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The Effect of Climate Change on Energy Consumption Using Smart Meter Dataset

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Abstract
Electricity use in the urban areas is more than in the rural areas because the ratio of the population is higher in the urban areas as compared to rural areas. Energy consumption increasing day by day worldwide, so there is a need to give the best plan for the best energy resource consumption to the producers. On the other side, various other energy types are also becoming most useable in the world due to many factors like an increase in usage due to population, line losses, loss of energy due to low-quality material, and especially usage ratio increases as compared to the production of energy. This helps to save energy from misuse and to utilize the energy properly. There are various approaches applied to forecast energy consumption but, in this study, we proposed the system using LSTM, ARIMA, and Prophet model to give the solution for smart meter dataset energy consumption forecasting in a good way. After applying this approach, we conclude that the weather variables are the major factors in energy consumption such that the temperature effect is larger than other variables. The proposed system proves its performance by forecasting the dataset using these algorithms and calculate the high-grade visual graphs.
Keywords: Energy Consumption, Smart Meter, Optimization, Machine Learning

1. Introduction and Background

Globally, energy is an essential part of various purposes. The use of energy overall is increasing day by day. There are various factors to increase energy usage that if we talk about electricity, the use of electricity is increasing due to the increase in population in the world. Electricity use in the urban areas is more than in the rural areas because the ratio of the population is higher in the urban areas as compared to rural areas (Hu et al.,). The second major factor of electricity usage is the line losses and low-quality materials used to transfer electricity from one place to another. On the other side, various other energy types are also becoming most useable in the world due to many factors like an increase in usage due to population, line losses, loss of energy due to low-quality material, and especially usage ratio increases as compared to the production of energy (Berriel et al., 2020). Household energy consumption is becoming a major factor in urban areas especially. Most people add multiple items in their house which are work using electricity or other energy sources. Due to the increase in household appliances energy consumption increasing day by day (Bloomberg et al.,).

According to the Bloomberg record, electricity demand will increase by 57% by the year 2050[6]. All over the world use electricity as their demand and it is continuously increasing daily. The major electricity-productive countries are China and India (Lange., 2022). With the advancement of vehicles now a day such that the introduction of electric vehicles has become one of the major energy consumers. It is estimated around 9% of demand will increase in 2050[7]. Electricity demand by countries such as China 3605 TWh, India 3444, Rest of the World 1747, and many other countries also going to increase their consumption. Bloomberg reported in 2017[8] the electricity consumption was 25000 TWh and it will become around 38700 TWh by the year 2050 (Bourdeau et al., 2021).

Energy consumption is the way where we use energy for useful purposes in our daily life activities such as the use of electricity in households, transport, factories, production plants of products, etc. Nowadays energy consumption is major in the household, electric vehicles, factories, and also in transport (Wei et al.,). The energy may be in different forms like it comes from electricity, petroleum products, and many more ways where we are getting the energy and consuming it for our purposes daily. Globally, multiple products shifted and most of them are still shifting from classical or analog to digital devices where these items are using energy to operate properly. IoT devices all over the world are used for different purposes such that it is used in the healthcare, education, and business domains where these devices use energy. People are moving towards a digital world where energy consumption increasing very fast. Electric vehicles are using energy in large quantities where it need to fulfil their demands to operate properly (Chou et al.,).

Energy consumption increasing worldwide so energy production companies need to make a plan to control the energy consumption cost. There is a need to develop a forecast plan for the energy consumption in daily use such that households, transport, factories, and many more places where it is used in large volume. There is a way to estimate the energy consumption on the customer level to check how much the customer needs energy for their usage. The approach discussed in (Iqbal et al.,) is where they are looking to estimate the energy consumption for their finite customers' energy consumptions monthly. This approach is only workable for limited areas and there is a lack in getting accurate data without any proper instrument. They used deep learning models to predict the customer's monthly energy consumption.

