

Article

Electricity Usage Efficiency and Electricity Demand Modeling in the Case of Germany and the UK

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Abstract: In this article, monthly and yearly electricity consumption predictions for the German power market were calculated using the multiple variable regression model. This model accounts for several factors that are often neglected when forecasting electricity demand in practice, in particular the role of the higher efficiency of electricity usage from year to year. The analysis performed in this paper helps to explain why no growth in power consumption has been observed in Germany during the last decade. It shows that the electricity efficiency usage dataset is a relevant input for the model, which mitigates the combined impact of other factors on the final electricity consumption. The electricity demand forecasting model presented in this article was built in the year 2013 with forecasts for the future years' electricity demand in Germany provided until 2020. These forecasts and related findings are also evaluated in this article.

Keywords: electricity consumption; demand forecasting; regression models; electricity usage efficiency

1. Introduction

During the last decade, there has been a heated discussion going on in Europe regarding the future consumption of electricity in the member countries European Union (EU). However, the analysis performed in various reports and publications offered very different views on future power consumption development. The disagreements are probably best exemplified by the following ministerial statements of Germany and the United Kingdom:

- “By 2050, electricity consumption is to drop by 25% compared to 2008, and should already be down 10% by 2020” [1];
- “In the longer term, by 2050, electricity demand is set to double, as we shift more transport and heating onto the electricity grid” [2].

The 2050 mark is too far away to forecast reliably, but also much shorter horizons were usually associated with very different views on power consumption developments. German government plans to decrease consumption by 10% until 2020 have been in sharp contrast with most of the other forecasts performed for different European markets [3].

The analysis in this paper was performed to establish realistic expectations regarding future power consumption in Germany and the UK as the largest electricity markets in the EU [4]. For these purposes, the linear regression model was developed, which considered crucial variables affecting electricity demand and establishing their effect on the final power consumption based on the 2005–2013

period. Modeled future consumption forecasts in Germany were made until the year 2020. Now, five years later, it is also possible to establish the performance of the model based on the real electricity consumption data and evaluate what this means for the expectations regarding power consumption development in Germany during the next periods.

The tendency today is to use more and more renewable energy sources, but care must be taken to ensure that the produced resources are properly used in the form of electricity [5,6]. New energy sources produce only a small fraction of the world's total energy. This share should be increased significantly in the future as there are fewer non-renewable energy sources and their reserves are running low, and their detrimental impact has been increasingly pronounced in recent years. The sun, without which there would be no life on our planet, gives the Earth several thousand times more energy than humanity manages to consume at the current stage of development. It speaks in favor of the fact that renewable sources can and must be put to better use and that if we act wisely, we do not have to worry about energy fossil fuels.

Energy efficiency has a big impact, so today bulbs that used to be around 100 w perform their function at 10 w. Other appliances used in households and industries also consume much less energy than before.

In addition to applying renewable energy, today many authors are concerned with predicting electricity consumption [7]. Frequent research deals with the topic of generating different methods of research on the prediction of electricity consumption [8–10].

Certainly, the amount of electricity consumed is increasing, but taking into account the contribution of renewable energy sources and energy efficiency, the total resulting consumption will be reduced by these impacts.

A novel nature-inspired, new meta-heuristic algorithm called Multi-Verse Optimizer (MVO) was employed to solve the optimal frequency regulation problem and to show the effectiveness of the proposed control strategy [8].

A fractional-order proportional–integral–derivative (FOPID) controller is investigated for a three-level inverter called Multi-Neutral Point (MNP). This method is based on Multi-objective genetic algorithms, and the main objectives are to remove the amplitude error, the phase shift error, and to decrease the total harmonic distortion of the current [9].

These methods are based on artificial intelligence and could certainly be applied in the case of predicting electricity consumption. However, the authors opted for the statistical model. Multiple linear regression (MLR), also simply known as multiple regression, is a statistical technique that uses several explanatory variables to predict the outcome of a response variable. The goal of multiple linear regression (MLR) is to model the linear relationship between the explanatory (independent) variables and response (dependent) variable.

Multiple linear regression (MLR) is used to determine a mathematical relationship among a number of random variables. In other terms, MLR examines how multiple independent variables are related to one dependent variable. Once each of the independent factors has been determined to predict the dependent variable, the information on the multiple variables can be used to create an accurate prediction on the level of effect they have on the outcome variable. The model creates a relationship in the form of a straight line (linear) that best approximates all the individual data points.

