of households are included in the consumption.csv. It is assumed that all the loads are measured form households of the type listed below and each household is made up of maximum four persons and

consumption.csv	
# households	3248
information	electric load
measurements	17520
granularity	$\frac{1}{2}$hour
timespan	year 2017
location	UK

weather.csv	
information	average temperature
	max temperature
	min temperature
granularity	daily
addInfo.csv	
# households	2143

Table 2.1: Table with information about the characteristics of the available datasets.

has a maximum of five bedrooms. industrial loads or small businesses, a bakery for example, are not considered.

- flat
- bungalow
- detached house
- semi-detached house
- terraced house

2.2 Preprocessing

Following steps discuss the preprocessing done on the consumption time-series containing measurements for the entire year.

2.2.1 Missing data

As discussed above the consumption dataset contains additionally to the missing months also missing data due to sending/receiving errors of the smart meters. When this happens the data of the whole day is lost. It should be emphasized that a missing value should not always directly be seen as an error. It can be that the smart meter was put off because the inhabitants were on a holiday for example. The nan values then also gives information about the consumption behaviour, namely that it is possible that the inhabitants go on vacation and the electrical load will in this case normally correspond to a constant base load. However, the assumption is made that in the case of the "consumption.csv" missing data corresponds to a sending/receiving error of the smart meter. This assumption is valid because when full year data is assessed, the missing values always perfectly correspond to a day of missing values. It is therefore highly likely that the organizers of the competition manually deleted days in the consumption to increase the difficulty of the forecasting and to model sending/receiving errors of the smart meters. That the missing values correspond to sending/receiving errors is also stated in the data description of the competition.

Two methods to impute the missing values are compared. Method one substitutes the missing values of a time-serie by the mean of all the measurements done by the meter. Method two replaces the missing values by the mean consumption value of the same moment on the next and previous day. If the next or previous day is also missing, the closest known day is used. The resulting signals can be seen in Figure A.2 and Figure A.3 in appendix A.

In order to ascertain which method of the two performs the best, a reference dataset is needed in order to compare the estimated with the true values of the missing measurements. From the original dataset which contain 3248 meters it was found that for 181 meters the month March was given without missing data. These 181 complete signals of the month March are used as reference dataset. In order to create the test data in each of the 181 meter signals 7 random days of the month March were removed and estimated by the earlier two methods. The normalized mean square errors, MSE_{AN} and MSE_{mean} given by $\sum_{i=1}^{D} e_i^2$ and normalized by MSE_{mean} are given in Figure 2.1.

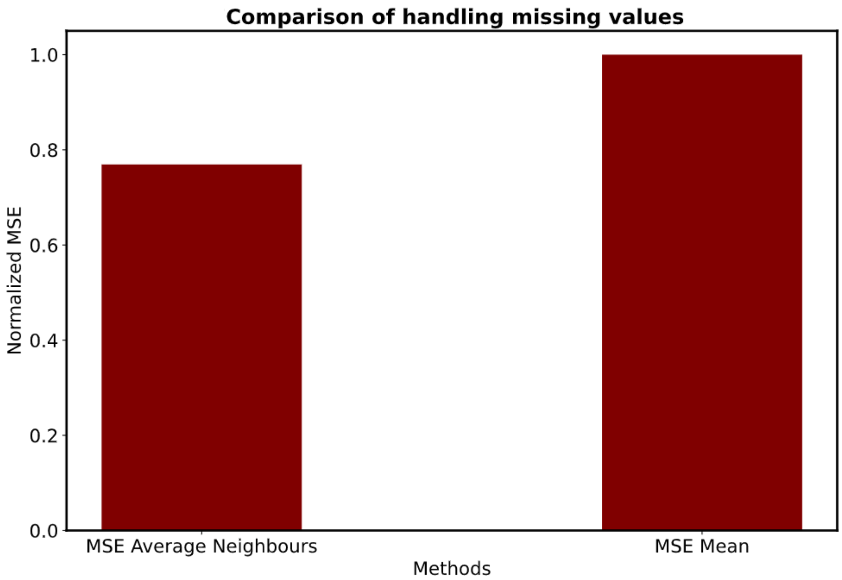

FIGURE 2.1: Resulting month of March after substitution of the missing values by the mean value of the measurements.

From Figure 2.1 it can be seen that using method 2 which estimates the missing values by the mean consumption value of the same moment on the next and previous day, outperforms method 1 which takes the mean of the signal. Therefore, all the missing values in the consumption dataset are estimated using method 2 with the only exception the first of January and thirty-one December. If one of these two days are missing, the method 1 is used because of the absence of two neighbouring days.

2.2.2 Zero days

When processing the consumption data, some untraditional meter measurements were identified. For example there were 9 meters that had multiple days with zero day consumption measurements. Because it is unlikely that a household produces exactly zero kWh on a day all these 9 meters were removed. The consumption time-serie of one of the meters is displayed in Figure 2.2 in appendix A.