Building the energy consumption mechanism needs time and we can easily identify the use of energy in different sectors. Customers' need for energy should be identified in large volumes and then we should need to identify were energy losses. Energy prediction for any area is the need where we can easily identify the use of energy and how it can be reduced by applying any best approach. The

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[6] https://about.bnef.com/blog/global-electricity-demand-increase-57-2050/
[7] https://eneroutlook.enerdata.net/forecast-world-energy-primary-consumption.html#:~:text=Energy%20demand%20in%20the%20residential,power%20generation%20to%2047%20TWh.
[8] https://www.statista.com/statistics/222066/projected-global-energy-consumption-by-source/

paper (Kiprijanovska et al.,) discussed the building consumption models and energy consumption for the different techniques. Data-driven models are proposed to develop scale applications, they analyze the pre-processing techniques and discuss the machine learning algorithms to identify the energy consumption in different sectors.
Another survey was conducted on energy consumption where comprehensive analysis was conducted for the Machine Learning algorithms for energy forecasting consumption. The paper presented the pros and cons of using machine learning algorithms in energy consumption prediction for buildings. For the investigation of accuracy and suitability of the ML algorithms are identified properly. They analyzed the best approach for forecasting where hybrid methods are more suitable as compared to the single method or ensemble approach. In planning energy, the concluded results are helpful and using ML algorithms for forecasting is the best approach because it gives the best solution to save energy.
The manuscript (Iqbal et al., 2022) discussed the forecasting criteria for energy consumption. Various approaches were reviewed for energy consumption forecasting using ML algorithms and Deep Learning approaches. Obtained accuracy values for these models are analyzed to check whether these models are the best fit or not for this purpose. The range for the MAPE is summarized using the discussed approaches above. In the future, they discussed more approaches that can apply to the best solution. (Ivana et al.,) discussed forecasting for household electricity consumption. They used deep learning approaches and deep residual neural network (DRNN) for the forecasting. The features were extracted from the weather and calendar dataset and the load for the house is stored in history and as a whole house load. The open-source dataset was used for the experiments and analysis. These deep learning approaches train the larger volume of data and give the best solution in forecasting.

1.1. Research Problem

After analyzing various approaches, we reach a point where need to give the solution for comprehensive forecasting of the energy consumption in household usage. Giving the solution with the best approach is the need for time with an open-source dataset where experiments can be conducted easily. How climate change can affect energy consumption forecasting.

1.2. Research Questions

Energy consumption forecasting is the need to investigate how the resources can easily manage to overcome the usage. An efficient usage procedure is required for energy usage due to the increase in the large volume of energy consumption. Based on the survey for various already applied approaches we reach the point to give the solution for the energy consumption forecasting for the following questions given below.

- Which will be the efficient approach to planning the usage of energy in large volumes?
- How to understand the trends in urban energy consumption?
- How to pick the energy usage behavior and the typical distribution behavior of energy?
- Investigate the weather effects on the energy consumption forecasting?
- What are the major factors affecting energy consumption and forecasting?

2. Material and Design

The dataset used for the experiment in this proposed system is open-source. Smart meters in London open-source dataset used for their experimental analysis and forecasting. This dataset is designed for analysis, forecasting, and energy consumption analysis. The basic purpose of this dataset the people of England to install smart meters and this may help to save energy. An estimated 26 million homes there should be smart meters by 2020. The dataset description is discussed below in detail.
Due to the open-source dataset, we just downloaded it from the Kaggle website and used it for our purpose. The dataset has a total of 19 files in it such that the informations_households.csv this file contains all the information about the household. Halfhourly_dataset.csv is the which contains the block data of smart meter measurements (Iqbal et al., 2022). Daily_dataset.csv is the complete zip folder containing the 112 blocks of code with the values of data measures. Acorn_details.csv is the data file that contains the acorn data in detail. Weather dailydarksky.csv is the data that contains the data of weather collected by dark sky.API. Weather hourlydarksky.csv is the data that contains weather data on an hourly basis and this is collected using darksky.API. Uk_bank_holidays.csv dataset is also available and it contains a total of nine files each file has three variables such as bank holidays, and types of holidays like Christmas, Boxing Day, and others.
All the data is saved in .csv format and most data are saved in the format of blocks. We can apply any techniques because this dataset is enough to train the deep learning models or can be used for Machine Learning algorithms for forecasting (Iqbal et al., 2022). The regression process can be applied to this type of dataset to give the forecasting and check the trends inside the dataset. Various approaches use deep learning algorithms for forecasting because to train the model this dataset is enough. More than three years ago this dataset was published to use open-source and in this duration lot of experiments were conducted and proposed solutions (Iqbal et al., 2022). Smart meter data of around 5567 was collected and included in the main repository.

