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Article

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An Overview of Electricity Consumption in Europe: Models for Prediction of the Electricity Usage for Heating and Cooling

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ABSTRACT

Although aggregate electricity consumption provides valuable information for market analysis, demand composition, including industrial, residential, illumination, and other uses, and special days, such as national or religious holidays and annual industrial shutdowns, differ for each country. This paper analyzes the hourly electricity consumption of European countries in the European Transmission System Operation for Electricity (ENTSO-E) grid from 2006 to 2018. We propose an outlier detection method to identify special days and a modulated Fourier Series Expansion model to determine the breakdown of industrial versus household consumption and heating versus cooling consumption. The proposed outlier detection method uses the time series for each hour and checks whether a day has more than a threshold number of hours with exceptional electricity consumption levels. The proposed demand prediction model has a 3% average error when electricity usage for heating is not dominant. It also allows country classification based on consumption patterns to efficiently manage regional or country-based electricity markets.

Keywords: Electricity Consumption Composition Analysis, Fourier Series Expansion, Special Days Detection
JEL Classifications: Q47, E17, Q40

1. INTRODUCTION

The liberalization trend that started in the 1990s changed and expanded the focus of electricity markets. Previously, electricity generation and transmission were managed centrally, generally by governments, to provide consistent energy. With liberalization, generating units, transmission system operators, and distribution system operators were separated, and different ancillary services appeared to monitor operational performance and efficiency. These services are essential for reliable, secure, and efficient power system operations and increase the importance of analyzing real-time electricity data (Rebours et al., 2007). As a result, the forecasting and analysis of electricity demand have become significant subjects in the literature (Pai and Hong, 2005). Accurately forecasting electricity demand leads to reliable congestion management, efficient frequency control, and increased general operational performance (Shenoy and Gorinevsky, 2014). In addition, the electricity forecast and analysis directly affect environmental sustainability, supply security, resource management, and economic efficiency (Bunn and Farmer, 1985).

Electricity consumption can be primarily classified as industrial and residential, and residential consumption can be for illumination, heating, and cooling purpose. These consumption patterns lead to daily, weekly, and seasonal variations. The aggregated consumption for a region or country is determined as the total industrial and residential consumption. For each country, the demand pattern over a year is expected to have a different shape, as the electricity demand is related to many factors such as climate, industrial demand, holidays, and work habits.

Countries in the European Union (EU) have different industrialization levels and work and holiday habits. Their climate, the duration of daylight hours in each country, and their heating and cooling methods are also quite variable. These combined effects are reflected in the aggregated country demand. The present work aims to determine the components of the consumption from an analysis of the aggregate consumption data as a time series, with the hope that this will serve the purpose of better planning the balance between energy production and energy demand for each country and the whole region.

The interconnection system through European countries has provided the European power market flexibility. Access to generation sources within the grid allowed each participating nation to balance its portfolio. To effectively manage the power, data such as hourly loads, capacities, and prices of 38 countries have been recorded for 2006-2018 and publicly released as a requirement of the open access policy. Due to the decommissioning of the database server, this service was suspended on November 19, 2019, by the European Transmission System Operation for Electricity (ENTSO-E) transparency system. This vast data provides valuable information to analyze the consumption patterns of European countries.

The ENTSO-E and Europe energy politics and developments evolve by targeting three principles; security of supply, affordable energy prices, and decreasing greenhouse gas emissions (Verseille and Staschus, 2015). ENTSO-E will continue expanding to increase cross-border electricity transmission for sustainable and efficient energy management and change primary energy resources from fossil fuels to renewable ones for de-carbonization. The growing renewable energy resource investment and its portion in electricity generation lead to a higher installed capacity and distributed power. The challenges of fully renewable energy resources are fluctuation in the era, the share of controllable renewable energy resources (i.e., biomass), large-scale and decentralized storage, load flexibility, and smoothing intercontinental power (Adam et al., 2012).

With the upcoming potential issues in energy supply, European countries may have to develop strategies for reducing energy consumption and improving energy efficiency. Moreover, some studies show that the EU's energy efficiency has slowed in recent years while consumption has increased Perillo (Perillo et al., 2022; Thomas and Rosenow, 2020). In this respect, it is of utmost importance to have a detailed picture of how and in which areas electricity is used. Furthermore, the European Green Deal announced in December 2019 aims to decrease greenhouse gas emissions by 55% compared to 1990 by 2030 and become climate-neutral by 2050 (European Court of Auditors, 2021). The European Union defined many strict targets to decrease the adverse effects of fossil fuels at the country level or in specific sectors. These changes and concerns increase the significance of the ENTSO-E grid system because of the distribution of renewable energy resources across the European region. Europe reached 19.7% renewable energy resources in total generation by 2019, below the defined target of 20%, showing that many countries still need to grow their renewable energy capacity (Eurostat, 2021). As renewable energy resources strongly depend on meteorological conditions, assessing the composition of electricity consumption for heating and cooling is essential.

Electricity used for lighting follows a deterministic pattern, reflecting the daylight cycle, which can be predicted quite accurately. On the other hand, heating and cooling lead to substantial seasonal variability in consumption, so reliable estimation of the electricity used for heating and cooling requires accurate meteorological information. Furthermore, the climate cycle of the country also plays a role in this type of consumption, i.e., northern countries are expected to have a different pattern than those of southern countries. Commercial and industrial electricity use have similar characteristics concerning the days of the week. Still, commercial facilities use electricity for utilities, while industrial facilities use it for utilities and production. We will not distinguish between commercial and industrial consumption in the present work. Relative proportions of industrial and household consumption are reflected in weekday and weekend consumption. Moreover, each country has special days and holidays when almost all industrial facilities are shut down, and electricity consumption consists mainly of household demand.

Forecasting consumption in each particular country and Europe is crucial for efficiently managing the transmission grid, market operation, and resource utilization. Although the demand patterns in each country on a given weekday can be estimated based on historical data, the special events that are particular to each country and the climatic conditions significantly affect country-based consumption and cause a deviation from expected demand. The demand for special days, holidays and days with important events need to be considered for demand forecasting, and they need to be carefully included in demand forecasting approaches.

A detailed analysis of the clustering of European countries concerning the types of consumption is presented in this study. A comprehensive literature survey on methods of modelling and predicting electricity consumption is given in (Yukseltan et al., 2017; Yukseltan et al., 2020). Several studies on electricity demand forecasting focus on short- and long-term, country-based, and economic forecasting. However, the methodologies that consider special events, including their impact on electricity consumption, techniques for determining consumption type from data, and the analysis of the effect of temperature on consumption, are limited. Authors studied forecasting weather-dependent electricity load profiles using an artificial network for Germany, France, Sweden, and Spain (Behm et al., 2020). Similar studies focus on forecasting electricity in the short and long-term and load profile analysis for specific regions (Kozarcanin et al., 2019; Peters et al., 2020; Pramono et al., 2019). While these studies are valid for particular areas with detailed data sets, in this study, we analyze all countries and reveal an overview of Europe's recent electricity consumption using only weather and consumption data as input. This makes the model easier to apply to different regions or consumption scales.

The ENTSO-E includes countries with different characteristics, climate patterns, special days, events, and habits, all affecting consumption patterns. To manage the system efficiently, methodologies that consider such differences in analysis and forecasting of the demand are needed. This work aims to contribute to the management process of the tasks while proposing a novel approach to analyzing and forecasting the consumption patterns of European countries. The proposed method provides insights into the consumption characteristics based on the region and time interval and aims to help decision-makers manage the tasks.

In this study, a modulated Fourier Series Expansion (FSE) model is applied to the hourly electricity consumption of European countries in the ENTSO-E electricity grid, covering the period 2006-2018. The method is used to the hourly data of each country to obtain a model for electricity consumption. In this model, special events such as holidays, industrial shutdowns during summer, and changes to/from daylight saving time appear as outliers, and they are removed from data as part of data pre-processing. The periods corresponding to industrial shutdowns are used to determine the household to industrial consumption ratio, and the difference between weekday and weekend consumption is further used to determine the percentage of industrial and office usage to household consumption, as in (Yukseltan et al., 2020). The modulated FSE, without any meteorological information, uses only mathematical functions as regressors and provides a reasonably satisfactory long-term prediction for hourly consumption. In this study, the goodness of the long-term fit of the predicted consumption to the data is used to determine the breakdown of the electricity consumption of a country into its industrial/household/heating/cooling components. Meteorological information and forecasts can be incorporated into the model for short-term forecasts. The proposed approach provides a framework for modelling consumption patterns from data and helps decision-makers with their market analysis and grid planning assignments. The models are applied at the country level in this work but are generic and can be used for operational planning and scheduling.

The novelty of this study is due to a comprehensive analysis made for multiple countries located closely. In contrast, each country has a different population, industrialization level, culture, and electricity consumption. This paper makes an important contribution to the conversation on electricity forecasting as it analyzes consumption profiles for 38 European countries, detects special events that affect consumption, analyzes the impact of temperature, and classifies the countries based on their similarities. The specific objectives of this paper are:

1. To analyze the electricity consumption of European countries in the ENTSO-E grid and classify the countries based on their consumption characteristics
2. To develop a novel methodology to estimate the special days, outliers, and their impact on consumption
3. To develop a methodology to analyze the ratio of industrial and household consumption for countries
4. To conduct an inclusive study, investigate the impact of various critical parameters such as temperature on electricity consumption and propose a reliable forecasting methodology.

