# George Mason University

# CS 504

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**Predicting Power Utilization Based on Historical Smart Meter Energy Consumption Data**

**Draft 1 Energy Project Report**

**Team Carbon**

**Team Members:**

**Jhony Islam**

**Spencer Marlen-Starr**

**Radha Kanuri**

**Cassidy Laskodi**

**Stavros Kalamatianos**

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# Abstract

[1-2 paragraph that summarizes your project: a) statement of the problem; b) research methods uses; c) results and findings; and d) conclusions and recommendations.]

# Introduction

## Background and Rationale

Energy consumption worldwide has been increasing at neck breaking speeds during the last 60 years. The overwhelming majority of the fuel chosen by heavily industrialized nations to produce electricity, in the geographical areas of North America, Europe and Japan has been relatively cost effective petrochemicals, the extraction technology of which humanity has mastered over decades of exploration.

The painstaking study of distillation of crude oil to its finest components facilitated the production of fuels specialized to power all types and sizes of motor/air transportation machinery, from vespas to unfathomably massive military aircrafts, such as the Ukrainian manufactured Antonov An-225 Mriya.

The aggressive entrance of a third of the world’s population, summed up in China and India, to the race on energy consumption, challenged the energy resource abundance utopia the world has been living on, and with the expected future depletion of crude oil resources in the near future, poses an immediate threat to our daily lives, adds unexpected items at the top of Governmets’ priority agendas, and sends alarming requests to the scientific community for new types of energy and supporting technology.

Unfortunately, the energy problem has been accompanied by the environmentally-insensitive behavior of a number of constituencies worldwide who via their unsubstantiated and aloof beliefs exacerbated a number of environmental problems. Their multi-year irresponsible activities have started manifesting in the form of global climate change, especially during the last couple of decades.

However, what has also been changing during the last 20 years is the outcome of sluggish, yet constant, research on renewable energy technologies, such as wind, biofuels thermal based on solar, and photovoltaics that finally show sufficient maturity to serve a long term energy supply without losing their cost competitive edge.

The result of progress on renewable technologies and their noticeable adaption shows in the following chart from Wikipedia (World Energy Consumption, 2021) as a positive annual increase of the comparative height among major energy sources. Despite Coal, Oil and Natural Gas dominating the chart [Fig. 1], renewable technologies have started contributing enough to be visible on the chart with an upward trend.

Chart, histogram

Description automatically generated

Figure 1: Global energy consumption comparison among major energy sources.

Today, more than 40% of the world’s energy consumption is in the form of electricity, and it is expected to grow to 60% by 2040. Figure 2 shows how according to the projections of the International Energy Agency [IEA] (Bizon, 2017). IEA projects that there will be a significant injection of renewables in the next 20 years to the point that they will account for about 44% of the world’s energy consumption.

Diagram

Description automatically generated

Figure 2: Projections of the world’s energy consumption by the International Energy Agency.

As the process of renewable innovations gets more support by Governments, it will help the industry get out of the slow progress from the last 10 to 15 years. Also, private capital will gain more faith to invest in them, their prices will decrease, and economies of scale would progressively emerge.

The presence of power electronics based energy conversion systems is of paramount importance to enable renewable electricity to be pumped into the existing electricity distribution grid.

The three major electricity consuming sectors that require those types of electronics are industry, transportation and residential.

Transportation has made great progress electrifying motor vehicles, speed trains, smaller boats and parts of bigger vessels. That’s possible with the use of power electronics.

Transportation and Industry consumers exist as more compacted business entities, where environmentally favoritistic policies can be implemented quicker through C-level governance as opposed to the last electricity consuming sector, residential.

The residential sector consists of millions of consumers that can be governed through legislature that can be steered towards certain constituencies interests taking advantage of the public's political beliefs. Depending upon that, it may be more difficult, or not, to get the public’s attention and assistance to the greater cause.

That cause is adapting responsible energy consumption habits focusing on energy reduction without jeopardizing quality of life, while promoting the use of relatively inexpensive energy efficient products and services. The overall goal is to decrease greenhouse gases and decelerate, stop or reverse climate change.

The United Kingdom [UK], as a member of the industrialized nations and the G8 is no different. Its investment on energy is dominated by the part devoted to electricity. As Figure 3 (Department for Business, Energy and Industrial Strategy, 2018) shows, it was 55% of the total in 2019.