3. Proposed Methodology

There are various approaches discussed in the background section where people used Machine Learning, Deep Learning, and Data-Driven approaches. We proposed the system by using deep learning and machine learning algorithms on the regression techniques for the forecasting of energy consumption. Open-source smart meters in the London dataset were used for the experiments. The details approach we used for the forecasting is discussed below:

Step 1:

The dataset contains the different blocks and is saved in .csv format. We combine these blocks and make it a single data frame for further processing. We keep all the relevant blocks in the same column name.

Step 2:

In this step, we load the day-level energy consumption data and the whole dataset normalized to make them inconsistent counts for the houses.

Step 3:
Weather conditions and energy consumptions relationships are analyzed in detail. In the day-level data, we create clusters for weather data.
Step 4:
To use data as an indicator we added UK holiday data at the day–level. We also use the Prophet machine learning algorithm for forecasting on the half-hourly dataset. We use the Propghet model for the forecasting of the Half Hourly dataset.
Step 5:
Here we use the ARIMAX model and also show the ACF, PACF, modeling and seasonal decomposition explored. LSTM model is fitted for the forecasting in the uploaded dataset.
Step 6:
SARIMAX model is fitted for the forecasting in the uploaded dataset for the daily and UK holiday datasets.
The whole proposed methodology is evaluated by plotting the results properly after each model and also analyzed in detail. We use Python libraries to build the proposed model and also apply the Deep Learning model LSTM and Machine Learning model prophet. All the results are plots using the python libraries.
In the end, seasonality of the results shows in plots clearly and the open-source dataset for daily and half-hourly used with the energy consumption. Also, check how weather changes impact energy consumption and plot the forecasting. Fig.1 shows the proposed method in detail or every step followed in the model.

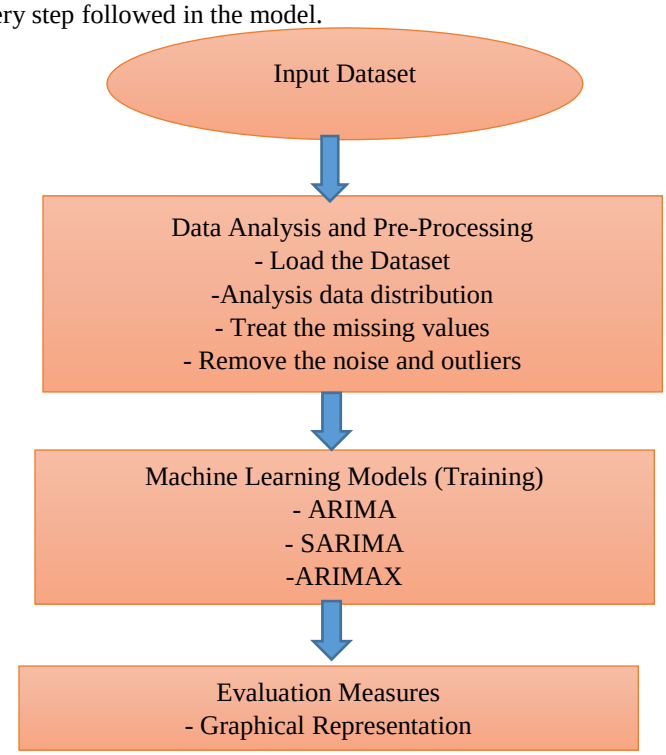

Figure A: Proposed model methodology

4. Results Analysis and Discussion

After applying the proposed methodology for the forecasting of energy consumption. And to check the climate change on the energy consumption forecasting there are some results and analysis. As already discussed, we used LSTM and Prophet model for forecasting the energy consumption using open-source smart meters in the London dataset. The detailed results are shown below, here we discuss how the weather conditions have a relationship with electricity or energy consumption.
Fig. 1 shows how the energy and temperature are in an inverse relationship. This proves that when low temperature the energy values are from heaters etc. we can see in the graph peaks of one appearing with troughs in the other. The temperature represents in pink and the average energy household in blue.