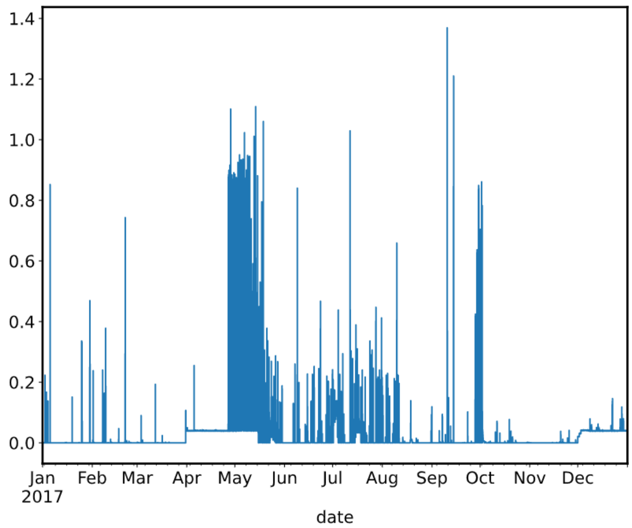

Figure 2.2: One of the 9 identified meters with multiple zero daily consumptions

Also, there has been looked if there were fundamental changes in the electricity consumption of certain meters. This is further discussed in section **??**.

2.2.3 Normalization of the data

Normalization is necessary because while absolute consumption differs, relative patterns of human behaviour are more similar [3]. The patterns in the human behaviour is what a forecasting model is trying to predict and normalization contributes by avoiding the disturbance of different magnitudes in which this human pattern may occur. Every individual household time-serie is normalized based on its yearly consumption. The advantage of using the yearly consumption to normalize in comparison of the minimum and maximum values, is the robustness against measurements out shooters and every smart meter has a total consumption of one at the end of the year.

$$normalized \quad value = \frac{consumption_i}{\sum_{n=1}^{17520} consumption_i} \tag{2.1}$$

As discussed in section 2.3 the average is taken over all the normalized time-series to obtain a single signal.

2.2.4 Removing of fundamental changes in the consumption load

After normalization of all the individual time-series it is looked for fundamental changes in the consumption load due for example when an extra person lives in the house or when systems are installed that use a lot of electricity, during the year. An example of such a time-serie can be seen in Figure **??** in appendix A. These changes are identified by looking at the maximum difference of the minimum and maximum rolling mean consumption over 7 days for each individual meter. If this difference can not anymore be explained by the dependency on the temperature, it is assumed that a fundamental change in electricity consumption took place. It is desired that the mean consumption doesn't change much during the year. This is because the model that later will be used doesn't expect fundamental changes and can thus lead to disturbance when it is kept in the training data. Figure 2.3 shows all the maximum differences between the minimum and maximum weekly rolling averages. The red line shows the cutoff and the smart meters above this line are removed. In total 251 smart meters remain. In Figure A.5 in appendix A the time-serie with the new maximum difference between the minimum and maximum weekly rolling averages is given.

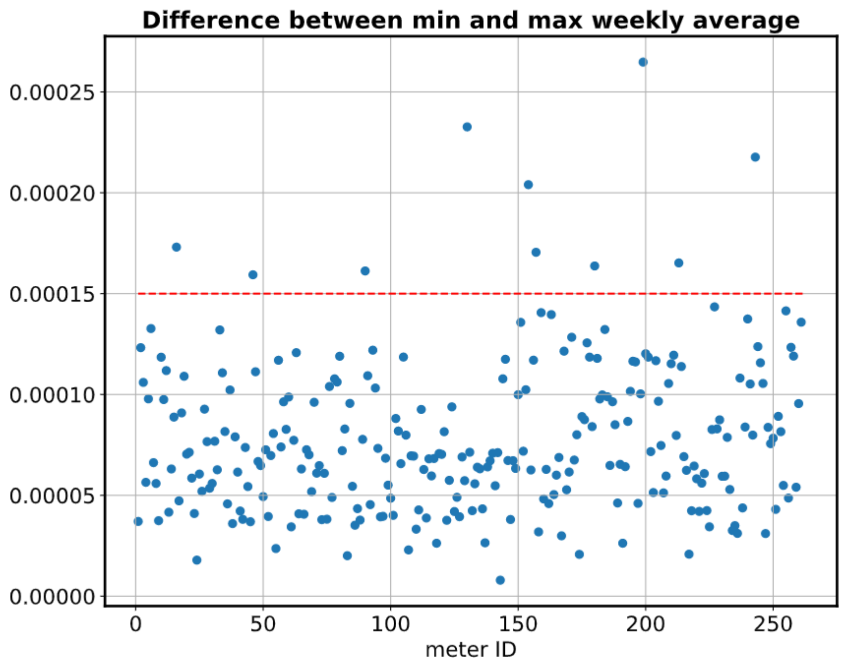

FIGURE 2.3: The maximum differences between the minimum and maximum weekly rolling averages for all the different time-series.