In Section 2, the data overview is presented. The data analysis results in detecting special days and events are given in Section 3, and the segregation of household and industrial consumption is given in Section 4. In Section 5, the consumption prediction methodology is presented. The results of detecting heating- and cooling-related consumption are provided in Section 6. Finally, Section 7 discusses insights based on the computational results.

2. DATA OVERVIEW

2.1. The ENTSO-E Grid

The generation and distribution technologies and increasing energy demand required joint power grids to secure sustainable and efficient electricity distribution across Europe**.** Members of the Internal Electricity Market (IEM) in the European Union founded ETSO in 1999 to create a shared network and cross-border electricity trade, which also conforms with the competitive market concept. With the success of ETSO in operation and compensation, in 2008, 36 European Transmission System Operator (TSO) signed a protocol to expand this shared network. At the end of that year, European Transmission System Operation for Electricity (ENTSO-E) was created. All ETSO activities were transferred to ENTSO-E in 2009. ENTSO-E consists of five Regional Security Coordinators (RSCs), Coreso, TSC, SCC, Nordic, and Baltic, and all members operate under these RSCs. Figure 1 shows the territory of the RSCs and adhered countries across Europe.

The data consist of hourly consumption and covers 2006-2018 (ENTSO-E, 2019b). Data quality was checked for each country, and in cases of extensive missing and inaccurate data, the whole year was excluded. Data for Ukraine is excluded because the entire country’s consumption is not available. Data for Albania, North Macedonia, Northern Ireland, Cyprus, Luxembourg, Montenegro, and Iceland either are incomplete or display irregularities and are excluded. Among these, part of the data for Cyprus and Iceland will be used for specific purposes. Cyprus is a typical example of dominant summer consumption for cooling. Iceland is located at high latitudes, an example of winter consumption in a country where electricity is not used for heating. After the initial data control, missing hourly values were filled with the data of the same hour of the same day in the previous week. The list of the countries, their full names, abbreviations, mean hourly consumption, and population is given in Appendix A in supplementary materials. A visual overview of the hourly consumption profiles of all countries except Ukraine and Luxemburg is provided in Appendix B.

2.2. Per Capita Consumption

In Figure 2, we present the average hourly consumption for the last year available in data versus the population for the ENTSO-E countries, using data presented in Appendix A. Data is scattered around a regression line, with a few exceptions. Among the ENTSO-E countries, Germany, France, the United Kingdom, and Italy form a cluster with a population above 50 million. In this group, the hourly consumption of France is above the regression line while the hourly consumptions of Italy and the United Kingdom are below.

The consumption of the countries with a relatively low population lies more or less on the same line. Finland, Norway, Sweden, and Romania are considered outliers within this group. Among the countries with a large population, Germany is almost on the same line, and Turkey is considerably below, Poland, Spain, Italy, and the United Kingdom are slightly below, while France is above. The role of industrialization or the use of electricity for heating is believed to be the main reason for extra consumption.

Figure 1: ENTSO-E RSCs and countries map (https://www.entsoe.eu)

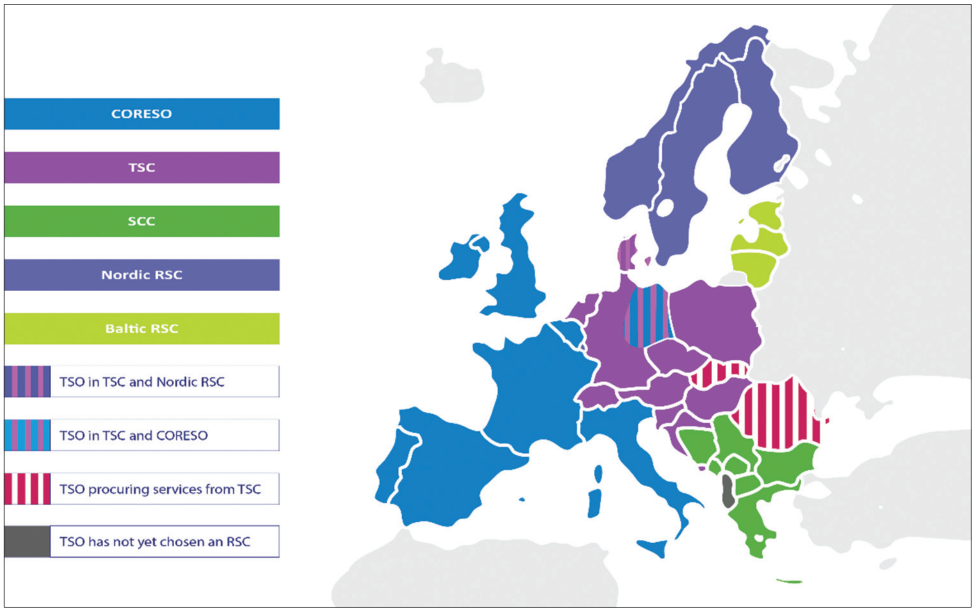


Figure 2: Mean hourly consumption versus population

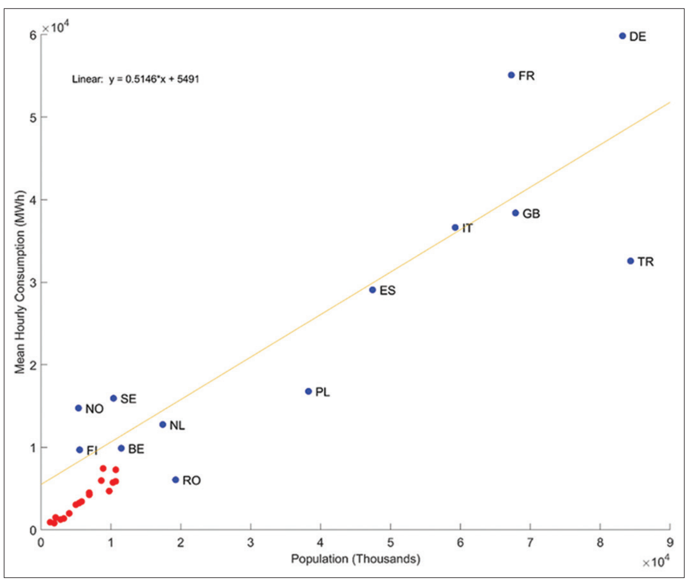


Figure 3: Average daily consumption of the countries between 2006 and 2018

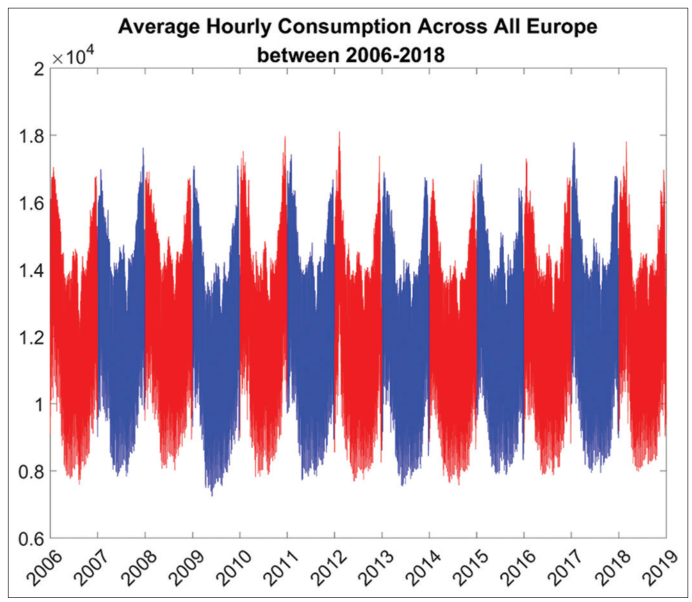


Figure 3 provides an overview of the average consumption for the countries that have full data for 2006-2008 in Europe. In these figures, a strong weekly variation reflecting the weekday/weekend effect is an indication of industrialization, while winter consumption that is higher than summer and spring consumption indicates that, in addition to increased illumination needs, electricity is likely to be used for heating. Further discussion of the breakdown of the consumption will be discussed in section 4.

2.3. Consumption Analysis

Electricity consumption is broadly classified as household and industrial/commercial/office consumption. Other consumption areas such as railroad transportation, street illumination, agricultural needs, and electric vehicles are not directly observable from the data; hence they are included in the basic types above.

The household component consists of the consumption due to household appliances, illumination, heating, and cooling needs. Appliances work more or less continuously, but illumination needs are determined by the (deterministic) daylight cycle, depending on the latitude only. The consumption for heating or cooling needs is much more complicated; it depends on weather conditions and social habits that determine comfortable temperatures and even display memory effects arising from the heating of buildings.