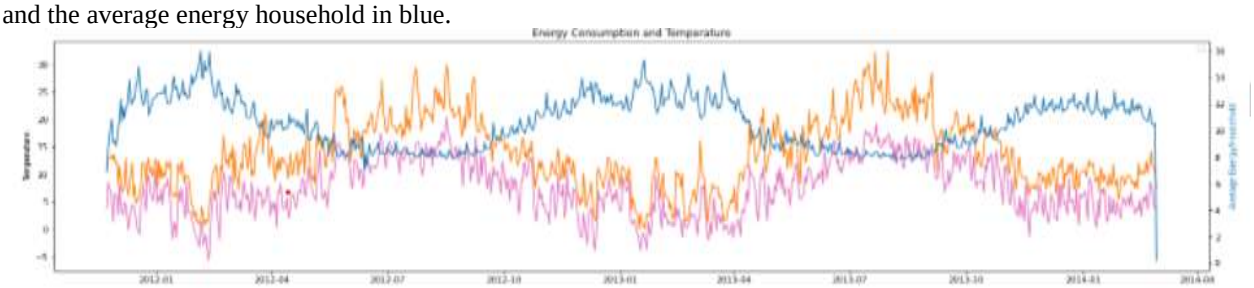

Figure 1: Energy consumption and temperature

Fig. 2 shows the relationship between energy consumption and humidity. These are almost having the same trend as shown in the graph.

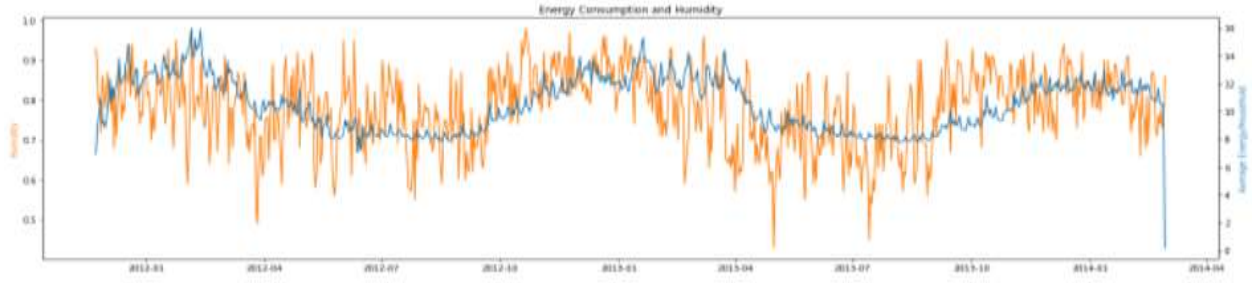

Figure 2: Energy consumption and humidity

In Fig. 3 cloud cover values and energy consumption are looking almost the same trend in the graph.