Chart, bar chart

Description automatically generated

Figure 3: UK’s Energy Industry Investments By Energy Resource

The UK is also in favor of renewables.Figure 4 displays the UK's primary fuel production constant increase in biofuels during the last 20 years.

Chart, bar chart

Description automatically generated

Figure 4: UK’s Fuel Production by energy source in tons of oil energy equivalents for Selected Years between 1990 and 2019

The impetus for UK’s elevated environmentally friendliness is the entire European Union commitment to it.

According to the European Environmental Agency, the region has been experiencing impacts of climate change such as rising sea levels and extreme weather. This is caused by greenhouse gases (such as carbon dioxide, methane and nitrous oxide) being emitted into the atmosphere. In Europe, energy consumption is responsible for about 78% of the greenhouse gases emitted in the European Economic Area (EEA) (Energy and Climate Change, 2017).

The Paris Agreement of 2015 is a legally binding international treaty through the United Nations (UN) which commits the signatories to reducing their greenhouse gas emissions, according to the United Nations Framework Convention on Climate Change (UNFCCC) (The Paris Agreement, 2015). Nearly 200 countries signed it in 2015, and since then there has been a growing desire for low-carbon solutions in the energy sectors of the signatories and some (New Zealand for example) have even adopted carbon-neutrality as a medium term national goal.

In the UK, residential energy consumption is responsible for 15% of the country's greenhouse gas emissions (ECIU).This amounts to the average UK household consuming 3,731 KiloWatt per hour (KWh) per year, and that number does not include heating (ovoenergy) (Topping, 2021).

The UK's commitment to energy savings with further focus on decreasing emissions that contributes greatly to a global campaign to stop and/or reverse climate change is shown in Table 1. This data is from a 2020 UK government sponsored publication titled “UK Energy in Brief” (UK Energy In Brief 2020, 2014). Table 1 also displays how UK’s bioenergy topped the list of energy increase by source type, after tripling during the last 10 years even (barely) surpassing the increase on nuclear energy use.

UK’s energy consumption changes by energy supply type

Table

Description automatically generated

Table 1: Percentage increase in UK’s energy consumption by type between 2010 and 2019.

UK’s progress adapting cleaner energy is more evident from another statistic showing that energy from renewables, such as biofuels, solar and wind were also increased, leaving nuclear energy supply behind in the list of energy resources.

Figure 5 stresses the magnitude of the change and shows the energy and the carbon ratio falling dramatically during the last 20 years. Both ratios are calculated per unit of Gross Domestic Product (GDP). Despite the increase of GDP, both energy consumption and carbon emissions decreased making the ratio drop more dramatically as it can be quickly realized from Table 2.

Graphical user interface, chart, line chart

Description automatically generated

Figure 5: Table 2 - Energy and Carbon ratios during the period of 1990-2019 in graphic display and explicit numerical format.

One more evidence of the nation’s incredible job is Table 3 in Figure 6 where energy production generated gas emissions have also dropped in hundreds of millions of tons since 1990.

Chart

Description automatically generated

Fig. 6 - Table 3: Greenhouse gas emissions in carbon monoxide mass equivalents expressed in millions of tons.

But what drives that uninterrupted pace of progress?

Simple, UK parliamentary democracy committed to reducing greenhouse gasses expedited their course of action in June 2019 when they passed legislation to become a 0% emitter relative to 1990 levels by 2050. That means the UK will be able to remove from the low atmosphere as many tons of carbon emissions as it produces for energy consumption and other industrial activity, to become a net zero mean emitter (UK net zero target, 2020).

The mandates of the UK government became bullet points in the agenda of priorities of the country’s energy suppliers who strive to meet the government’s expectations with programs like the smart meter installation. Such programs will guide their efforts to collect consumer data. This analysis will help develop ways to educate the public on how to save energy and the emergence of products and services to serve that cause. Smart meters, unlike traditional analogue meters, are more interactive and multifunctional. They are easier for customers to read and share information over wireless frequency networks.

London, as the UK's capital and Europe’s widest, has been in a “greener is cleaner” state of mind for a while.

The LowCarbon London page of UK Power Networks (Innovation at UK Power Networks) advertises a few dozen innovation projects developed to decrease carbon emissions. Some of those that stuck out are:

* “Above and Beyond” uses drones for visual power line and asset inspection, instead of helicopters.
* “Arc-Aid” features quick-response sensors for overhead power line fault detection to minimize repair crews driving around trying to locate the electrical network culprit.
* “Edge FCLi'' collaborative project uses machine learning technology, called “PowerFactory” to ensure the substation [electricity distribution station] equipment prone to fault at, or after, 95% of their rating limits, do not reach that level of usage. Preventing that from happening minimizes the fault current coming from distributed generators connected to the greater network, thus supporting the UK's Net Zero carbon emissions target.