It is very important to establish a power plan for the stable operation of electricity [11]. This refers primarily to the consumption of electrical appliances, cars, and other energy products that are designed to use an adequate amount of energy [12]. That is, as little as possible while maintaining the designed functions of the devices and their stability during operation.

2. Development of Electricity Consumption, GDP, and Industrial Output in Germany

In this section, the development of some crucial market variables which affect electricity consumption is presented. Countries analyzed include Germany as well as the UK as another

substantial market for electricity in the EU region. The UK data are provided particularly for comparison purposes as the structure of the UK economy is very different compared to Germany.

There are several economic factors which do affect electricity prices. Various studies have dealt with this issue establishing that electricity demand depends particularly on economic variables and national circumstances as well as on climatic conditions [13–15]. However, at the beginning of this decade, the development of economies of western European countries and their electricity consumption have decoupled. This factor has significantly complicated the issue of forecasting the electricity demand for the future years.

The idea of rising electricity demand seemed to be based on two main considerations [2,16,17]:

1. Long-term historical trends, as rising economical output has been associated with higher power consumption in Europe for decades;
2. Increasing usage of electricity in the energy-intensive industries instead of oil and gas (as mentioned in the UK ministerial statement above), while the point that the demand for electricity will decline was supported by the following factors [1];
3. The shift of European economies to sectors other than industries, which are less power consuming [18];
4. Slower expected economic output growth in Europe in the future [19];
5. More efficient electricity usage in the future as for the unit of output less electricity is needed every year.

Creating future forecasts based on long-term historical trends may be tricky. As shown in Figure 1, electricity consumption was rising by an average of 1.5% a year during the period from 1995 to 2005 (the increase was even sharper in the previous decades) in both Germany and the United Kingdom. However, the next periods have seen the opposite trend with the demand for electricity decreasing visibly.

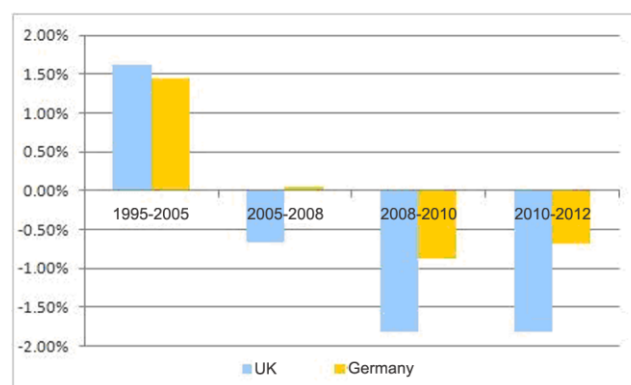


Figure 1. Electricity consumption, average yearly % change over the following periods: 1995–2005, 2005–2008, 2008–2010, and 2010–2012 (data source: transparency.entsoe.eu, gov.uk).

Decreases in demand for electricity during the 2008–2010 period were usually linked to the economic woes in Europe; however, the power consumption was already not growing during the relatively stable 2005–2008 period and went down even during the post-crisis years of 2010–2012. As shown in Figures 2 and 3, the United Kingdom was more affected by the sliding GDP growth and industrial production than Germany, hence the power consumption also decreased more rapidly there.

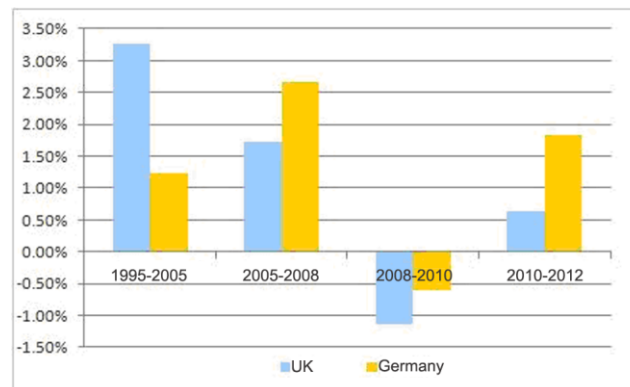


Figure 2. GDP (REAL), average yearly % change over the following period: 1995–2005, 2005–2008, 2008–2010, and 2010–2012 (data source: worldbank.org).