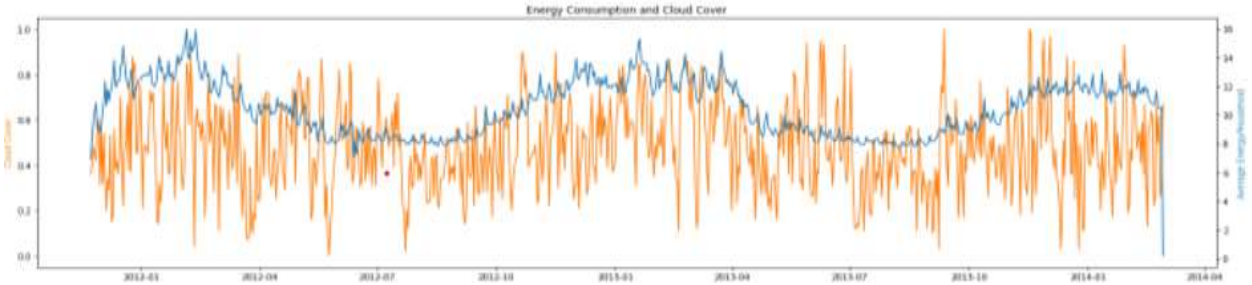

Figure 3: Energy consumption and cloud cover

Fig. 4 shows the relationship between energy consumption and visibility. Visibility is not a more affecting factor and it is showing increases or decrease has no effect on energy consumption.

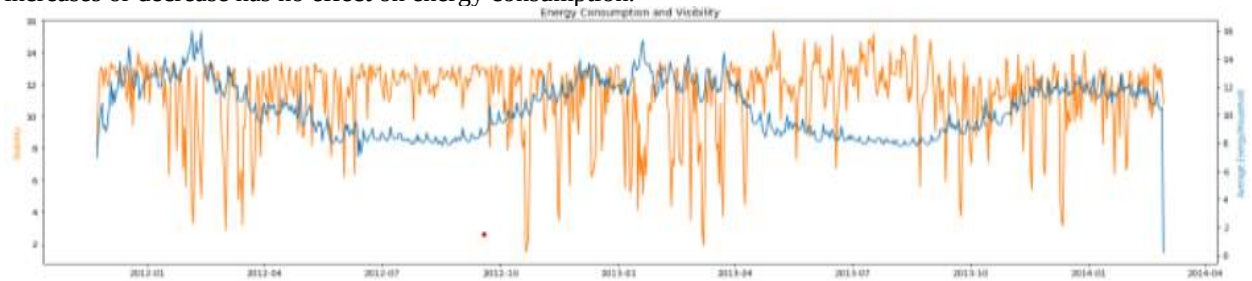

Figure 4: Energy consumption and visibility

Figure. 5 shows the relations between energy consumption and wind speed and it seems no effect on it and it looks outdoor.

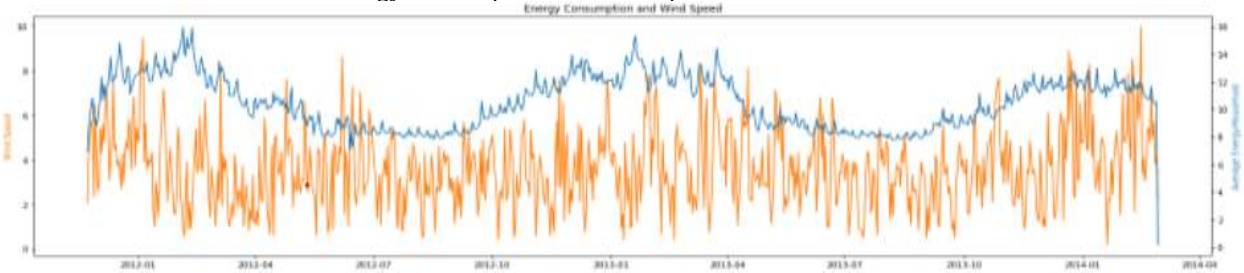

Figure 5: Energy consumption and wind speed

Fig. 6 shows the relationship between energy consumption and UV index and it looks inverse relationship.