In this study, a representative sample of a few thousands of households spread out in the urban London area is split into two different groups.

1. The first control group was subject to: “dynamic time of use” pricing with the prior knowledge of the tiered pricing structure per KWh as total consumption increased during the day.
2. The second control group was subject to receiving price signals when pricing was getting adjusted during the day, so they could regulate their house’s energy use to save money and contribute their small quota to a lower emissions London.

The experimental group of “non-time of use” customers remained on a flat price rate per KWh.

The goal of the study was dual.

1. The first goal was to test the types of signals the supplier could send to the public to control and manage high renewable sources supply times.
2. The second goal was to adjust prices purposefully to throttle down consumption at certain parts of the grid under stress during high utilization times.

The data sets involved carry useful information about the participants' way of living, income and spending habits indexed in an index called ACORN. It shows whether the level of the social stratum of the people who belong in the ACORN group lies above or below the national scale in the UK.

The accompanying weather data completes the set and provides two major variables that influence energy consumption in the residential sector of the UK, where more than half of the UK’s energy investment went to.

The Kaggle data set “Smart Meters in London” will be the analysis resource we’ll use for the rest of this study.

## Research

The problem we look to address is whether there are effective methods to cut down energy consumption for individuals. A main point of focus is utilizing smart meters within the capital of the UK, London. There have been additional studies revolving around the tracking data through smart meters with one to state in particular done by four authors with electrical engineering backgrounds.

In the study, “Probabilistic Peak Load Estimation in Smart Cities Using Smart Meter Data” performed by Mingyang Sun, Yi Wang, Goran Strbac, and Chongqing Kang, the authors seeked to estimate peak demand for customers within London using smart meters similarly to what our team is looking to accomplish. They identify two major challenges surrounding the project being, “Different types of properties with various future customers exhibit different consumption behaviors” and “The demand diversity among customer loads significantly increases the difficulties in estimating the group peak demand” when they are defining their problem (Sun, Wang, Strbac, Kang, 1609).

It is helpful to see the challenges they identified in their problem statement as we may face similar challenges as well. The study proposes a solution where they utilize historical smart meter data in order to predict potential consumption behavior for future customers (Sun, Wang, Strbac, Kang, 1611). They go in depth on the model they chose to best represent and predict the data by identifying the factors used, identifying the model to predict data, and describing the dataset as a whole. This study chose to focus on using probability to determine peak demand for future customers which will aid in our study as we can see the factors identified in consumption as well as the data description from a previous study. By giving us a starting point in determining which factors are most effective in understanding the data, we can take a more effective approach to our problem. This study helps set up an excellent starting point for beginning our study.

## Project Objectives

This project aims to understand important aspects of energy consumption and more specifically how stakeholders are affected due to weather phenomena and other factors. A few questions we look to answer are:

* How are individuals at the household level affected by weather phenomena?
* Are there policies in place pertaining to weather phenomena and energy consumption?
* What role do price and cost play in energy output by energy suppliers?
* Does climate change play a significant role in energy consumption patterns?

These questions identify different stakeholders and their stances on energy consumption, while also focusing on energy consumption as a whole. Through our analysis of the UK dataset, we hope to get a general understanding of how energy consumption works worldwide.

## Problem Space

In this study, we look at homes in London, England and attempt to find out how people consume energy in their homes. The data is a sample of 5,567 homes in the London area from November 2011 to February 2014. This data comes from “smart meters'' placed in people’s homes by the British Government at the European Union’s recommendation. The weather data is from a darksky Application Programming Interface (API).

The energy consumption habits of the monitored houses is correlated to a number of factors of residents' daily lives, such as using more heating energy at night during the winter months when temperatures are lower, or the reverse in the summer days when temperatures soar upwards. Both scenarios vary by the house size, its location and its surroundings (surrounding trees will block a morning sun that would warm the house naturally, in lieu of heating), they vary by whether they plan outings during holidays or not, by how many appliances they run in their house and at what time of the day, their spending habits and plainly speaking whether they want to or even care to be more vigilant when it comes to energy savings.