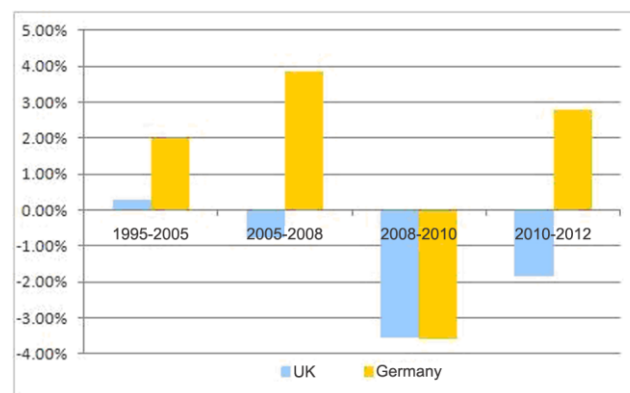


Figure 3. Industry Output, average yearly % change over the following periods: 1995–2005, 2005–2008, 2008–2010, and 2010–2012 (data source: Eurostat).

These charts show that there is some underlying force responsible for the electricity consumption decrease for the two countries shown. This could have been caused by the increased emphasis put on improving the efficiency of electricity usage which is also stated as one of the goals by the German Ministry for Technology and Economics. The idea is analyzed in the next sections of this paper.

3. The Methodology of Electricity Demand Model Creation

The hypothesis analyzed in this article is that electricity usage efficiency is an important factor affecting electricity demand in Germany and it is responsible for decoupling between industrial output and electricity consumption variables. To further confirm this, the hypothesis linear regression model was built, where electricity efficiency usage was one of the inputs.

Variables analyzed in the previous section constitute the main part of the regression model created. Multiple variable regression models were confirmed to provide excellent results in forecasting a long-term demand for electricity by many different publications analyzing various regions and periods [20–22]. A comparison of different forecasting electricity demand techniques was also presented by Tso et al. [23].

Linear regression is characterized by the following formula:

$$Y = a + b_1 \times X_1 + b_2 \times X_2 + \dots + b_p \times X_p \quad (1)$$

where Y is the dependent variable and X_1 to X_p are independent variables. In this case, six variables were used to explain the monthly consumption dataset.

For the regression model described in this article, monthly data regarding the German market from 2005 until April 2013 were used. The output of the model was the monthly electricity consumption forecast until the year 2020. The dependent dataset in the model is German electricity consumption. Independent input into the model consists of six different datasets:

- The monthly average temperature in Germany (measured as an average of 10 different places in Germany) in Celsius degrees (variable X_1);
- Dataset measuring subtraction between average temperature in Germany and 17 degrees Celsius. In the case of a negative value, the dataset value returns to zero. This dataset is designed to account for increased electricity usage due to air conditioning in summer (variable X_2);
- The monthly industrial production in Germany based on Eurostat data (variable X_3);
- The number of days in a month (variable X_4);
- Yearly GDP data for Germany (variable X_5);
- Electricity efficiency usage coefficient with a gradually decreasing value for every month. We assume that electricity efficiency improves gradually and regularly, which is certainly not the case, but such an approach still leads to much better results than neglecting this factor completely (variable X_6).

The variables were chosen based on the fundamentals of the electricity market [24,25]. Household demand especially depends on temperature. Heating demand is strong during the winter months while cooling demand increases during the summer months. This is reflected by the temperature variables chosen. Business electricity demand depends on GDP and industrial output. Logically, the number of days in a month also affects electricity demand. The innovative variable in the model is gradually increasing the efficiency of the electricity usage variable. It is confirmed by the R square of the model and the p -value of the efficiency variable that this input is indeed crucial for the modeling of electricity demand on the present markets. We have not seen this variable to be used by other researchers, and thus, the research presented in this article is innovative in this respect. While from a modeling perspective, there might be better ways to incorporate this variable into the model, it is our strong belief confirmed by the data that it should not be neglected by the researchers and analysts dealing with the subject.

The model developed explains electricity demand movements reasonably well, with an R square coefficient on the level of 0.788 (Figure 4).