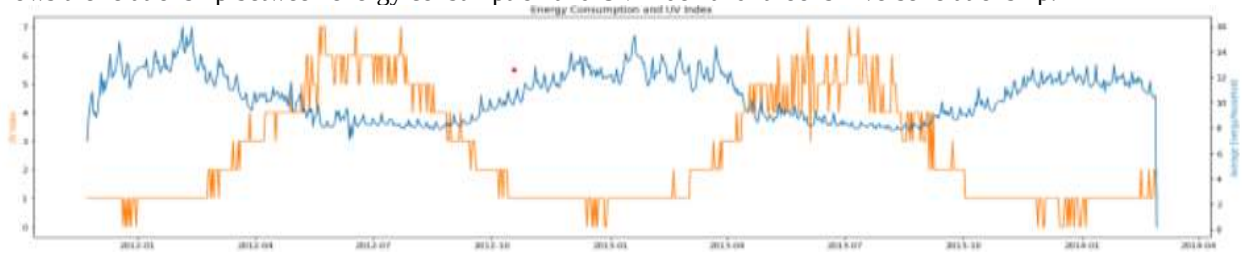

Figure 6: Energy consumption and UV Index

Fig. 7 shows a similar relation between energy consumption and dewPoint.

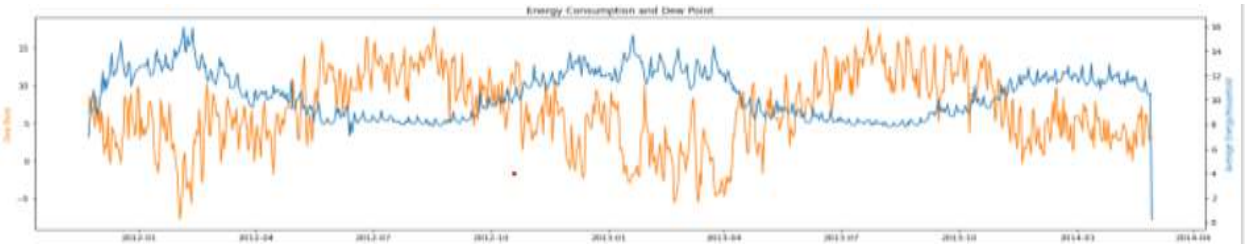

Figure 7: Energy consumption and dewPoint

If we talk about the relationship between energy consumption and weather variables. It clearly shows that energy has a high positive correlation with humidity and a high negative correlation with temperature. All other variables are discarded due to low relation with the energy.

As we observe the electricity or energy consumption increases in the summer from April to September. It can be seen in figure 8 which clearly shows the seasonal decomposition of the dataset.

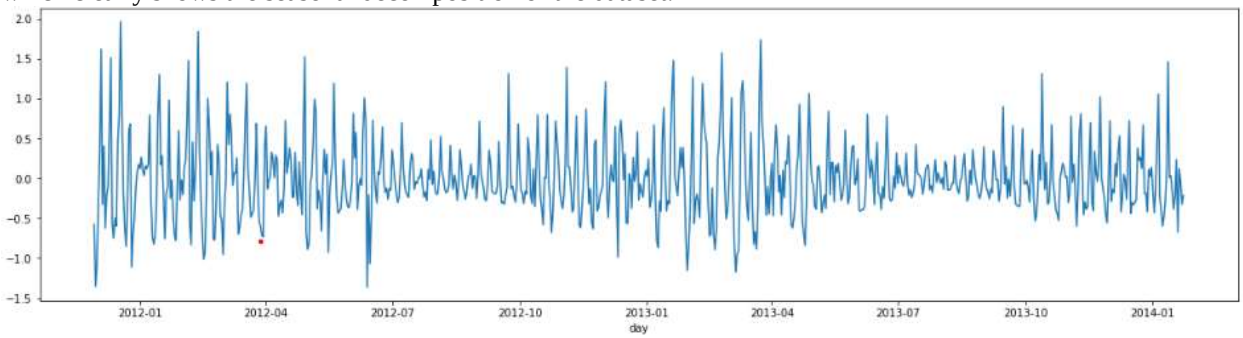

Figure 8: Seasonal decomposition of energy in the summer from April to September

The forecasting of the ARIMA model is shown in Fig.8 and Fig. 9 where red lines show the average energy consumption and it shows this model outperforms for this data to forecast the energy.

