Introduction

Project Overview and Background

The UK has recently experienced an energy crisis which has led to difficulty in providing electricity and heating to homes across the country as well as the collapse of at least 12 energy providers (with even more expected to collapse as the crisis continues)[[1]](#endnote-1). There are several reasons behind the energy crisis; the UK is extremely reliant on fossil fuels for heating and to a lesser extent electricity production[[2]](#endnote-2), the reduced supply of natural gas from Norway and Russia due to production issues, last winter being extremely cold throughout Europe and therefore requiring a greater energy usage to heat homes across both continents, increased demand for liquified gas in Asia and significantly reduced wind and solar production, and general exacerbation of issues with supply and demand due to Brexit and the pandemic [[3]](#endnote-3),[[4]](#endnote-4),[[5]](#endnote-5).

This project seeks to address the issues regarding fluctuating supply of renewable resources and the associated contribution to energy supply failures as well as unnecessary overproduction of energy from non-renewable sources. The world is experiencing a climate catastrophe and it is imperative that a transition to renewable energy use in every possible scenario occurs as soon as physically possible, this transition is happening, but not fast enough, and in the last year increases in renewable energy production capacity increased by the smallest margin in recent years[[6]](#endnote-6). However, due to the fact that renewable energy sources can provide energy as long as the turbines, solar panels or other technology are in working condition many people often overlook the fact that while the production method may be fully functional its supply source still fluctuates, wind speeds change as pressure fronts move, solar energy fluctuates with daylight hours due to cloud cover and the seasons, although it should be noted that solar energy is produced during the day, and especially on hot, sunny days, when electricity demand is typically higher[[7]](#endnote-7). These fluctuations in energy supply can happen very quickly, particularly with wind energy, and until a point is reached where tidal and hydroelectric production (more consistent methods of energy production) have been greatly expanded and can compensate for these fluctuations, non-renewable energy production methods, such as nuclear, coal and gas, must be used to meet energy demand. With the climate crisis being directly driven by the CO2 emissions that come from coal and gas power production there use needs to be reduced to only what is necessary until renewable energy production reaches a point where it can cope with both fluctuations in production, and in sudden changes in demand.

In an effort to aid in the improving efficiency of non-renewable energy usage, the aim is to develop a program which takes short to mid-term weather data to determine the production possible from renewable sources. Using watts per square metre of solar radiation, wind speed and other factors calculation of how much energy must be provided by non-renewable resources to meet demand can be done, reducing waste from unnecessary non-renewable energy production. The program will also include a feature that allows for simulations to be run on a longer timescale with data input by the user and using the same underlying algorithms as the forecasting function, allowing for better scheduling of energy production to be done. It is also hoped that this application will provide an educational tool for students at all levels of education to develop a greater understanding of renewable energy, showing them how the weather can affect how we live our lives, and the necessity for renewable energy going into the future.

Requirements

Users

The primary intended users for the forecasting aspect of the software are industry professionals working in energy production, at energy suppliers, who would use the tool in their work to calculate short term energy production targets, and regulators such as Ofgem, who could use the software to ensure energy companies are not unnecessarily using non-renewable energy resources.

The other function of the software is to provide the user to predict energy production in simulated scenarios. This tool could be used by a variety of different researchers; academics and university students could use it to estimate the impact of continued fossil fuel usage based on current weather trends in the interim before fully renewable energy production is achieved or looking at the potential impact to energy supply of global warming and the extreme weather events it causes (such as more frequent storms leading to reduced solar and wind production[[8]](#footnote-1)) , or by government researchers trying to set quotas for non-renewable production in the coming years again based on present weather trends.

For each of these two primary groups of users there will be a separate main interface to provide the required tools and data representations for the tasks. One interface for present forecasts based on live updated weather information and another interface which is used to create potential scenarios, which can be used by academics for long term projections. In addition to this the tool may have a supplementary use as an education tool for students at all academic levels.

From the key users a set of user personas were devised to aid in design and development, keeping these personas in mind throughout the process of the project ensured consistent logic and reasoning behind each decision made.

* **Government researcher in energy department**- wants to use the software to help simulate longer term energy production statistics, this will help determine whether government will meet clean energy production quotas based on long term weather trends
* **Academic modelling climate changes effects on energy production-** wants to use software to map possible energy production scenarios based on best- and worst-case scenarios of weather due to climate change, the UK will experience more storms as climate change worsens, this will reduce energy production
* **Energy company employee**- needs to determine how much energy the companies coal and gas plants need to produce in order to meet customer demands during a particularly rainy winter week. With energy companies currently collapsing, reducing costs is imperative and accurate forecasting a must.
* **University student**- wants to add theoretical new onshore windfarm in the north of Scotland to measure whether the clean energy production potential outweighs the negatives to wildlife in the area of proposed site for project, they will want free access to the service as they are unlikely to have the funds to pay for a service