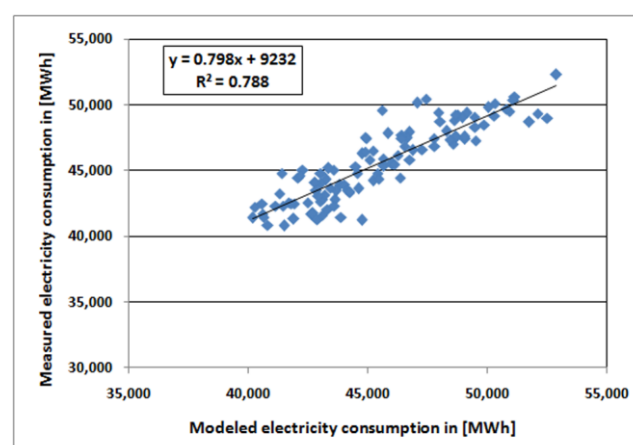


Figure 4. R square coefficient with linear regression.

Similar models were also built for other European countries with the outputs in line with the case described for Germany. Statistically, the most important input (according to p -value) into the model constituted the two somewhat innovative variables. These were the second and the sixth datasets representing the electricity efficiency variable and temperatures over 17 degrees Celsius.

In the next step, the model was used to forecast electricity consumption during the 2013–2020 period in Germany. For long-term forecasting purposes, temperature datasets were based on the average data from the years 2005–2012. GDP and industrial growth forecasts were taken from the official documents for the years 2013 and 2014, and forecasts for the next years were set at 1% for industrial growth and 2% growth for GDP. These data were also in line with data forecasted for the year 2014. The electricity efficiency usage coefficient further gradually decreased until 2020. Outputs of these forecasts will be discussed in the next section of this paper.

4. Model Output

Table 1 shows monthly data regarding the German market from 2005 until April 2013 used for regression analysis.

Table 1. Monthly data regarding the German market from 2005 until April 2013 used for regression analysis.

	Y	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆
Month-Year	Demand	Temperature	Temp. over 17 °C	Industrial Output	Days	GDP	Efficiency
Janaunry-2005	50,927	2.75	0	87	31	100.00	100
February-2005	48,766	−0.4	0	89	28	100.00	99.70089731
March-2005	49,467	4.55	0	98.3	31	100.00	99.40268924
April-2005	45,074	10.15	0	97.7	30	100.00	99.10537312
May-2005	43,240	13.7	0	90.4	31	100.00	98.80894628
June-2005	43,598	17.05	0.05	102.7	30	100.00	98.51340606
July-2005	43,805	19	2	93.5	31	100.00	98.21874981
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
May-2006	43,565	13.75	0	102.7	31	103.40	95.32022782
June-2006	43,178	17.6	0.6	102	30	103.40	95.03512246
July-2006	45,224	23.15	6.15	98.5	31	103.40	94.75086985
August-2006	43,645	16.2	0	97	31	103.40	94.46746744
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
July-07	45,204	18.05	1.05	107.4	31	106.20	91.40543281
August-20-07	44,619	17.5	0.5	102.2	31	106.20	91.1320367
September-2007	42,259	12.8	0	109	30	106.20	90.85945832
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
July-08	46,350	18.8	1.8	111	31	107.00	88.17811552
August-2008	44,225	18.1	1.1	97.2	31	107.00	87.9143724
September-2008	43,347	12.3	0	114.8	30	107.00	87.65141815
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
May-2009	40,591	14.45	0	84.5	31	101.60	85.57590151
June-2009	41,487	15.65	0	90.8	30	101.60	85.31994168
July-2009	42,644	18.7	1.7	91.4	31	101.60	85.06474744
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
April-2010	42,082	9.25	0	96.4	30	105.20	82.8020749
May-10	42,788	11.15	0	95.5	31	105.20	82.55441167
June-2010	44,736	17.3	0.3	103.6	30	105.20	82.3074892
July-2010	44,225	20.7	3.7	99	31	105.20	82.06130528
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
June-2011	43,093	17.6	0.6	103	30	108.50	79.40139954
July-2011	43,307	16.7	0	104.7	31	108.50	79.16390782

Table 1. Cont.