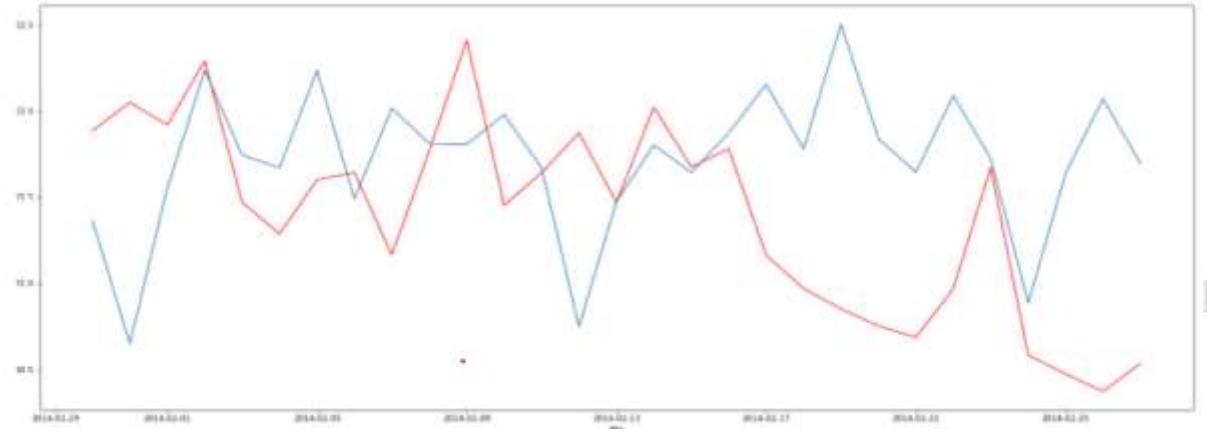

Figure 9: ARIMA model results on the test dataset

In the end, we use the LSTM model which gives the best results and the root means square error (RME) is 0.000 which proves the model's performance. We train the LSTM model and their loss values are very low as shown in Fig. 10. The prophet model also outperforms and gives the forecasting for the energy consumption.

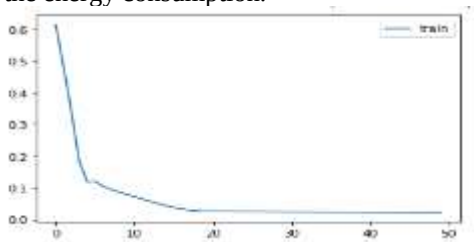

Figure 10: LSTM model performance

Fig. 11 shows the energy consumption in the half hourly dataset with using Prophet model. Each day energy consumption forecast is shown. In the Fig. 11 y-axis shows the energy level and x-axis shows the weekday and in each day the hourly energy consumption shown.