2.3 Analysis

Finally, the average is taken over all the remaining 251 time-series to obtain a single signal. This is done to investigate the dependence of the smart meters on seasonality, temperature, weekends and holidays. At the end of this chapter a baseline forecasting will be introduced that will be used as null-hypothesis in chapter 6to assess if the developed models lead to an improvement.

2.3.1 Seasonality

In this section the seasonality of the consumption data is discussed. In [2]it was concluded that all the forecasting algorithms that were considered, produced more accurate forecasts when they were combined with a preprocessing stage that extracted the seasonality before forecasting, compared to applying the same algorithms directly on raw data. The forecasting model is left with the task of modelling the deviation of the template consumption instead which is less challenging than performing a forecast out of the blue. These templates or filter are extracted from the consumption dataset by the use of equations 2.2 and 2.3. D and W gives respectively the number of days and weeks in the dataset. $\bar{y}_i$ and $\bar{y}_j$ gives the consumption of half an hour, averaged over respectively all days and weeks. **read paper again...**

$$\bar{y}_i = \frac{1}{D}\sum_{d=1}^{D} y_{di} i \in [1, 48] \tag{2.2}$$

$$\bar{y}_j = \frac{1}{W}\sum_{w=1}^{W} y_{wj} j \in [1, 336] \tag{2.3}$$

Figure A.6 shows the daily filter in appendix A.
Figure 2.4 shows the weekly filter. S
In the daily and weekly filters there can clearly be seen a consumption peek after midnight. This is due to heat storage systems that use electricity in the hours of low tariff and that release heat during high electricity tariffs.

2.3.2 Influence of temperature

In following section the correlation between the temperature and the electricity consumption is discussed.

Pearson correlation

The Pearson correlation is a measurement of the linear dependency between two variables which is based on the covariance variable. A Pearson correlation values gives information concerning the magnitude of the association and the corresponding direction of it. A Pearson value of one and minus one give respectively a perfect positive and negative linear relation between the variables. A value of zero, corresponds

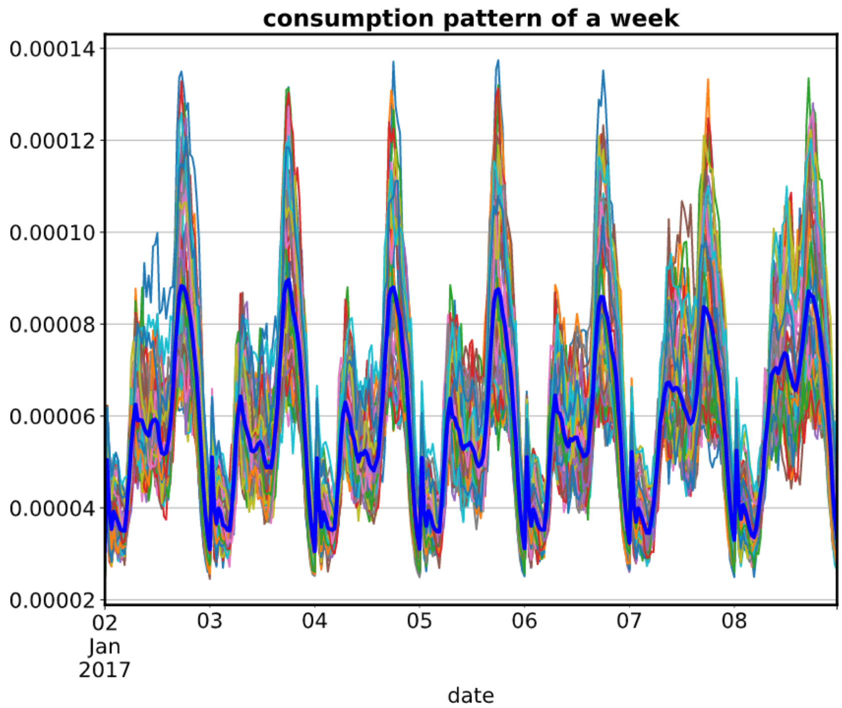

FIGURE 2.4: Figure that shows the seasonality of the electrical load during the week.

to independent behaviour. Following formula is used when calculating the Pearson correlation.

$$\rho_{X,Y} = \frac{\sigma_{x,y}}{\sigma_x \sigma_y} \tag{2.4}$$

Assumptions concerning Pearson correlation are that samples used for the correlation should be independent, normal distributed and linear related to each other. Also, homoscedasticity is assumed. Homoscedasticity is important when performing linear regression and assumes that σ_x and σ_y are constant and not in function of each other. This final assumption is validated by making use of Figure 2.5.
This figure shows the classic cone-shaped pattern of heteroscedasticity. On days when it is warm there is overall similar human behaviour in lowering the electricity consumption. However, on colder days the variation in consumption is higher. Because the assumptions of the Pearson correlation are not fulfilled, care should be taken with its output.