Commercial use of electricity is mostly confined to daylight hours, and it may be effective during weekends also. On the other hand, offices are normally off during weekends. Industrial usage of electricity is a crucial component of non-household consumption, and it is hard to estimate because certain plants may work uninterruptedly. Nevertheless, in certain countries, there may be holidays or vacation periods during which all (non-crucial) plants are shut down. In such cases, it is possible to estimate the share of purely household consumption from data. The relative proportions of weekday and weekend consumption also indicate industrial activities.

When the electricity consumption data of all countries are examined, different consumption patterns are observed. The data for Sweden, Croatia, Germany, and Poland are displayed in Figure 4 as examples. The consumption of Sweden is high and irregular in winter, indicating the use of electricity for heating. For Croatia, increased summer consumption indicates cooling needs, and summer and winter consumption is higher than in spring and autumn due to the same heating and cooling capacity. The seasonality of electricity consumption in Germany and Poland is less dominant, indicating a higher weight of industrial consumption. Strong weekly variations are also indicators of industrialization. The consumption patterns for Germany and Poland are at different scales but follow a similar pattern throughout the year.

Figure 5 below presents the hourly electricity consumption of four Mediterranean countries, Cyprus, Greece, Spain, and Italy, for 2014. Cyprus has a typical Mediterranean climate with mild winters and hot summers. Thus, electricity consumption is expected to be higher in summer. The weather in Greece is more moderate, and summer and winter consumptions are comparable. The climate in Spain and Italy also have the same Mediterranean character, but for these countries, industrial usage of electricity has a greater share. Thus, the increase in electricity consumption in summer is less dominant. In Italy, the low consumption period in summer corresponds to the shutdown of industrial plants.

Increased electricity consumption in winter is related to both the diminishing of daylight hours and the use of electricity for heating. Thus, increased electricity consumption in winter may not be the sole indicator of its usage in heating. In Figure 6, we present electricity consumption in 2014 in the high-latitude countries Norway and Iceland and the mid-latitude countries France and Bulgaria. Although Norway and Iceland are high-latitude countries, the increase in winter consumption for Iceland is moderate compared to Norway and also compared to Sweden, as can be seen in Figure 4. The comparison of the electricity consumption patterns for Norway, Sweden and Iceland shows that electricity is not likely to be used for heating in Iceland.

In general terms, electricity demand may have a trend component arising from population growth or from increasing industrialization, periodic components arising from diurnal variations of illumination needs, weekly variations reflecting industrial practices and temperature-dependent variations due to heating and cooling needs and stochastic variations of various origins.

In our analysis of electricity consumption data, we used a linear model involving a modulated Fourier series to forecast hourly electricity demand over a 1-year horizon. This method proved to be powerful and reliable in cases where electricity is used predominantly for illumination, i.e., heating and cooling-

Figure 4: Comparison of consumption patterns for Sweden, Croatia, Germany, and Poland

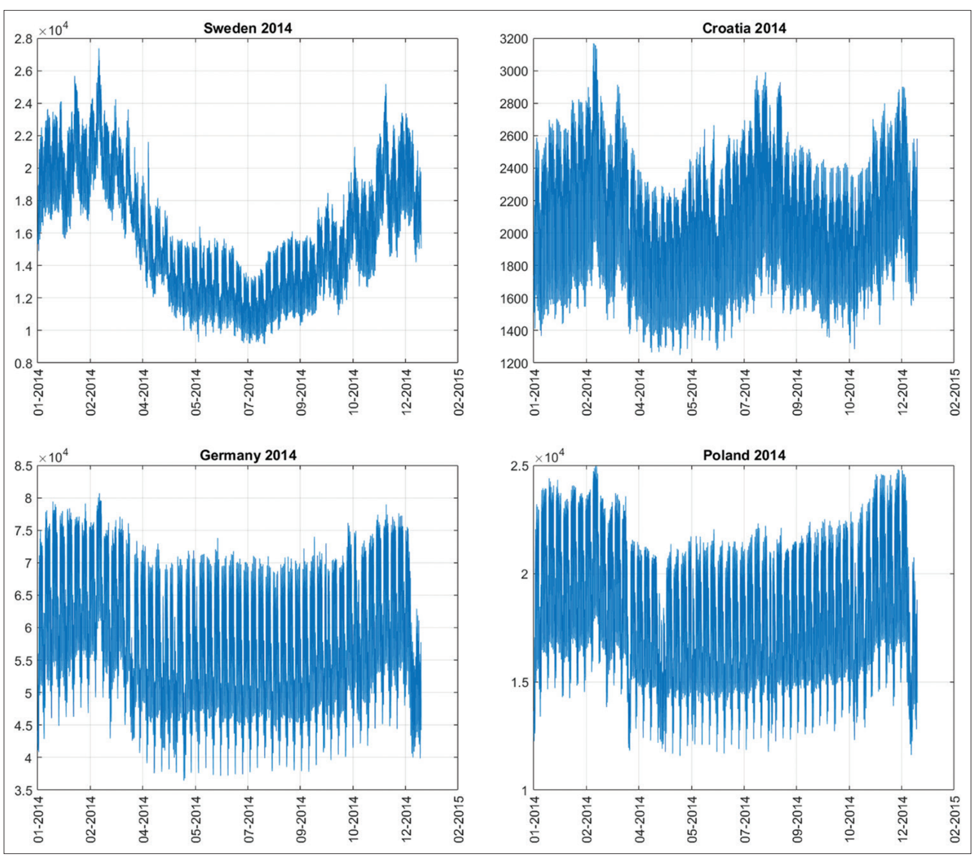


Figure 5: Comparison of consumption patterns for Cyprus, Greece, Spain, and Italy

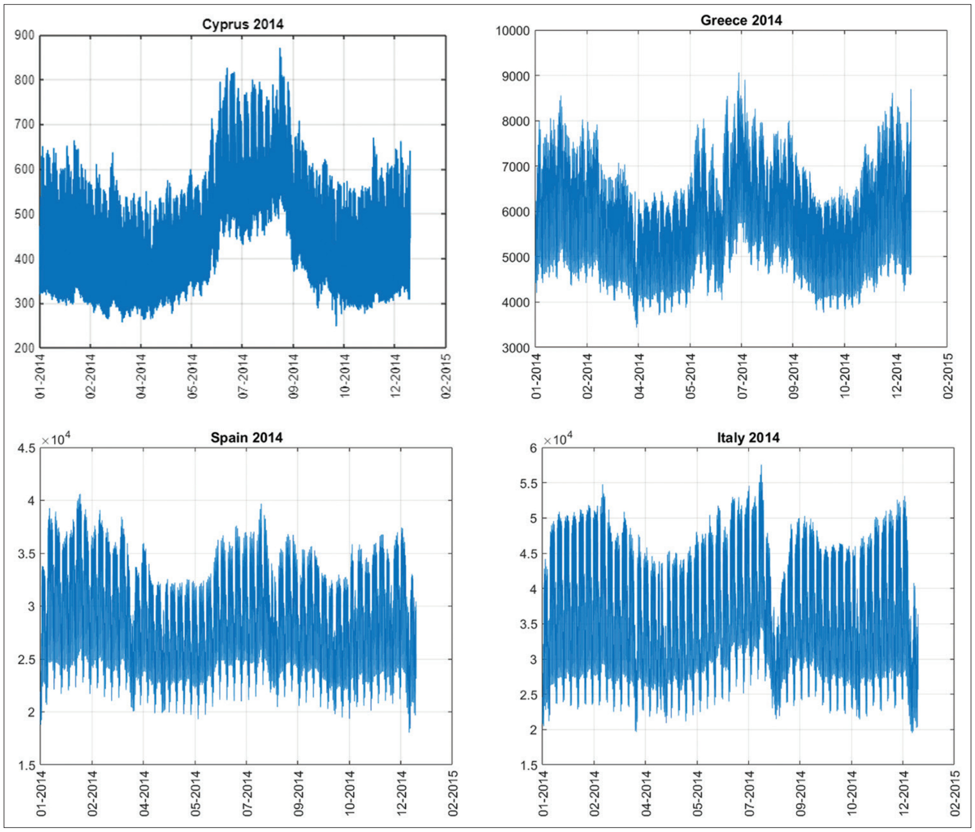
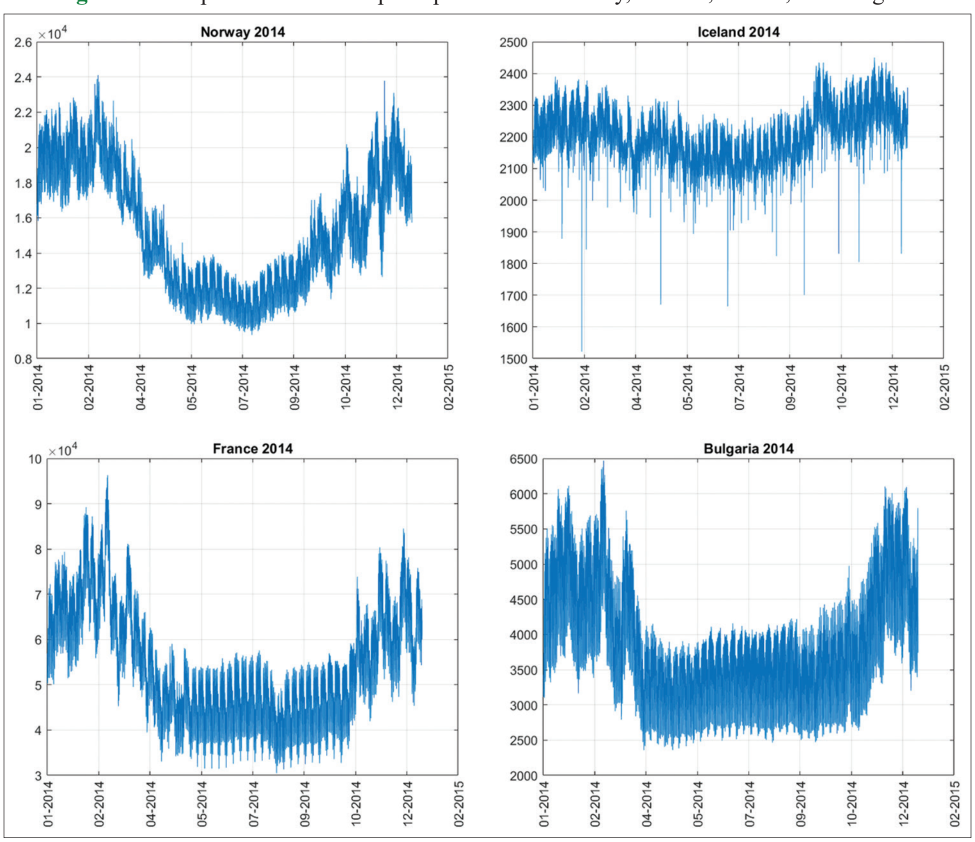