Other Technologies

There are several similar technologies at present such as SAS Energy Forecasting, Synergi Forecaster, Matrica Nominator, and Itron’s Forecast as a Service tools (FaaS). Each of these services provide highly detailed energy forecasting software, however none meet all the requirements of this project.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Feature | SAS Energy Forecasting | Synergi Forecaster | Matrica Nominator | Itron’s FaaS tools |
| Short term forecasting (Hourly) | Yes | Unknown | Yes | Yes |
| Mid-term forecasting (daily, weekly) | Yes | Unknown | Yes | Yes |
| Long Term Forecasting (Month+) | Yes | Unknown | No | Yes |
| Renewable energy production statistic | Yes | No | Yes | No |
| Free to use version | No (Trial version is free)\* | No\* | No\* | No\* |
| All services in one package | Yes | Yes | Yes | No |
| UI suitable to non-technical user | No | Unknown | Unknown | No |
| Users can add data for forecasting | Yes | Yes | Yes | Yes (required for functionality) \* |
| Can be used to lower wasted production/costs | Yes | Yes | Yes | Yes |

Table 1: Comparison of similar existing energy forecasting tools

\*- these features, or lack of make the tools unsuitable for use as an educational tool, and for wide user base. Unknown- require company credentials to access information about product

User Stories

Going through the aims and objectives of the project, a list of specific user stories was drawn up to help give an overview of the main functionalities that the program must have, in addition to providing a basic framework to build the program’s detailed design around. The user stories were allocated values using the MoSCoW priority system. The must have stories are shown below in Table 2, with a full list of user stories found in Appendix I.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Story | Description | Forecast/ Simulation | UI/Backend/API/Data Storage | MoSCoW |
| 1 | I want to see a breakdown of energy production statistics | Displayed with either icons or with graphs | Forecast/ Simulation | UI/Backend/API | M |
| 2 | I want to be able to see statistics for a specific region/county | Interactive map, either clickable map or a dropdown menu to select viewed regions | Forecast/ Simulation | UI/Backend/API | M |
| 3 | I want to be able to adjust timescale | Can edit from hourly to weekly forecast | Forecast | UI/Backend/API | M |
| 4 | I want to be able to adjust timescale | Can edit from daily to monthly projections | Simulation | UI/Backend | M |
| 5 | I want to specify energy types used for statistics | Can select from wind, solar etc. to be displayed | Forecast/ Simulation | UI, Backend | M |

Table 2: Must Have User Stories

Modelling

For both main functionalities of the system mathematical modelling is required to take the raw weather data and use it to produce meaningful energy production values. The general principle is to use well documented methods for calculating energy output of wind turbines and solar panels and adapt them to use weather data to calculate potential output as opposed to typical inputs such as turbine heights or solar power dimensions. Access to detailed dimensions of every turbine on a wind farm or each panel at a solar plant is hard to access as often the details are not public, as well as the vast amount of time and computing power that would be required to input all of this information for each induvial turbine or panel and subsequently compute the capacity from these values as well as weather data. This process would have to be done for every piece of energy producing equipment with different sets of weather data over a range of time periods, due to the short time scale of this project a broader strokes approach will be taken to allow for a completed functional product to be produced. The approach taken will mean the program is unlikely to achieve extremely high accuracy in exact energy production statistics, however this extremely precise nature of the data is less important than achieving a reasonably good, predicted value.

Outlined below are the constraints applied to the modelling to ensure a balance was achieved between accuracy of calculated energy production, efficiency of the program and ensuring goals were completed in the project timescale.

Modelling Constraints

1. Due to the limited availability of details about individual turbines and panels, information about entire solar plants and wind farms were used in the calculation of energy output. This works on the assumption that weather conditions are almost entirely uniform across the site of the plant/farm.
2. The renewable energy plants are grouped into regions, and constituent counties. This minimises the number of calculations required and allows for an additional level of specificity in forecasting and simulating energy production. However, a relatively small number of regions were used to divide the UK into manageable areas, this leads to a trade off in how small an area a forecast or simulation can be viewed. This is deemed an acceptable trade off as more often than not energy production companies and researchers will want to see details across a region as opposed to at a singular wind farm or solar plant
3. Weather data used to calculate output will initially be generalised to the region of the plant/farm for initial development, if in development/testing phase all other essential functionalities of the program are completed, making the weather data more specific to individual plants will then be done.
4. There will be a difference in the exact modelling techniques used between the forecasting and simulation functions of the program. This is due to the fact that the forecasting modelling will use technical weather data (such as watts per metre squared) which may be confusing to a slightly less specialised user, for example a government employee who does not work directly in climate science but needs to know energy production statistics. For forecasting the user will not need to know how the energy statistics are produced, they just need to be able to see the weather and energy forecasts, but for simulation the user needs to provide the inputs into the system, and therefore must understand the terminology. For the simulation wind speed and average daylight hours will be used to simplify the program for users, and will thus need to use a different set of calculations to determine potential energy output. In future it would be a fairly simple task to add more options with higher level technical data used as inputs in order to expand the usability of the program within the high-level users of the software.
5. Due to financial restrictions, it is difficult to gain access to exhaustive lists of all wind and solar projects in the UK. The most comprehensive dataset that could be found for use only consisted of wind turbines producing more than 100kW, the majority of turbines below this threshold are typically used to power a specific building, such as an office or factory sited nearby. Most of the energy produced, if not all, will be used for these purposes and are therefore unlikely to put significant amounts of energy back into the grid, so will be assumed negligible in the initial design. Only minor modifications would be required to adapt if a larger data set with these low-capacity turbines can be accessed.