Applying the Pearson correlation on Figure 2.5 gives a correlation value of -0.87. This means there is a reasonable linearly decreasing relation.

Spearman correlation
Spearman correlation is a "Rank correlation". This means that the ordering of the consumption and temperature in a sample are each compared in their corresponding

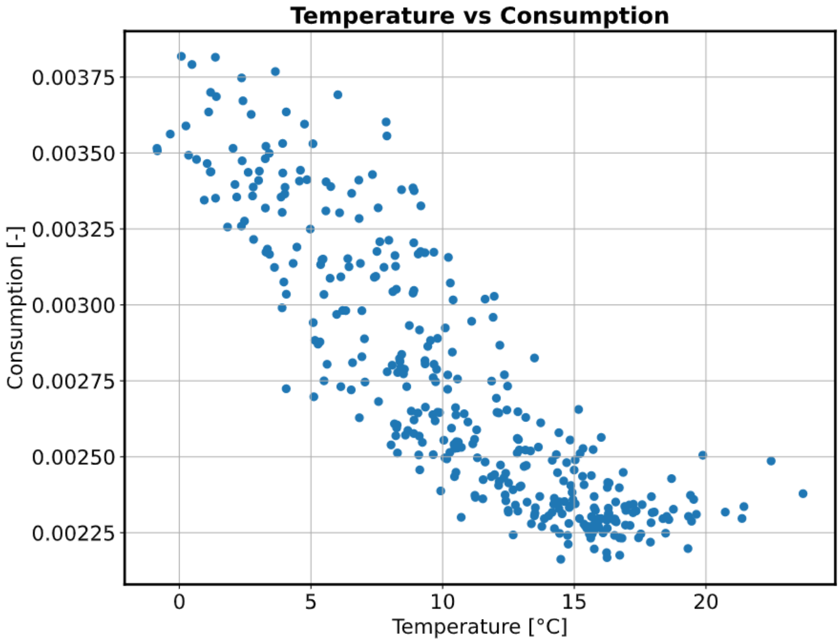

Figure 2.5: Relation between consumption and temperature.

array of measurements. When the ordering of both variables in a sample are similar, correlation is strong and positive. If the ordering is reversed, correlation is strong and negative. There is a perfect positive ordering if larger consumption always corresponds to a higher temperature. Notice that for a perfect ordering, no linear relation of the variables is necessary. The Spearman correlation coefficient is calculated using equation 2.4, but takes into account the rank of a variable in all the measurements of this variable instead of the measurement value itself.

In order to use the spearman correlation data has to be ordinal, which means that it can be ordered. The spearman correlation gives information about the monotonicity relation between the variables. $\rho = 1$ corresponds to a monotonically increasing relation.

Applying the Spearman correlation gives a correlation value of -0.89, which means there is a reasonable negative monotonicity relation.

Kendal correlation The "Kendal correlation" is also a rank based correlation. Here it is looked at the pairs of observation that are concordant, discordant or neither. A correlation coefficient close to one occurs when both variables have the same ranking and similar a coefficient close to minus one occurs when rankings in one variable are the reverse of the other. Equation 2.5 gives the equation to calculate the "Kendal correlation coefficient".

$$\tau = \frac{n^+ - n^-}{\sqrt{(n^+ + n^- + n^x)(n^+ + n^- + n^y)}} \tag{2.5}$$

- n^+ is the number of concordant pairs
- n^- is the number of discordant pairs
- n^x is the number of ties only in x
- n^y is the number of ties only in y
- concordant $\rightarrow (x_i > x_j)$ and $(y_i > y_j)$ or $(x_i < x_j)$ and $(y_i < y_j)$
- discordant $\rightarrow (x_i > x_j)$ and $(y_i < y_j)$ or $(x_i < x_j)$ and $(y_i > y_j)$
- neither $\rightarrow (x_i = x_j)$ or $(y_i = y_j)$
- if both $(x_i = x_j)$ and $(y_i = y_j) \rightarrow$ not included in either n^x or n^y

Applying the Kendal correlation gives a correlation value of -0.67, which means there is a reasonable negative monotonicity relation.

2.3.3 Comparing weekdays with weekends

Weekdays vs weekends can be compared with the help of Figure 2.4. It can be seen that the consumption of the average weekday is very similar to a weekend day.

2.3.4 Impact of holidays

In order to look at the impact of a holiday all the holidays all the holidays of the English and welsh holiday calendar are identified for the year 2017. For each of the 8 holidays a corresponding business is selected with an as close as possible average temperature of the day. This is done to remove the temperature dependency.