Figure 6: Comparison of consumption patterns for Norway, Iceland, France, and Bulgaria



related demand is negligible (Yukseltan et al., 2017; Yukseltan et al., 2020).

In the next section we will study methods for the detection of the proportion of electricity consumption for heating and cooling needs. The basic idea is the following. Electricity consumption for illumination and industrial production is mostly deterministic and it can be modeled in terms of a Fourier series with variations with periods 24 h and 7 days. On the other hand, electricity used for heating and cooling depends on the deviations from comfortable temperatures and depends heavily of the temperatures.

3. DETECTING ELECTRICITY CONSUMPTION FOR HEATING AND COOLING

Temperature is one of the primary external information that affects electricity consumption. The sensitivity of the consumption depends on countries' resource allocation for heating and cooling. If the electricity is used for heating, consumption during winter is high and irregular. On the other hand, if electricity is used for cooling, summer consumption is high and irregular. Furthermore, residential use of electricity for heating or cooling may lead to a difference in weekend and weekday consumption. In general, irregularity indicates the usage of electricity for heating and cooling purposes. In such cases, the data must be supplemented by meteorological information to make a reliable model and forecast. To make a comparison of countries' climatic conditions, we calculated the average cooling and heating days in each country. We calculated the deviation of hourly temperature from the comfortable temperature for winter and summer separately. Comfortable temperatures for winter and summer are determined as 18.5° and 23°C, respectively. There are different comments about the ambient temperature level in winter and summer, but these values are acceptable to mark the start of the heater or cooler use. We calculated the cooling (CDD) and heating (HDD) degree requirements for each hour with the equations below.

$$CDD_i=Max(T_i-T_s,0) \quad (1)$$

$$HDD_i=Max(T_w-T_i,0) \quad (2)$$

In Figure 7, we present the heating and cooling needs of the European countries in the grid.

We recall that electricity consumption for illumination and industrial purposes is more or less deterministic, and the modulated Fourier series expansion provides quite satisfactory models. On the other hand, electricity consumption for heating and cooling is temperature dependent and cannot be determined solely from the periodicities in the data. To detect the share of electricity consumption for heating or cooling, we first obtained models using solely modulated Fourier series expansion (MFS), and then we supplemented the model with deviations from comfortable temperatures as an additional regressor (MFST). The average prediction errors range from 3% to 11% for the selected countries with different consumption patterns. Thus the model can be used to predict hourly consumption over a year, with an accuracy of around 3% in cases where the usage of electricity for heating purposes is not dominant. The improvement in the modelling error when MSFT is used instead of MSF is shown in Figure 8.

From Figure 8, one can see that Norway, Sweden, Finland, Serbia, and France form a cluster of countries for which electricity consumption is weather dependent. For the remaining countries, the improvement in the error decreases gradually. It is noteworthy that this improvement is the lowest for Germany and Denmark.

Figure 7: Average heating and cooling degree days for European countries in the ENTSO-E grid

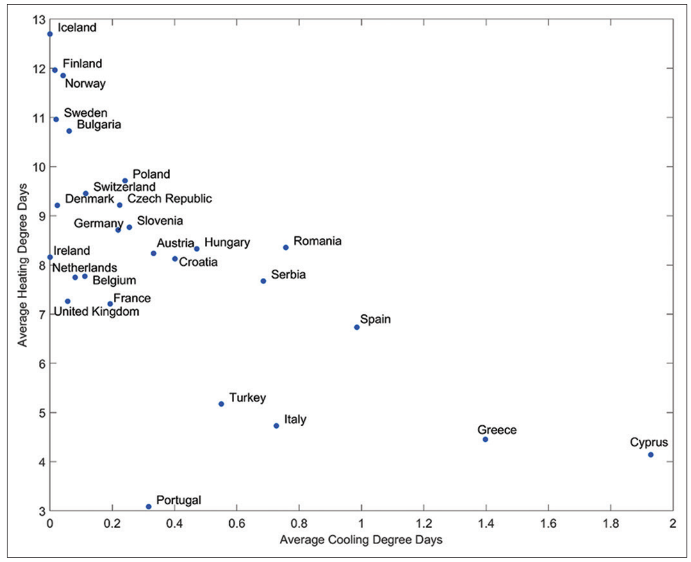
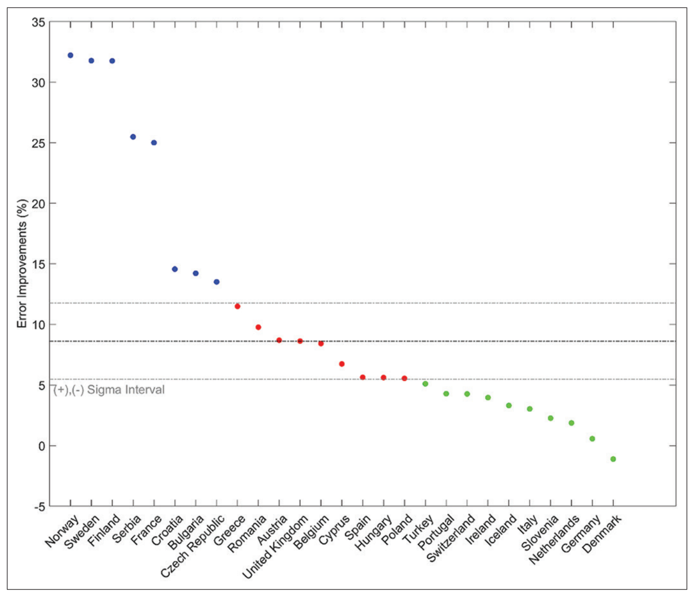


Figure 8: Improvement in the modeling error after adding deviations from comfortable temperatures as a regressor



In Figure 9, we present the improvement in the errors for Finland, Sweden, France, and Serbia as examples of the most significant improvement in the error.

We note that a significant improvement obtained by introducing temperature information is not enough to conclude that electricity is used for heating. For example, in Sweden, electricity is not used directly for heating; there is a central heating system that pumps hot water, and electricity is used to operate these pumps (Werner, 2017).

In Figure 10, we present the charts for the improvement in the modeling error for Greece, the United Kingdom, Spain, and Germany.