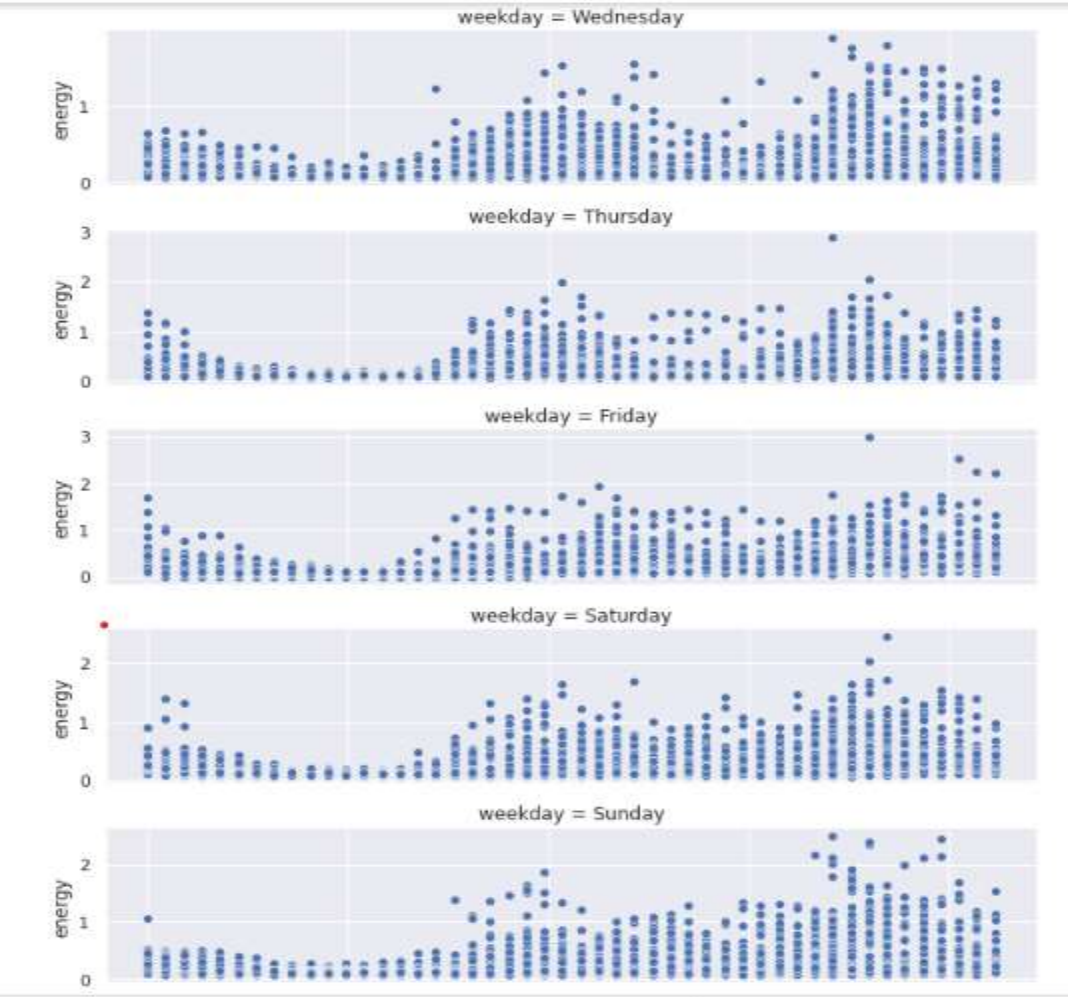

Figure 11: Halh Hourly dataset forecasting of energy shows for each day with hours

In Fig. 12 shows the results obtained after using SARIMAX model for the energy consumption forecasting. We can see the energy per household is calculated against the maximum temperature values, and also mention the number of clusters make in the different holidays. Here also predicted the results of the energy consumptions and in the last column shows the difference in household use with the prediction of the energy consumptions.

day	energy_per_household	temperatureMax	Clusters	holiday_id	prediction	diff
2014-02-28	0.208997	7.35	0	0	11.851811	-11.642814
2014-02-27	10.356350	10.31	4	0	11.521227	-1.164878
2014-02-26	10.202945	11.29	4	0	11.308251	-1.105306
2014-02-25	10.294997	11.43	3	0	11.350390	-1.055393
2014-02-21	10.518126	10.15	4	0	11.473181	-0.955054
2014-02-19	10.674624	10.13	0	0	11.418753	-0.744129
2014-02-18	10.781898	10.13	1	0	11.419956	-0.638058
2014-02-24	10.411403	14.23	4	0	10.998925	-0.587522
2014-02-20	10.573835	12.50	3	0	11.155260	-0.581424
2014-02-03	11.280011	7.99	4	0	11.839176	-0.559164
2014-02-04	11.095584	8.88	4	0	11.626631	-0.531046

Figure 12: Energy consumption forecasting and prediction

5. Summary, Limitation, and Future Works

Energy consumption increasing day by day worldwide, so there is a need to give the best plan for the best energy resource consumption to the producers. This helps to save energy from misuse and to utilize the energy properly. There are various approaches applied to forecast energy consumption but, in this study, we proposed the system using LSTM, ARIMA, and Prophet model to give the solution for smart meter dataset energy consumption forecasting in a good way. After applying this approach, we conclude that the weather variables are the major factors in energy consumption such that the temperature effect is larger than other variables. The proposed system proves its performance by forecasting the dataset using these algorithms.

In the future, this study can extend to use various other approaches such that applying deep learning models for the large volume to give a real-time solution. Real-time data for the testing can be used.

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