2.4 Baseline model

2.5 Conclusion

The final section of the chapter gives an overview of the important results of this chapter. This implies that the introductory chapter and the concluding chapter don't need a conclusion.

Chapter 3

Clustering of the load profiles

3.1 The First Topic of this Chapter

3.2 Tables

Tables are used to present data neatly arranged. A table is normally not a spreadsheet! Compare Table **??** en Table **??**: which table do you prefer?

3.3 Conclusion

The final section of the chapter gives an overview of the important results of this chapter. This implies that the introductory chapter and the concluding chapter don't need a conclusion.

Chapter 4

State of the art forecasting techniques

Do a literature study about forecasting. What is the current state of the art methods to do forecasting.

4.1 The First Topic of this Chapter

4.1.1 Item 1

Sub-item 1

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Sub-item 2

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4.1.2 Item 2

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4.2 The Second Topic

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4.3 Conclusion

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Chapter 5

Forecasting of time-series

Typical variables used in a forecasting model are: past electricity consumption loads, weather information, calendar information and error-correction terms [1].

5.1 The First Topic of this Chapter

5.1.1 Item 1

5.2 Conclusion

Chapter 6

Evaluating results

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6.1 The First Topic of this Chapter

6.1.1 Item 1

Sub-item 1

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6.3 Conclusion

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Chapter 7

Conclusion

The final chapter contains the overall conclusion. It also contains suggestions for future work and industrial applications.

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Appendices

Appendix A

Introduction to the dataset

Appendices hold useful data which is not essential to understand the work done in the master's thesis. An example is a (program) source. An appendix can also have sections as well as figures and references[**?**].

A.1 Introduction to the dataset

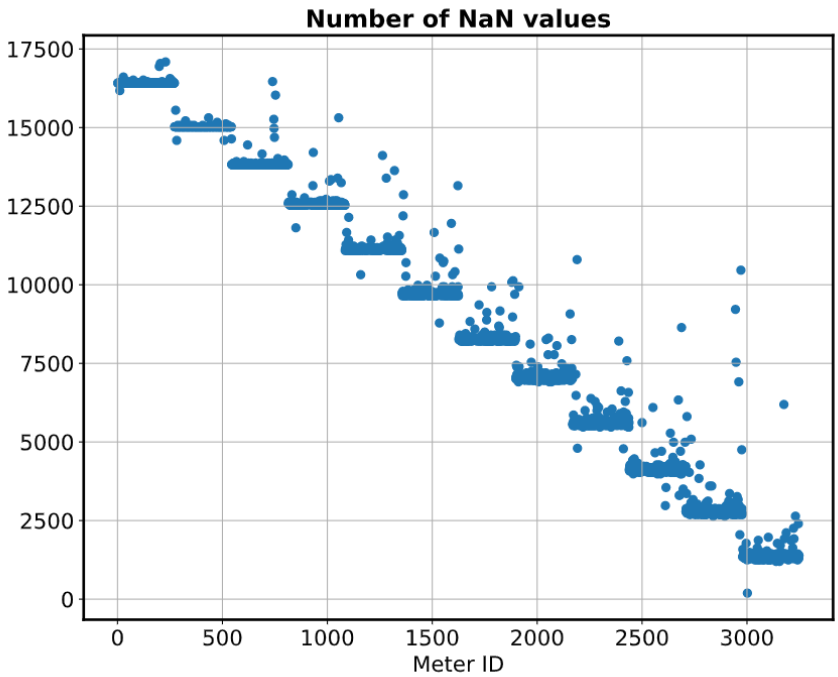

FIGURE A.1: The amount of NaN values in all the 3248 smart meters.

Attribute	Filled places
Dwelling type	1702
# Occupants	74
Heating fuel	1859
Heating fuel	78
Hot water fuel	76
Boiler age	74
Loft insulation	75
Wall insulation	75
Heating temperature	74
Efficient lighting percentage	73
Dishwasher	76
Freezer	70
Fridge freezer	70
Refrigerator	73
Tumble Dryer	76
Washing machine	76
Game console	72
Laptop	70
Pc	70
Router	69
Set top box	70
Tablet	70
Tv	75

Table A.1: Amount of response on the voluntary questionnaires.