Figure 9: Improvement in the modeling error for Finland, Sweden, France, and Serbia (Black series: MFS, Red series: MFST)

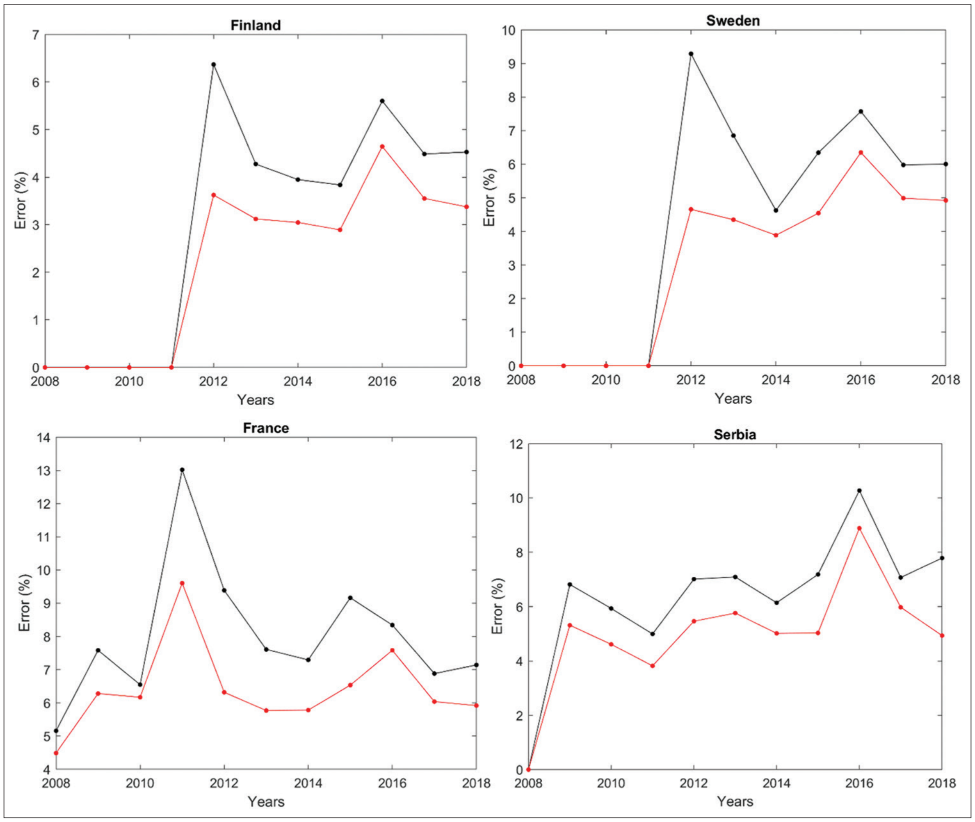
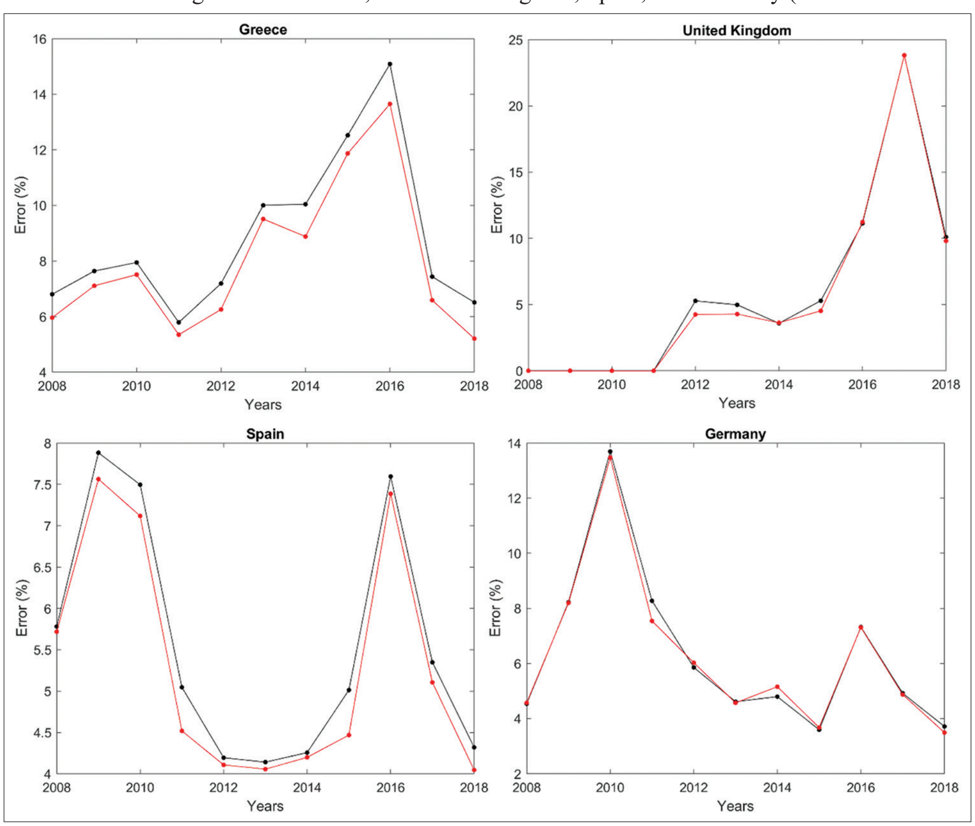


Figure 10: Improvement in the modeling error for Greece, the United Kingdom, Spain, and Germany (Black series: MFS, Red series: MFST)



The information displayed in Figures 7 and 8 can be combined to present the percentage improvement in the modeling error as a function of average heating degree days, as displayed in Figure 11. From this figure, it is clearly seen that Norway, Sweden, and

Figure 11: Percentage improvement in the modeling error as a function of average heating degree days

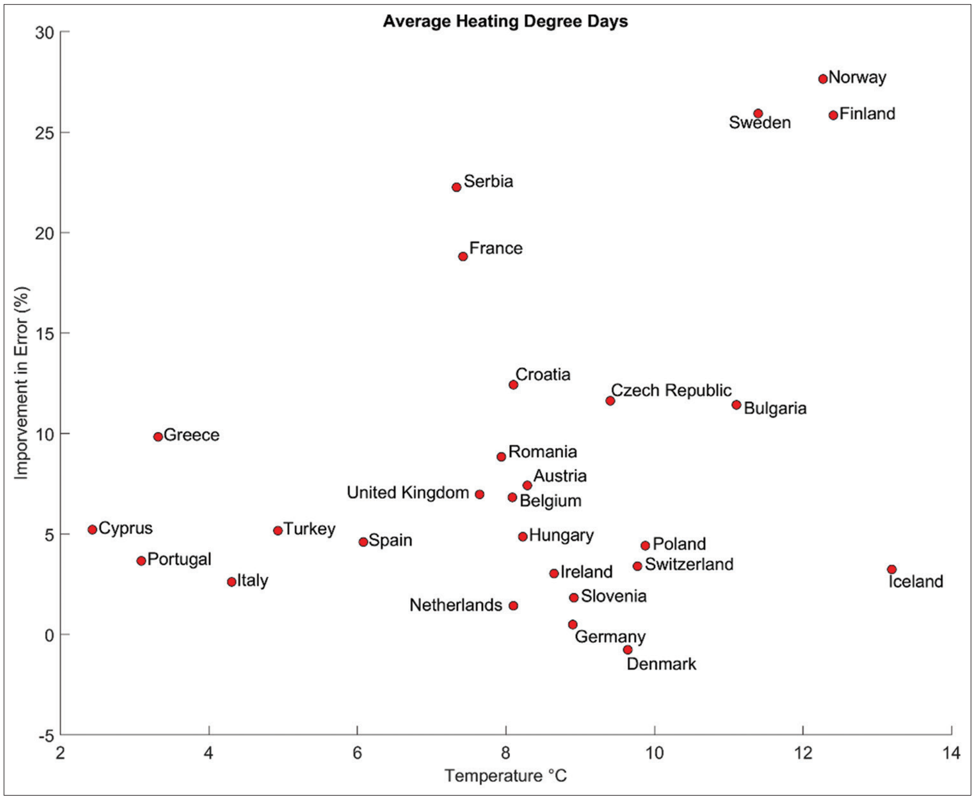
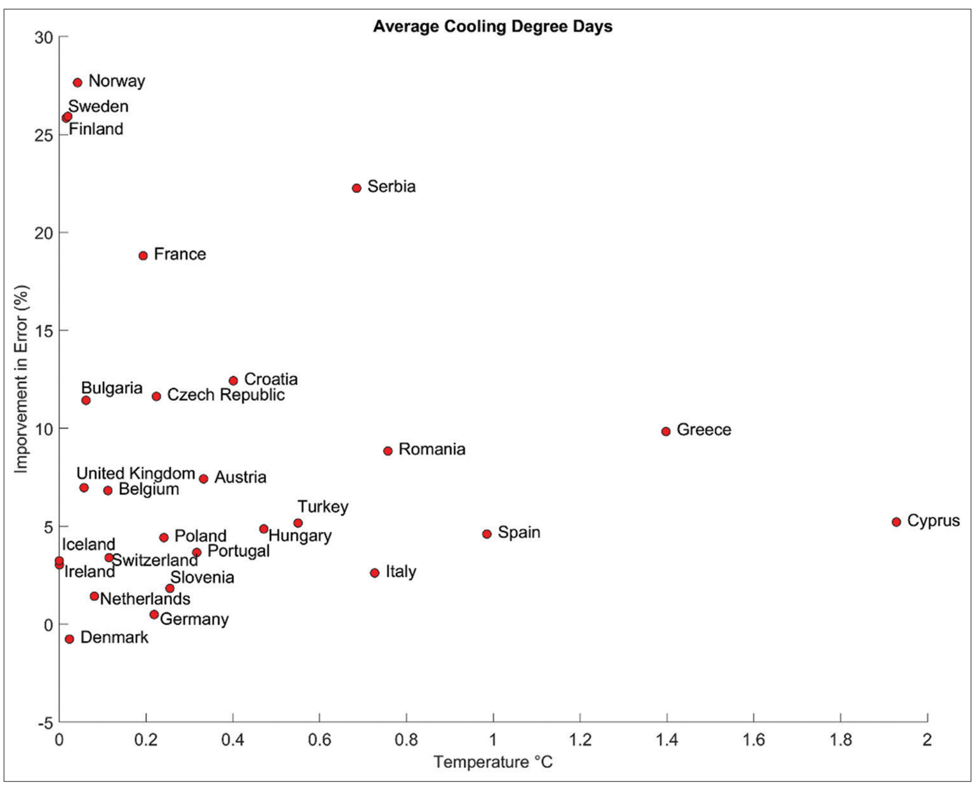


Figure 12: Percentage improvement in the modeling error as a function of average cooling degree days



Finland form a well-defined cluster of countries whose electricity consumption has a strong dependence on cold temperatures. The cluster consisting of Greece, Portugal, and Italy have low heating needs, and they do not benefit from additional climatic information. The modelling error details for each country is given in Appendix C in supplementary materials.