Moreover, a greater problem we will try to address in this study is how to exploit the multi-variable demographic dependency of energy utilization and local weather data, to analyze patterns of energy consumption at the household level and make recommendations for how to potentially expand it to energy forecasting at the level of a greater metropolitan area that tends to be the energy consumption hog of a geographical region.

All the above wonders will stimulate our minds while examining the data more closely in the next few weeks. Exploratory analysis and examination of data relationships will help us extract meaningful information from the data to answer the above questions.

## Primary User Story (-ies):

* As a head of a household, I want to understand how my energy usage rate works, so that I can be more cost effective.
  + Understand what usage rates are accessible to households
  + Determine what households can change to affect usage rates
  + Determine if changes can make households more cost effective
  + Identifying if economic status plays a significant role and if so its effect
* As an energy supplier, I want to determine which factors impact energy usage, so that I can improve my revenue.
  + Which factors can energy suppliers manipulate (e.g. household income, long term investments, family size, occupations and others that collectively define pretty accurately the social strata of the city of London where the energy consumption data was collected from.)
  + How do I manipulate these factors to improve revenue?
  + How do I balance supply and demand to determine pricing?
  + What services are offered to promote reduction in costs, i.e. savings for energy usage?
* As a government official, I want to identify the different factors that affect energy usage, so that I can create relevant policies which will reduce energy usage.
  + Discover the factors that are impacted through government policies
  + Will government officials be more aggressive or passive with their policies?
  + Understand what drives the consumption of energy and it will perhaps stimulate ideas for possible changes in how to decrease useless energy consumption..

## Solution Space

Considering the intense pressure of time to deliver a workable system in less than 6 weeks we will claim that our system, at least from its design, will provide warning scenarios where certain events or combinations of independent variables will trigger a phase of higher energy consumption. The basis of such a situation will be examined with predictive and possibly prescriptive statistics to the point the quality of the data supports it. The reader then will be left with a few takeaway points about what can be done to suppress energy consumption, smooth the distribution of energy consumption throughout the day (reduce the sharpness of the spike in daily energy consumption which probably occurs around 5 - 7 pm) or the reasons why it is not possible to do either.

## Product Vision - Sample scenarios (why would someone want to use this)

### Scenario #1

### One interested party would be a startup with innovative products in the works. Such a business entity would like to know what’s their market segment and the weather conditions in their geography to adjust energy saving product development by wallet capacity and scope, i.e., for a residence or for an individual. Lifestyle information of potential customers will also help marketing the product properly. Some obstacles the startup might face could be availability of resources to produce their goods as well as availability of data to market to their customer base.

### Scenario #2

Policy makers would be interested in this energy data analysis. Being informed about the current usage of energy according to demographic will help them establish rules about energy consumption. They can form a team who closely monitor different demographics such as age, gender, annual income, etc. For example, if a certain demographic area is consuming more energy than needed, policy makers can enforce restrictions to control the area. A major obstacle policy makers may face is gaining traction and support from individuals for their particular policies. Without support, it would be difficult to enact any policy created by officials.

## Definition of Terms:

**ACORN**- Acorn is a powerful consumer classification that segments the population into 62 different types, providing a detailed understanding of the consumer characteristics of people and places across the UK.

**Apparent Temperature** - The perceived temperature in degrees Fahrenheit derived from either a combination of temperature and wind (Wind Chill) or temperature and humidity (Heat Index) for the indicated hour.

**Bank Holidays** - A bank holiday is a business day during which financial institutions are closed.

**Cloud Cover** - forecasts total cloud cover. The colors are picked from what color the sky is likely to be, with Dark blue being clear. Lighter shades of blue are increasing cloudiness and white is overcast. This forecast may miss low cloud and afternoon thunderstorms. When the forecast is clear, the sky may still be hazy, if the transparency forecast is poor.

**Dew Point** -  the temperature the air needs to be cooled to (at constant pressure) in order to achieve a relative humidity (RH) of 100%.

**Energy** - Energy, in physics, the capacity for doing work. It may exist in potential, kinetic, thermal, electrical, chemical, nuclear, or other various forms.