A.2 Missing values

A.2.1 Fundamental change

A.3 Daily filter

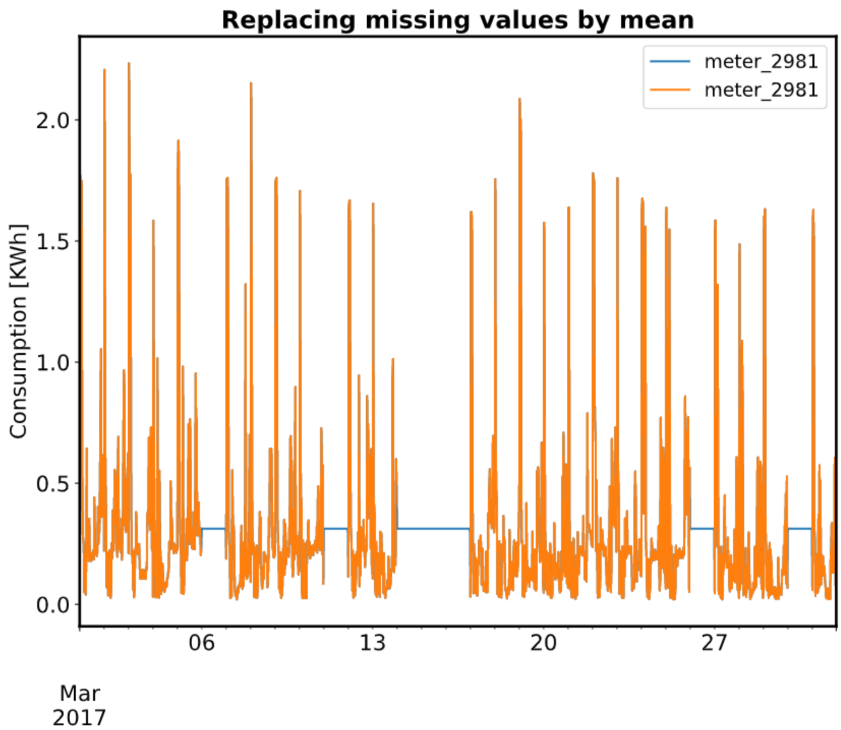

FIGURE A.2: Resulting month of March after substitution of the missing values by the mean value of the measurements.

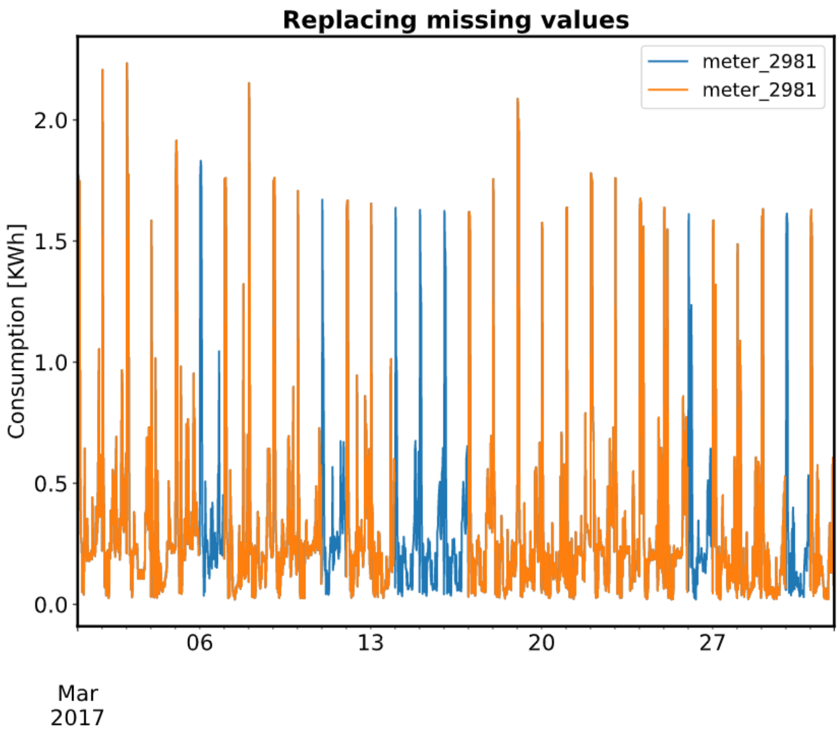

Figure A.3: Resulting month of March after substitution of the missing values by the mean value of the same moment on the next and previous day.