	Y	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆
Month-Year	Demand	Temperature	Temp. over 17 °C	Industrial Output	Days	GDP	Efficiency
August-2011	41,915	18.3	1.3	102.7	31	108.50	78.92712644
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Jane-2012	49,492	2.65	0	100.3	31	109.20	77.75380056
February-2012	50,031	−2.55	0	105.5	29	109.20	77.52123685
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
October-2013	44,571	9.73125	0	111	31	109.746	73.01330926
November-2013	45,651	6.13125	0	111.8	30	109.746	72.79492448
December-2013	44,871	1.975	0	94.6	31	109.746	72.5771929

The output of the regression model looks as follows:

$$Y = -11400 - 468.8 \times X_1 + 1009.5 \times X_2 + 49.5 \times X_3 + 582.0 \times X_4 + 221.9 \times X_5 + 176.2 \times X_6 \quad (2)$$

Variable Y is measured in MWh. Variables X₂, X₅, and X₆ are coefficients which were set to 100 as the average number for the year 2005. Variable X₃ represents the number of days, and X₁ and X₄ are measured in Celsius degrees.

p-values of the variables included in the model are included in Table 2 below:

Table 2. p-value for the selected variables in the model.

Variable in Model	p-Value
Monthly average temperature	2.1×10^{-29}
Temperature over 17 °C	1.35×10^{-5}
Monthly industrial production	0.043171
Days in a month	0.001391
Yearly GDP	0.025366
Efficiency	3.63×10^{-7}

It is possible to conclude that apart from the temperature variables, the efficiency variable is the most important one in the model presented.

Models explaining electricity demand movements for the period analyzed show very similar relations for Germany and other large EU countries, such as France and the UK. According to the models, for the same output, about 1.2% less electricity was needed every year. At the same time, an increase in GDP and industrial production by 1% caused the electricity consumption to go up by approximately 0.6%, meaning that with a 2% yearly increase in GDP and industrial production, the level of electricity consumption would have been approximately maintained. However, the average GDP growth has only been 0.6% in the UK and 1.5% in Germany during the period, while the industrial production index was increasing by 1.4% on average in Germany and dropping by 1.5% in the UK. These values were not enough to maintain the level of power consumption during the years 2005–2012, and this trend continued in 2013 as well.

Based on these data, we concluded that (a) the long-term historical trends have reversed and power consumption was not likely to increase substantially during the next decades. An exact power consumption trajectory depends particularly on economic activity where a GDP growth of approximately 1.8% is needed for the level of power consumption to be maintained. This is particularly due to the increased efficiency of electricity usage in Europe.

The factor which can cause power consumption to go up significantly again is the possibility of increasing usage of electricity in other energy-intensive sectors (e.g., automobile industry) due to the

lowering costs of renewable power generation and increasing prices of traditional energy sources. This assumption was also the basis for the UK Department of Energy and Climate Change forecast.

However, the crucial change is probably not going to happen any time soon for many reasons of which some are stated below:

- Generation costs are a relatively small part of the final electricity prices;
- Feed-in tariffs for renewable generation are set for 20 years, meaning that technological advances will not lower the final electricity prices immediately;
- With the advance of renewable generation, prices of coal and other energies decrease;
- Whole infrastructures for the new electricity industries would need to be built.

Furthermore, it has to be mentioned that with a consumption of 30 kWh/100 miles, 1 million electric cars performing 10,000 miles a year will increase the country's electricity consumption by only 3 TWh, which equates to only about 0.5% of the total consumption in Germany.

All factors combined, with GDP increasing by 2% points a year, industrial production in Germany increasing by 1% a year, and electricity usage efficiency improving by about 1% annually, we expected the German power consumption in 2020 to be about 3% lower compared to 2008. A reversal of this trend could be expected somewhere between 2020 and 2030 due to the increasing demand for new electric intensive industries. While we agree with the UK Department of Energy and Climate Change that electricity consumption is likely to be higher in 2050 than it is today, we do not think the increase could be anywhere close to 100%.

Various consulting bodies, such as McKinsey and Company, considered that for achieving clean energy targets, EU electricity consumption will have to increase substantially by 2050 [26], by 48% between the years 2010 and 2050 [17] and by 1.1% points per year between 2010 and 2020, mentioning that this rate is still lower compared to a 1.5% electricity demand growth during the 1990–2007 period. It is visible from this analysis that such studies probably neglected the very important factor of electricity usage efficiency, which led to an approximately stable demand during the period analyzed, as is shown in Figure 5. These results are also important when analyzing electricity demand in EU countries in the future years. While it is hard to predict if the electricity efficiency can be gradually improved until 2050, it still has an important impact on electricity consumption during the present years and there is no reason to expect a crucial change any time soon.