Implemented Model

Considering the above constraints, the following finalised models were developed for solar and wind production for the forecasting and simulation.

Solar

The primary difference in the modelling for simulation solar and forecast solar outputs will be the use of daylight hours in simulation and WM2  for forecasting. Both can be used to calculate the output of solar panels, with only slightly different accuracy. These choice were made as it was felt that for a less well-informed user, with regards to energy production, daylight hours was a far more tangible variable than WM2  as many users wouldn’t know off hand what a reasonable value for WM2 would be, but would be able to estimate the number of daylight hours in a given time period. The advanced simulation option that is provided for more advanced users however does also use WM2 as it is assumed that a more technically knowledgeable user would have a better grasp of more complex weather concepts.

The following equations were used for calculating solar production:

* Forecast: *(1)*
* Simulation: *(2)*

Where P is energy produced, W is WM-2, H is daylight hours, and the 0.75 in *(2)* is an efficiency factor.

Wind

For both the forecasting and the simulation calculations the same method was used for calculating wind energy production, wind speed was used as the main variable in calculating wind production, as wind speed is a value that both technical and non-technical users are likely to understand. The model used was a simplified version of the wind turbine power curve methodology of calculating energy production, this method is based on wind speed at the height of the hub of the turbine. Wind turbines have a wind speed over which they begin to operate, the cut-in speed (Vi), a speed at which they meet optimum production, the rated speed(V­r), and a speed at which the wind is too fast for the turbine to operate safely, the cut-off speed(Vo­). Between the rated and cut-off speed an optimal power output is at maximum capacity (Region III). Between the cut-in and rated speed the production gradually increases with increasing wind speed(Region II). These regions make up the producing portion of the power curve of a wind turbine and are illustrated in Graph 1, along with region I and region IV where wind speed is respectively either too low or too high for the turbine to operate[[9]](#endnote-8),[[10]](#endnote-9),[[11]](#endnote-10).

P

Vi

Vo

Vr

V

I

II

III

IV

C

Diagram 1: A typical power curve

In reality every wind turbine will have a slightly different power curve due to manufacturing conditions and specifications, however in general most wind turbines energy production maps closely to curves such as these. Highly common specifications were used to determine the Vi, Vr and Vo which were used in the model for this project, with values of 18 KPH (5 ms-1), 50KPH (~15 ms-1) and 90KPH (25 ms-1) respectively. This curve was simplified and adapted for calculations in the program with small increments of wind speed grouped together and mapped to the graph.

1. https://www.ft.com/content/9007f3d8-8fad-4133-88f8-cc1c3a027845 [↑](#endnote-ref-1)
2. https://www.newscientist.com/article/2290840-blame-fossil-fuels-not-renewables-for-the-uks-winter-energy-crisis/ [↑](#endnote-ref-2)
3. https://www.reuters.com/business/energy/bleak-house-why-europe-faces-steep-winter-energy-bills-2021-09-15/ [↑](#endnote-ref-3)
4. https://news.sky.com/story/energy-crisis-why-gas-prices-have-soared-and-left-uk-facing-prospect-of-food-shortages-12412951 [↑](#endnote-ref-4)
5. https://www.theguardian.com/business/2021/sep/19/uk-energy-market-crisis-what-caused-it-and-how-does-it-affect-my-bills [↑](#endnote-ref-5)
6. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\_data/file/1021952/Energy\_Trends\_September\_2021.pdf [↑](#endnote-ref-6)
7. https://www-sciencedirect-com.ezproxy.lib.gla.ac.uk/science/article/pii/S0960148114007836?via%3Dihub [↑](#endnote-ref-7)
8. For obvious reasons solar energy production is reduced during storms, but wind power is also reduced, as although wind speeds are higher, they are often so high that turbines cannot be used without risk of damage occurring. [↑](#footnote-ref-1)
9. https://www.hindawi.com/journals/jen/2016/8519785/ [↑](#endnote-ref-8)
10. http://xn--drmstrre-64ad.dk/wp-content/wind/miller/windpower%20web/en/tour/wres/pwr.htm [↑](#endnote-ref-9)
11. https://www.researchgate.net/publication/229393440\_Wind\_energy\_conversion\_with\_a\_variable-ratio\_gearbox\_Design\_and\_analysis [↑](#endnote-ref-10)