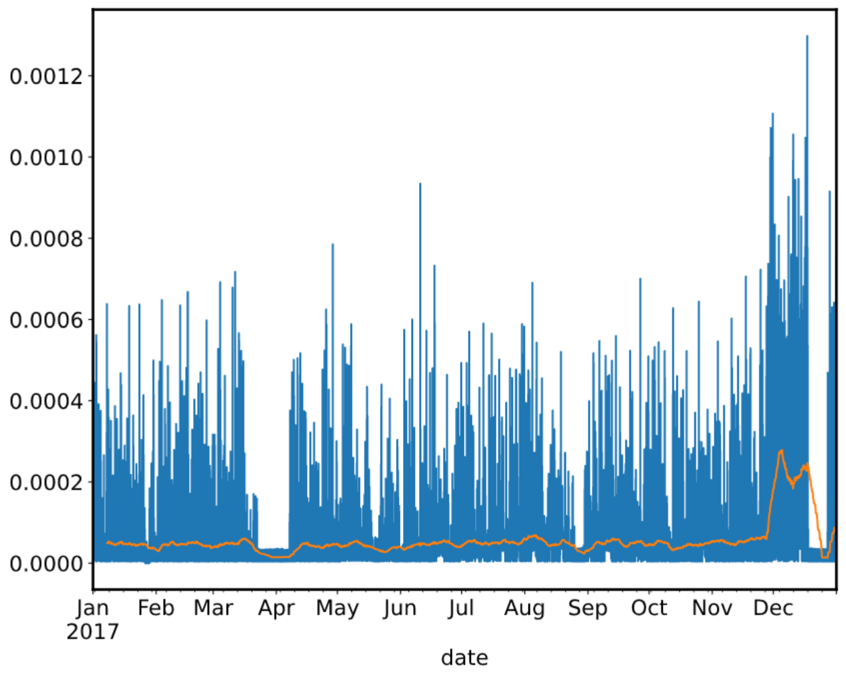

FIGURE A.4: The time-serie with the original maximum difference between the minimum and maximum weekly rolling averages.

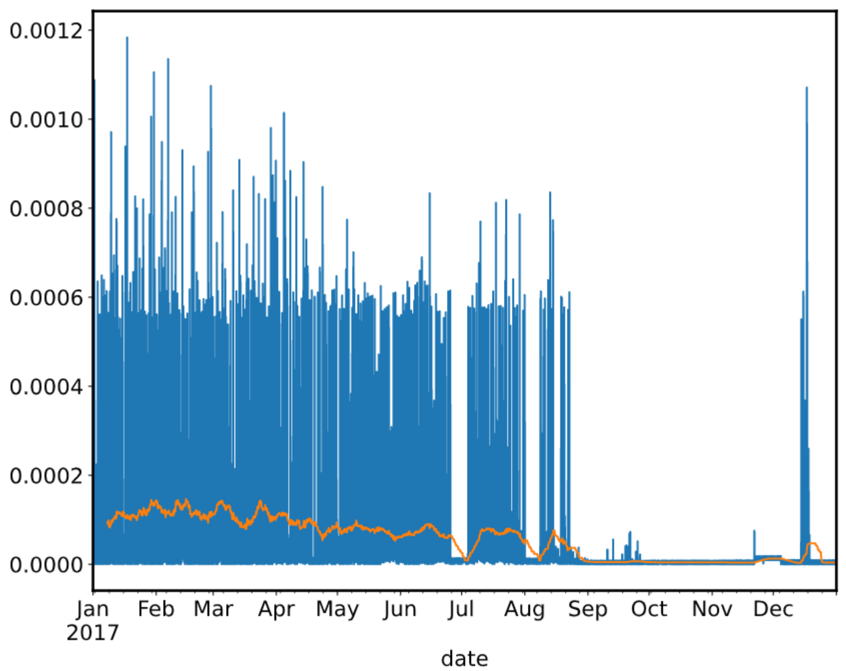

FIGURE A.5: The time-serie with the new maximum difference between the minimum and maximum weekly rolling averages.

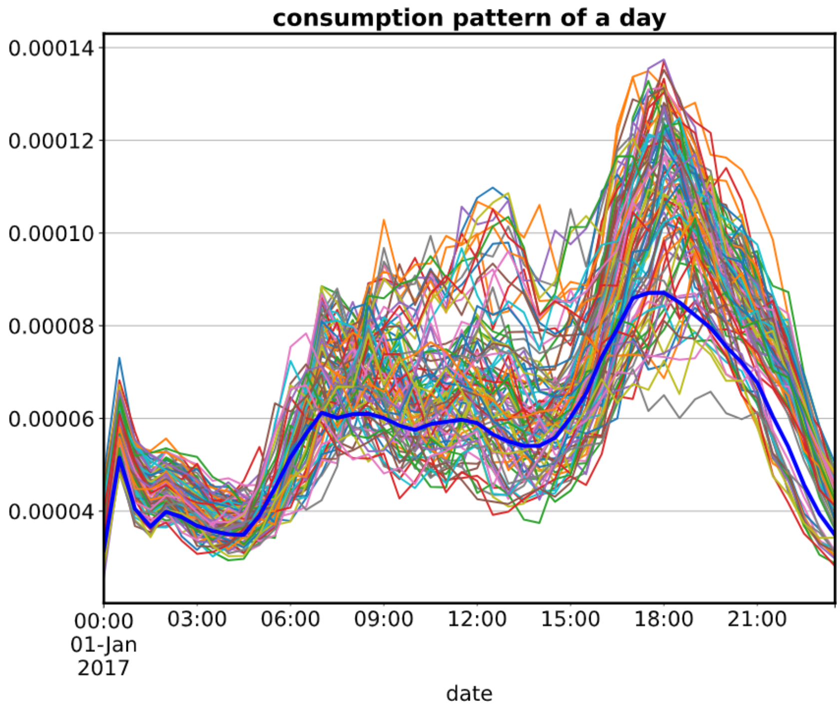

Figure A.6: Figure that shows the seasonality of the electrical load during the day.