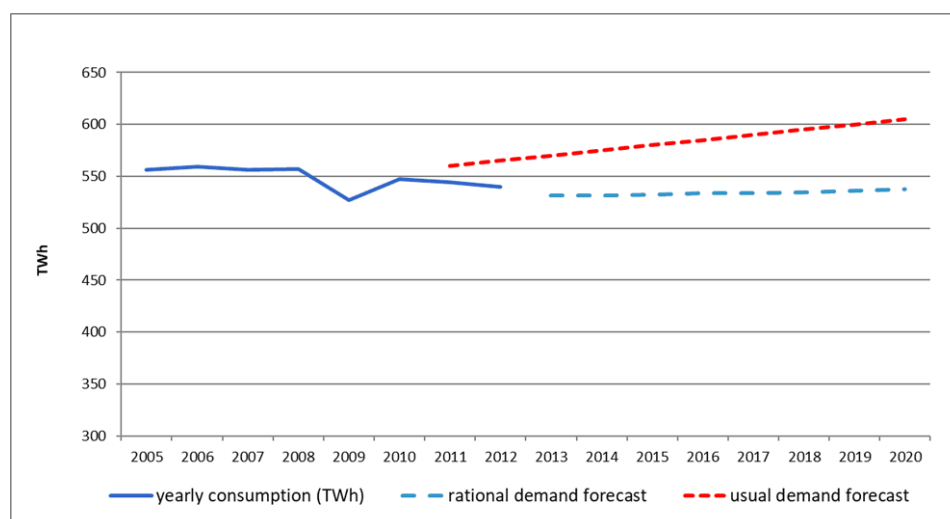


Figure 5. Germany, consumption by year, real data, modeled forecast, and usual demand forecast based on [17].

Table 3 provides reference data for the period 2013–2020. Based on this reference data, it is possible to further analyze the prediction accuracy of the proposed model (Equation (1)).

Table 3. Monthly data of the German market from 2013 to 2020 used to predict the results.

	Y	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆
Month-Year	Demand	Temperature	Temp. over 17 °C	Industrial Output	Days	GDP	Efficiency
January-2014	49,515	1.2625	0	100.798	31	111.6117	72.3571929
February-2014	44,684	1.29375	0	103.4745	28	111.6117	72.1371929
March-2014	45,846	5.225	0	112.8675	31	111.6117	71.9171929
April-2014	41,714	10.16875	0	105.7975	30	111.6117	71.6971929
May-2014	41,770	14.075	0	104.2825	31	111.6117	71.4771929
June-2014	39,959	17.2125	0.2125	108.07	30	111.6117	71.2571929
July-2014	43,542	19.15625	2.15625	108.5245	31	111.6117	71.0371929
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
May-2015	39,607	14.075	0	105.325325	31	113.8439	68.8371929
June-2015	39,875	17.2125	0.2125	109.1507	30	113.8439	68.6171929
July-2015	41,470	19.15625	2.15625	109.609745	31	113.8439	68.3971929
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
August-2016	41,953.76	17.8125	0.8125	103.6482806	31	116.1208	65.5371929
September-2016	42,673.66	14.51875	0	108.3876652	30	116.1208	65.3171929
October-2016	45,622.56	9.73125	0	114.363411	31	116.1208	65.0971929
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
May-2017	43,376.11	14.075	0	107.442364	31	118.4432	63.5571929
June-2017	40,637.28	17.2125	0.2125	111.3446291	30	118.4432	63.3371929
July-2017	41,789.89	19.15625	2.15625	111.8129009	31	118.4432	63.1171929
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
October-2018	45,113.71	9.73125	0	116.6621156	31	120.8121	59.8171929
November-2018	47,585.15	6.13125	0	117.5029236	30	120.8121	59.5971929
December-2018	46,681.36	1.975	0	99.42555074	31	120.8121	59.3771929
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
January-2019	-	1.2625	0	105.939711	31	123.2283	59.1571929
February-2019	-	1.29375	0	108.7527394	28	123.2283	58.9371929
March-2019	-	5.225	0	118.6248768	31	123.2283	58.7171929
April-2019	-	10.16875	0	111.1942358	30	123.2283	58.4971929
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
August-2020	-	17.8125	0.8125	107.8568164	31	125.6929	54.9771929
September-2020	-	14.51875	0	112.788639	30	125.6929	54.7571929
October-2020	-	9.73125	0	119.0070241	31	125.6929	54.5371929
November-2020	-	6.13125	0	119.8647324	30	125.6929	54.3171929
December-2020	-	1.975	0	101.4240043	31	125.6929	54.0971929

Figure 6 Provides a more detailed comparison of the model output and the real data during the 2013–2018 period. As can be seen, the model managed to forecast the real market situation reasonably well except for the very high electricity consumption during the winter of 2017. It would be impossible for the model to predict 4 years in advance.