In a similar vein, percentage improvement in the error as a function of average cooling degree days is shown in Figure 12. Data for Cyprus and Turkey are included in this graph as examples of Mediterranean countries with higher cooling needs. In this figure, Cyprus and Greece appear as a cluster of countries with high cooling needs and benefit from introducing weather information. The cluster in the upper left consisting of Norway, Sweden, and Finland displays a big improvement in the modeling error, but as they have low cooling needs, this improvement cannot be tied to information about high temperatures.

As a further confirmation of the use of electricity for heating or cooling and deciding whether the improvement obtained by introducing temperature information is related to high temperatures or low temperatures, we give the scatter plots of the electricity consumption together with a piecewise linear fit to the data.

In Figures 13-16, we present the scatter plots of the mean hourly consumption for Cyprus, Spain, Germany, and Finland, respectively, for weekdays and weekends, for the years 2016-2018. We also note that these scatter plots indicate the threshold for "comfortable temperatures" for each country.

From Figure 13, it is clearly seen that electricity is used for cooling after a threshold slightly higher than 20°C. The relatively low difference in consumption between weekends and weekdays indicates a low level of industrialization.

Figure 13: Mean hourly consumption (MW) with respect to temperature for the years 2016-2018, Cyprus

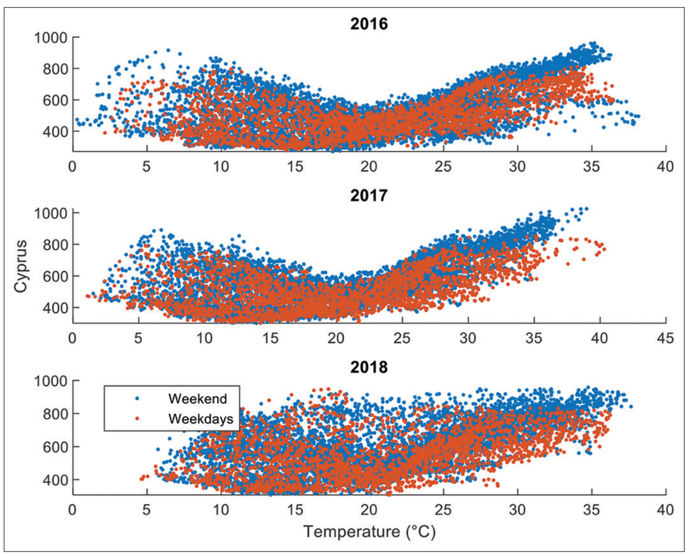


Figure 14: Mean hourly consumption (MW) with respect to temperature for the years 2016-2018, Spain

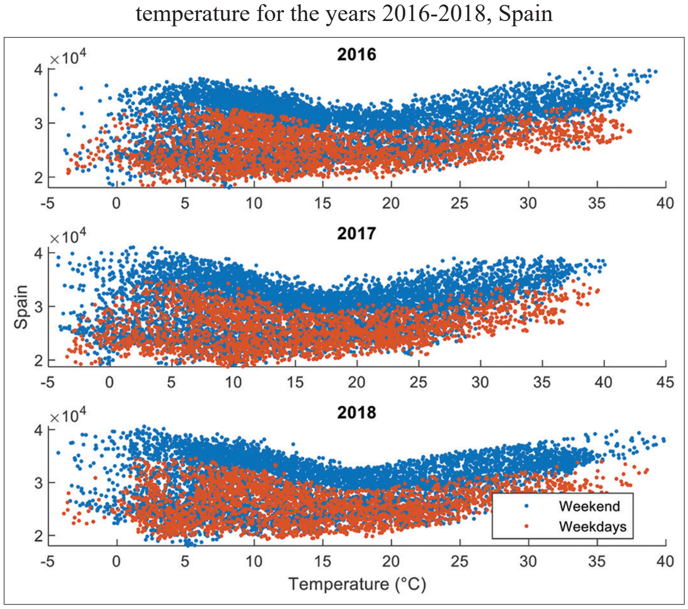


Figure 15: Mean hourly consumption (MW) with respect to temperature for the years 2016-2018, Germany

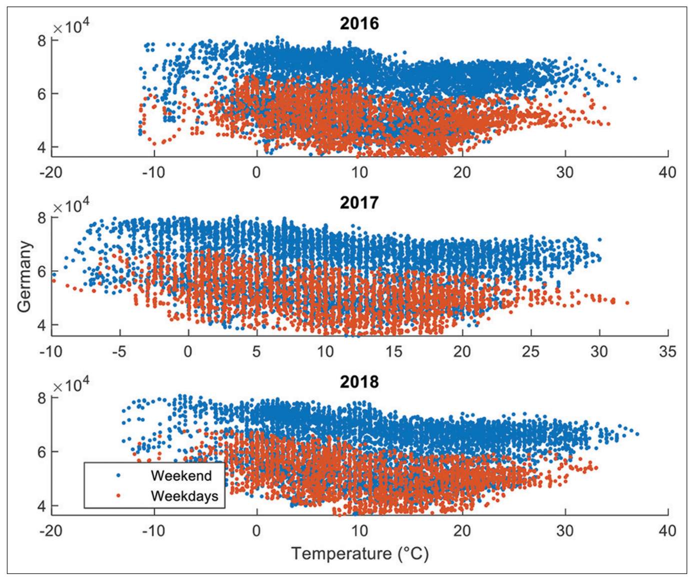


Figure 16: Mean hourly consumption (MW) with respect to temperature for the years 2016-2018, Finland

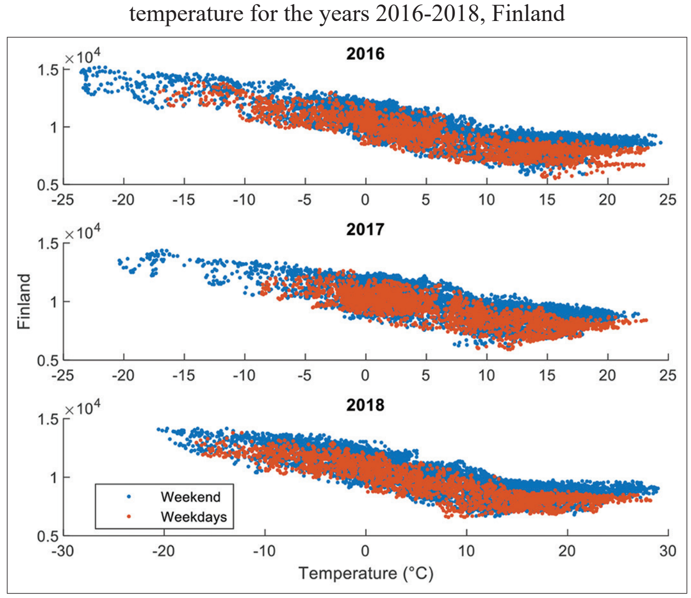


Figure 17: Piecewise linear fits to the electricity consumption data for the year 2014 for Norway, Greece, France, and Serbia