Appendix B

Old things

B.0.1 Removing outliers

After the missing values are replaced by estimations, the outliers of the electricity consumption signals are identified. This is done by looking at the z-scores of the yearly consumptions. A z-score is calculated using equation **??** and assumes that the yearly consumptions are normally distributed around the average consumption. Consumptions that have a very low probability to occur are removed by imposing that $|z - score| < 3$.

$$z - score = \frac{x - \mu}{\sigma} \tag{B.1}$$

Figure B.1 gives the obtained z-values. It can be seen that 6 meters with an unlikely high or low consumption are removed.

B.0.2 Normalization of the data

Normalization is necessary because while absolute consumption differs, relative patterns of human behaviour are more similar [3]. The patterns in the human behaviour is what a forecasting model is trying to predict and normalization contributes by avoiding the disturbance of different magnitudes in which this human pattern may occur. Every individual household time-serie is normalized based on its maximum and minimum value according to equation B.2.

$$normalizedvalue = \frac{x - x_{min}}{x_{max} - x_{min}} \tag{B.2}$$

As discussed in section **??** the average is taken over all the normalized time-series to obtain a single signal.**Ask if this is good??** Because the maximum is taken into account during the normalization, measurement out shooters have an influence on the normalization.

B.1 ARIMA

What is ARIMA. Assumptions of ARIMA...

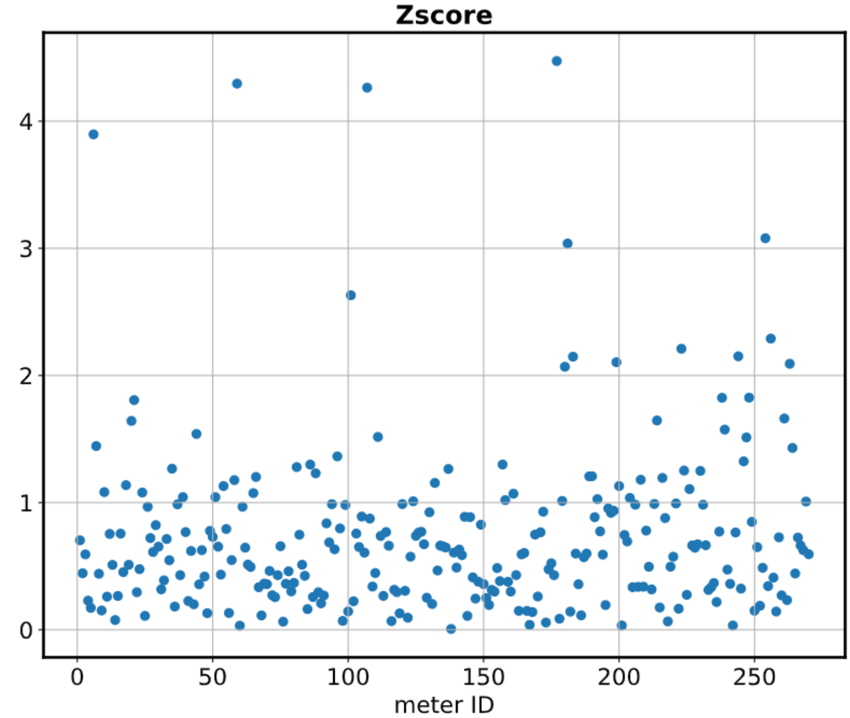

Figure B.1: Z-scores calculated from the yearly consumptions.

Stationarity
https://machinelearningmastery.com/remove-trends-seasonality-difference-transform-python/ When data is modelled it is assumed that the statistics of the data are consistent or stationary. This means the mean and standard deviation is not changing in time. However, because time series are often subdued to a trend or seasonality this assumption of stationarity is violated. In order to model not stationary observations by a stationary model as ARIMA, trends and seasonal effects should be removed. A way to check the stationarity of your observations, the “Dicky-Fuller test” can be used. A way to remove non-stationarity is by using “Difference Transform”. Here the trend and seasonality is subtracted from the observations leaving behind a stationary dataset.

Bibliography

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[2] B. A. Hoverstad, A. Tidemann, H. Langseth, and P. Ozturk. Short-Term Load Forecasting With Seasonal Decomposition Using Evolution for Parameter Tuning. *IEEE Transactions on Smart Grid*, 6(4):1904–1913, 2015.

[3] J. Lago. A ratios and clustering based approach to forecast electricity consumption, 2020.