A similar output, structured by year, is summarized in Table 4. This table also confirms that the model was able to provide results very close to the real market data. The highest deviation of the model came in the year 2015 and was at the level of 2%. The average yearly deviation of the model was at the level of 0.8%, and the difference between the model and reality for the whole six-year period of 2013–2018 was at the level of 0.1%.

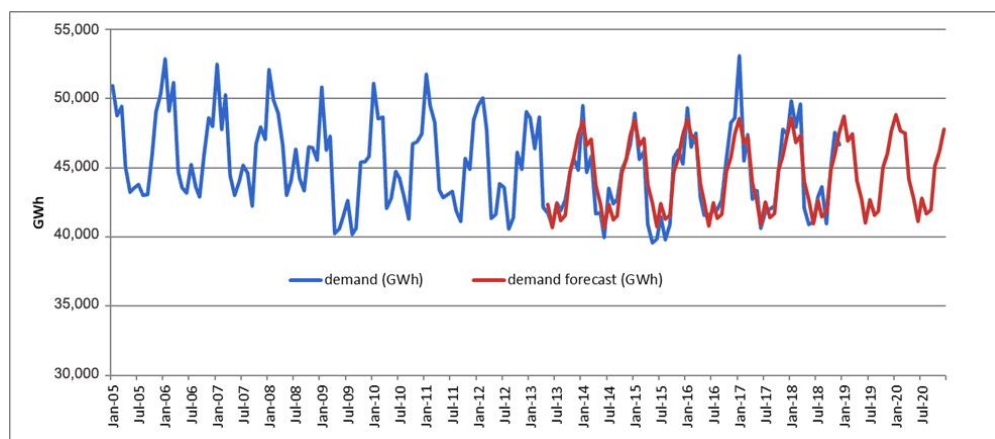


Figure 6. Germany, consumption by month, real vs. forecast (source: entsoe.eu, modelled data).

Table 4. Consumption by year in Germany, market data vs model in TWh (source: entsoe.eu).

Year	Real Demand	Modeled Demand
2005	556	553
2006	559	561
2007	556	560
2008	557	559
2009	527	529
2010	547	545
2011	544	540
2012	540	540
2013	531	532
2014	529	532
2015	521	532
2016	538	534
2017	539	534
2018	538	535
2019		536
2020		538

The model presented in this paper has confirmed that increased electricity efficiency during the last decade was responsible for lower consumption values relative to what would have been otherwise expected. This increase in the efficiency of electricity usage is probably related to the environmental actions of the EU during the last decade. These have been observed in many areas of business and household management, such as the development of engines with lower consumption, buildings insulation, more efficient equipment, and more emphasis put by individuals on energy savings. A more detailed study on the contributions of different areas to the total energy efficiency usage increase is not a part of this article.

The presented model can be implemented in other countries if there are reliable databases on electricity consumption in previous years. It should be taken into account that the external average daily temperature also varies from region to region.

5. Conclusions

The main conclusion of this paper is that not only the economic output growth and weather conditions but also the efficiency of electricity usage are the crucial factors affecting electricity consumption development in the contemporary EU power market environment. This factor should not be neglected when forecasting or planning future electricity consumption. Such a mistake was made by many consulting and governmental bodies which forecasted significant power demand changes during

the last decade, while in the real world, the electricity consumption remained relatively stable. Plans for a substantial increase in electricity consumption have not materialized, similarly to the German ministerial plans to decrease electricity consumption by 10%. Power consumption in Germany has risen only very slowly during the last six years but is still far from reaching the 2008 pre-crisis levels. The model described in this paper is relatively simple but includes all the crucial variables affecting power demand, and thus seems to provide very good results in predicting future power consumption. Another advantage of this model is its scalability as similar models can also be easily created for other EU countries with often different market structures compared to Germany. While other EU countries are not included in this article, outputs of the models created for other EU electricity markets, such as France and the UK, confirm the findings presented above. The electricity usage efficiency has an important impact on the final electricity consumption, not only in Germany but in the EU as a whole.

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