**Icon** - This is the icon that shows up on the weather app to show the user what the weather would be on that particular day or hour

**LCLid** - LCLids are the ID numbers of Power Meters.

**Pressure** - Pressure is the ratio of force to the surface area over which it is exerted.

**Energy Tariff** - An energy tariff is the pricing scheme an energy provider uses to charge a customer for gas and electricity consumption. A fixed rate tariff defines the cost of a unit of energy for a certain amount of time, typically per hour, while prices of a variable tariff fluctuate according to the market[.](https://www.comparethemarket.com/energy/content/energy-tariffs-explained/)

**Temperature Min & Max** - Extreme observed temperatures during the last 24 hours between 7pm CST - 8amCST per USA’s National Weather Service [NWS] definition. NWS’s defintion may very well differ from UK’s Weather Service, however, this quick description of the variable provides an idea of how it’s defined.

**Temperature Min & Max Time** - denotes the time a temperature minimum or maximum gets recorded in contract to the expected time. The weather phenomenon finds its explanation in the abrupt movements of air masses that influence the weather dynamics in the region of measurement, henceforth, the  skewness in the time of manifestation.

**Wind Bearing** - the generally accepted definition of the term dictates that bearing is associated with the direction of movement of an object within the zone by an active wind pressure differential. For example, a southern wind on a lake will favor a northbound sail the most.

**Wind Speed** - The speed of air at a fixed set of coordinates, measured either as the integral of speed variation during a prespecified period of time or as an instantaneous speed measurement, usually in cases the wind speed fluctuates insignificantly for all intents and purposes of the measurement.

# Data Acquisition

## Overview:

[Provide a descriptive overview of your datasets]

## Field Descriptions:

[Described your dataset field. Make sure you study the example below and you will more than likely expand these fields:

* URL (Type: string) – The web address or Universal Resource Locator for the webpage that contained the news article. This includes the protocol (http or https), host name, and subdomain. Some URLs also include parameters (text following ‘?’) or named anchors (text following a ‘#’). Each URL can only be present once in the database, even if the webpage is not static over time.
* Title (Type: string) – The title of the news article as parsed by the Newspaper 3K module. This field may be null (~150 articles in our dataset do not have titles).
* Authors (Type: string) –The authors of the news article as parsed by the Newspaper 3K module. This field may be null (~23,000 articles do not have authors) and articles with multiple authors have their names joined with a comma into a single string. This field may also pick up descriptions of the author, including their titles and background.
* Publication Date (Type: datetime) – The article publication date and time as parsed by the Newspaper 3K module. The datetime is displayed in ISO 8601 format (YYYY-MM-DD Thh:mm:ss+offset). Publish dates without specified times are assumed to be published at midnight. Publication dates with time information, but without a timezone listing, are assumed to be in Eastern Standard Time. This field is not allowed to be null.
* Text (Type: string) – The text of an article as parsed by Newspaper 3K. This field may be null (~8,000 articles do not have text) as some news stories are delivered as only video, audio, or a picture. The mean word count for text is 538.9 across all news sources.
* Tags (Type: string) – Article tags as determined by Newspaper 3K. These appear to be important (rare or “topicy”) words taken from the article text, not meta tags contained in the article’s HTML. Multiple tags are concatenated with a comma into a single string.]

## Data Context:

[Provide a description of the data context.]

## Data Conditioning

[Describe the data conditioning required for each data set.]

## Data Quality Assessment:

[At a minimum you must assess your data sets with the following attributes:

* Completeness:
* Uniqueness:
* Accuracy:
* Atomicity:
* Conformity:
* Overall Quality:]

## Other Data Sources

* [If you are considered other data sources, however, you decided not to use these sources provide some reason why they were not utilized.

# Analytics and Algorithms

[Provide detailed descriptions of the analytics you used and how this related to your project analyses.]

# Visualization

[Describe and show findings and results based on a mix of figures and descriptive text. If you have video, it will be limited to presentation, however, it can also be reference as media file in your Blackboard file exchange.]

# Findings

# Summary

[Summarize your findings and results for the reader. What did you discover, prove, disprove, etc.]

# Future Work

[Critical section! Propose future work or next step(s) for this project.]

# Appendix A

Code references – any code used for the analysis

# Appendix B: Risks

# Risk: The sample data is too small to represent the population.

# Probability: low

# Impact: high

# Mitigations:

# Identify a different dataset that better represents the population.

# Risk: Computing power may not be enough to process and analyze the data.

# Probability: low

# Impact: high

# Mitigations:

# Partitioning the dataset to split up the computing power required.

# Risk: The integrity of the data may not be up to standards.

# Probability: medium

# Impact: high

# Mitigation:

# Scrub the data so that it can be utilized appropriately.

# Appendix C

Agile Development

# Appendix D: References

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