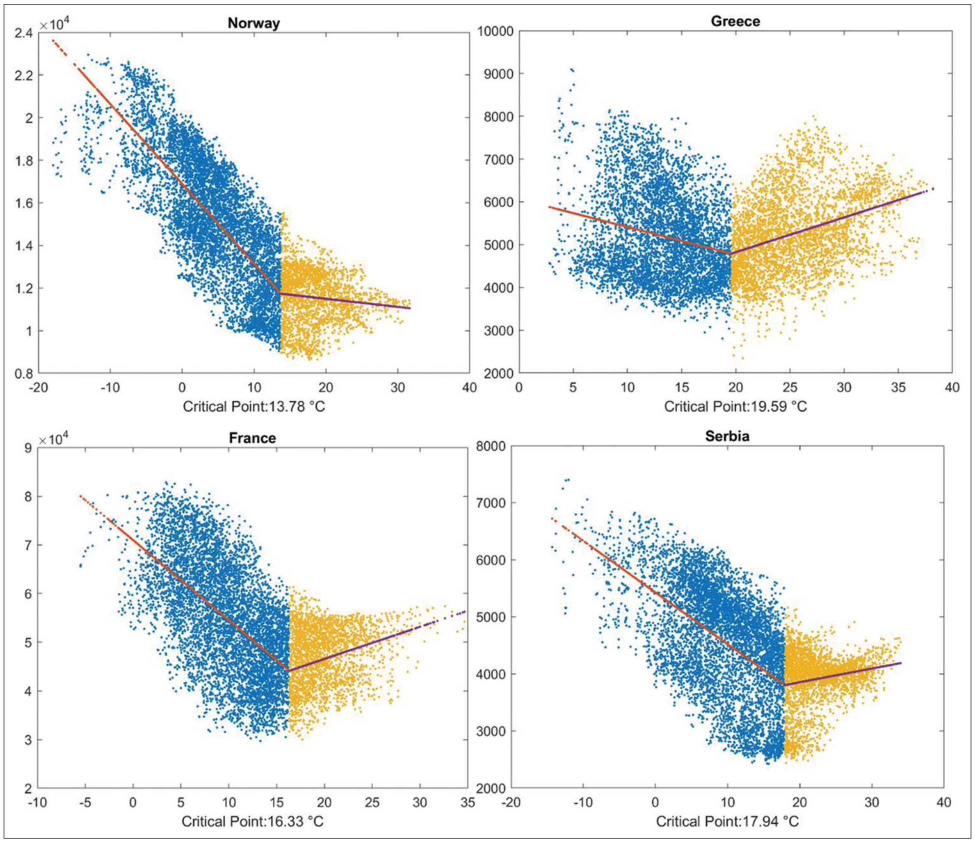


Figure 18: Slopes of piecewise linear fits for heating and cooling needs

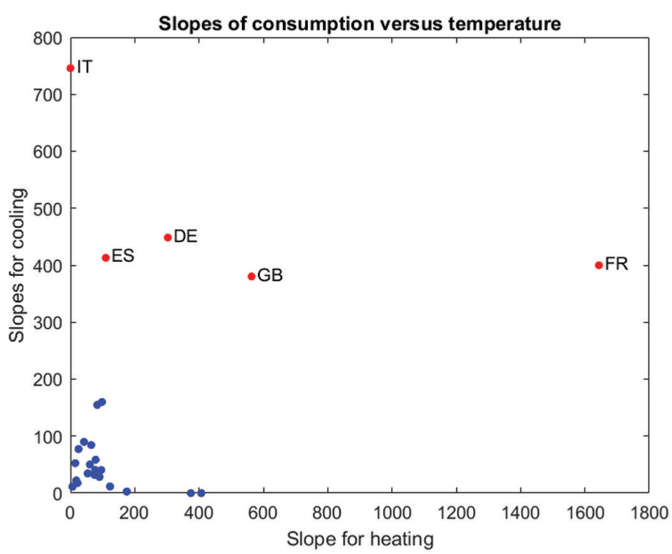


Figure 14 displays the mean hourly consumption for Spain as a function of temperature, indicating a moderate use of electricity for cooling. The difference between weekend and weekday consumption is an indicator of a higher level of industrialization.

As shown in Figure 15, electricity is used moderately for heating and cooling, but industrial consumption dominates because the maximal consumption is almost independent of temperature, particularly during weekdays.

Finally, the data for Finland displayed in Figure 16 shows that electricity consumption increases linearly with the absolute value of the difference from comfortable temperatures, around 10°C.

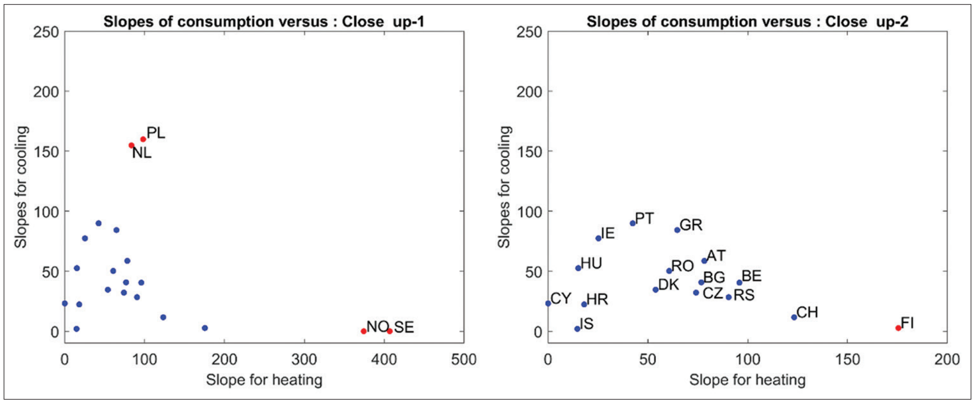
In order to quantify the electricity consumption dependence on heating and cooling, we used a piecewise linear fit to the scatter plot of the electricity consumption as a function of temperature. The junction of the lines with positive and negative slopes is estimated by a one-dimensional optimization by minimizing the least-squares error of the regression lines. Typical results for the modelling of data for 2014 are shown below in Figure 17.

Recall that Norway and Greece are expected to use electricity for heating and cooling needs, respectively. This is consistent with steeper slopes at low and high temperatures, respectively. For France and Serbia, the slopes at colder temperatures are steeper; thus, we can conclude that the use of electricity for heating purposes is more common in these two countries.

To obtain a clustering of the ENTSO-E countries according to their use of electricity for heating and cooling purposes, we plotted the slopes of the regression lines at high and low temperatures as a scatter plot. Note that for Norway, the slope of the regression line is slightly negative; such cases have occurred in a few countries, and these exceptional values were replaced by zero. This information is displayed in Figure 18 above.

Those countries with a large slope, Italy, Spain, Germany, the United Kingdom, and France, form a cluster, in which Italy and

Figure 19: Close-ups on slopes of piecewise linear fits for heating and cooling needs



France are characterized by steeper slopes for cooling and heating needs, respectively. Close-ups excluding these countries are presented in Figure 19.

As seen from Figure 19, at a first close-up, Norway and Sweden appear as countries whose electricity consumptions are sensitive to cold temperatures, while Netherlands and Poland appear to be sensitive to warm temperatures. The sensitivity of Finland to low temperatures is seen only in the second close-up.

We note that a high level of consumption in winter may not be tied directly to heating because electricity consumption can be much higher in winter compared to summer due to shorter daylight hours, especially at high latitudes. Nevertheless, a well-defined, linear increase in consumption as a function of the deviations from comfortable temperatures is a clear indication of the use of electricity for heating or cooling, as in the case of Norway, Sweden, and Finland.

4. CONCLUSIONS

In this study, the hourly electricity consumption of countries in the ENTSO-E electricity grid from 2006 to 2018 was analyzed, and the results are presented. First, the official and religious holidays of the countries are detected according to their general consumption profiles without any additional information. Even if all the particular day information of the countries is available, it is challenging to estimate the level of impact of each particular day on consumption. With this method, information on only the special days that affect electricity consumption can be obtained from electricity consumption data.

The proposed Modulated Fourier Expansion method is powerful in modelling periodic variations. Therefore, regular components of electricity consumption, like lighting and the weekend-weekday effect, are appropriately predicted. On the other hand, irregular components such as heating and cooling are sensitive to weather conditions. The properties of the modelling error are used to obtain a clustering of the countries with respect to the breakdown of electricity consumption into various components.

After the daily analysis was completed, the Modulated Fourier Series expansion method was used to obtain information about the general consumption characteristics of the country. With this method, the electricity data of each country is modelled, and each year's consumption is estimated using the data of the previous two years. When the results are compared with average daily heating and cooling degree days, prediction errors are higher for the countries that use electricity for heating or cooling in similar climate conditions. When we examine the figures in detail to verify this, it is seen that the error rates of Norway and Iceland, which are in the cold climate zone, are different. This is because Iceland uses a district heating system in heating, while Norway uses electricity.

The proposed model is used to determine the breakdown of consumption into industrial and household components as well as consumption for heating and cooling purposes. The model is also used to predict the annual hourly consumption for different countries, and the average prediction errors range from 3% to 11% for the selected countries with different consumption patterns. The model can be used to predict hourly consumption over a year, with an accuracy of around 3% in cases where the usage of electricity for heating purposes is not dominant.

The proposed methodologies that include consumption analysis, classification of countries based on their consumption profiles, consumption segregation into industrial and residential, and detecting special days and consumption using forecasting are generic and can be extended to other countries as well. The policy- and decision-makers can benefit from the results while making short- or long-term supply planning to meet the demand, managing the transmission grid, and making generation expansion and operation decisions.

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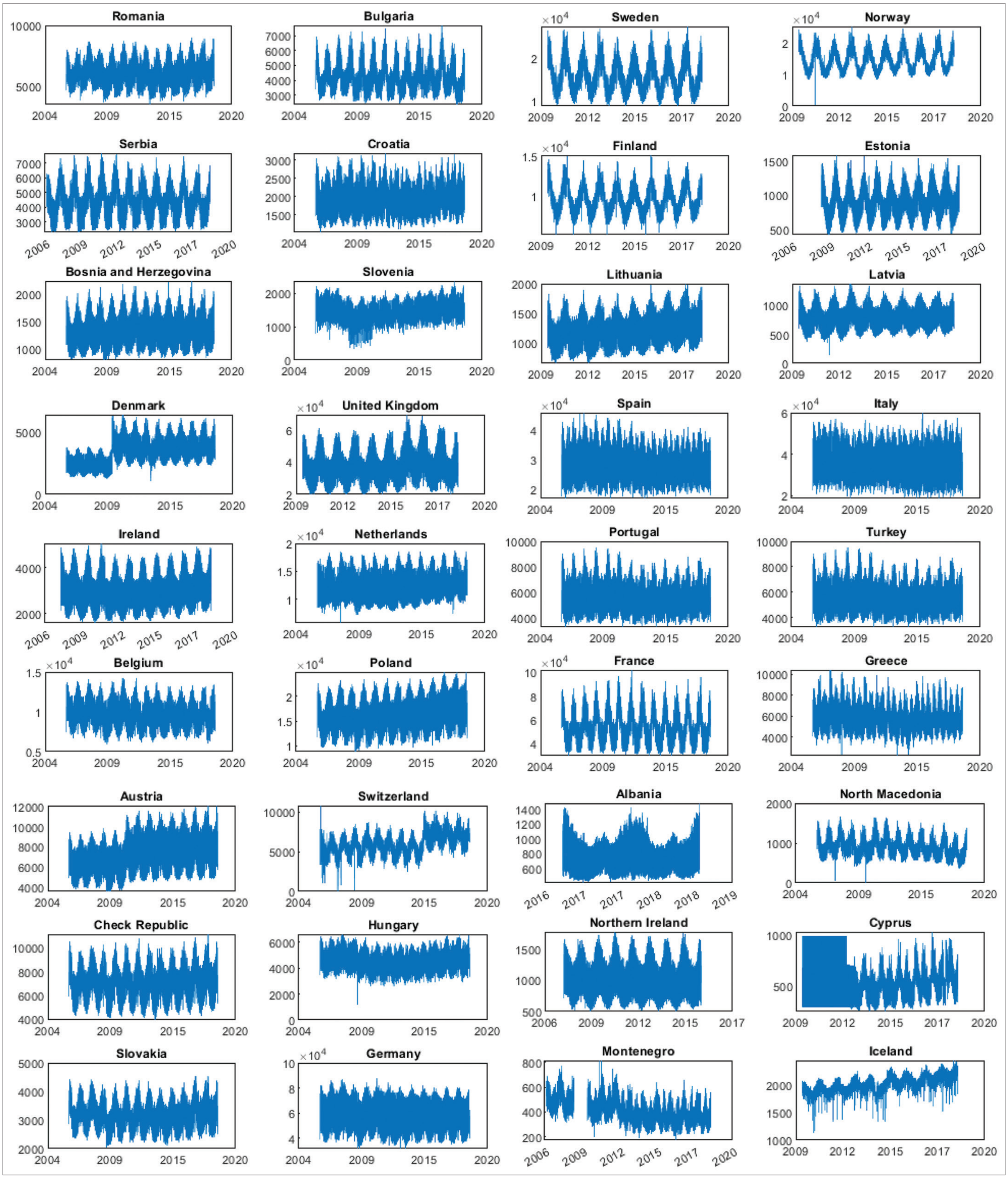
APPENDIX

Appendix A. Mean Hourly Consumption (MHC) (MWh) and population of ENTSO-E countries

Country	Code	MHC (All Available Years)	MHC (Last Available Year)	Population
Turkey (1)	TR	32576	33352	84340
Germany	DE	59840	59085	83191
United Kingdom	GB	38391	38831	67886
France	FR	55097	54303	67287
Italy	IT	36634	36777	59258
Spain	ES	29076	28946	47431
Ukraine (2)	UA	630	634	41902
Poland	PL	16785	18468	38268
Romania	RO	6065	6402	19266
Netherlands	NL	12760	13302	17425
Belgium	BE	9886	9734	11493
Czech Republic	CZ	7285	7620	10702
Greece	GR	5873	5875	10689
Sweden	SE	15943	16095	10379
Portugal	PT	5737	5810	10305
Hungary	HU	4702	4928	9770
Austria	AT	7440	8132	8901
Switzerland	CH	5973	6874	8637
Bulgaria	BG	4254	3876	6917
Serbia	RS	4499	4476	6908
Denmark	DK	3426	3899	5823
Finland	FI	9692	9977	5536
Slovakia	SK	3244	3369	5460
Norway	NO	14753	15460	5368
Ireland	IE	3048	3299	4995
Croatia	HR	1994	2092	4047
Bosnia and Herzegovina (4)	BA	1382	1424	3281
Albania (3)	AL	814	818	2878
Lithuania (4)	LT	1250	1382	2795
Slovenia (4)	SI	1504	1640	2100
North Macedonia (3)	MK	913	779	2083
Latvia (4)	LV	815	838	1902
Northern Ireland (3)	NI	1025	1003	1890
Estonia (4)	EE	920	959	1331
Cyprus (3)	CY	526	586	1207
Luxembourg (3)	LU	734	729	632
Montenegro (3)	ME	408	388	622
Iceland (3)	IS	2026	2207	366

(1) Data excluded because Turkey is not part of the ENTSOE grid (2) Data excluded because only west Ukraine data is available (3) Data excluded due to insufficiency (4) Data excluded because of low consumption

Appendix B: Electricity consumption profiles of countries in ENTSO-E (MWh)



Appendix C: Yearly prediction errors of each country (ND: No Data, T: Training)

Years	AT	BE	BG	CH	CY	CZ	DE	DK	ES	FI	FR	GB	GR
2006	T	T	T	T	ND	T	T	T	T	ND	T	ND	T
2007	T	T	T	T	ND	T	T	T	T	ND	T	ND	T
2008	3.41	3.61	4.87	10.68	ND	4.34	4.59	3.97	5.70	ND	4.10	ND	5.86
2009	5.87	7.79	8.66	9.72	ND	7.32	8.20	6.03	7.51	ND	5.83	ND	7.06
2010	6.43	13.95	6.70	7.30	ND	10.03	13.48	44.86	7.08	T	5.93	T	7.37
2011	13.62	11.24	6.40	7.34	ND	4.23	7.47	45.31	4.39	T	8.81	T	5.38
2012	15.80	3.92	9.19	8.92	ND	4.01	6.04	4.47	4.11	3.32	5.71	4.00	6.07
2013	3.30	5.87	6.32	8.14	ND	4.41	4.56	9.01	4.00	2.94	5.23	4.05	9.38
2014	3.47	4.57	4.92	5.38	T	3.50	5.25	11.61	4.19	2.83	5.06	3.71	8.72
2015	3.57	3.84	6.35	25.75	T	3.52	3.69	6.15	4.39	2.75	5.90	4.41	11.58
2016	7.63	6.12	12.49	25.32	11.34	5.94	7.30	7.95	7.34	4.36	7.36	11.17	13.44
2017	4.80	4.14	8.22	7.30	6.94	4.70	4.87	5.05	5.04	3.23	5.72	23.63	6.43
2018	3.93	5.55	18.81	4.82	11.81	3.93	3.42	4.01	3.95	2.89	5.41	9.66	4.96

Years	HR	HU	IE	IS	IT	NL	NO	PL	PT	RO	RS	SE	SI
2006	T	T	ND	ND	T	T	ND	T	T	T	T	ND	T
2007	T	T	ND	ND	T	T	ND	T	T	T	T	ND	T
2008	4.14	4.60	T	ND	5.78	6.35	ND	4.39	4.02	5.31	0.00	ND	13.89
2009	5.17	5.77	T	ND	6.87	12.37	ND	5.40	4.49	10.99	5.13	ND	5.63
2010	4.20	3.78	6.81	T	11.95	11.34	T	8.57	4.35	12.56	4.39	T	19.54
2011	4.25	7.79	4.14	T	6.20	4.23	T	3.43	5.33	3.36	3.59	T	5.60
2012	5.27	3.84	5.05	1.37	4.66	4.88	6.22	3.88	3.60	5.86	5.18	4.16	6.67
2013	4.68	3.92	4.45	1.94	6.20	8.99	4.51	3.30	5.39	5.10	5.54	3.97	6.20
2014	4.28	3.48	3.90	5.83	4.54	7.82	2.83	3.42	3.36	6.33	4.85	3.46	6.00
2015	5.40	3.55	4.45	8.30	5.87	4.67	3.73	3.30	3.69	5.29	4.69	4.29	4.40
2016	8.66	6.49	8.61	7.13	10.20	6.44	4.66	6.99	9.13	7.73	8.74	6.13	8.02
2017	5.93	4.31	4.54	4.55	6.90	4.74	4.85	4.81	4.94	5.32	5.87	4.65	5.36
2018	5.94	4.37	3.06	1.91	5.15	4.03	4.76	3.56	3.90	3.90	4.65	4.42	4.77