# CS310 Progress Report:
## Efficient Allocation of Renewable Energy Sources Under Uncertainty Across the UK

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## 1 Introduction

In the first 8 weeks of this project, as planned, most of the progress made so far has been research to lay the groundwork for a smooth development stage. With this research done we can now refine our plans for the development. In this document we will highlight what new details we have to consider for the project and how what we have learnt has impacted the original plans for the project. Up to this point the schedule set out in the specification document (appendix of this document) has been followed without problem, so we will begin by examining the research done during this period. Following that we will use this information to determine what has changed with the plan and discuss why these changes are important to producing the best end product possible. Finally, we will outline the next steps to be taken in the project and discuss our management approach to ensure we keep up a good pace.

## 2 Research Progress

When setting out on this project it was uncertain what types of renewable energy we would be examining after collecting a variety of sources we found that wind and solar generators had the most information available relevant to the UK, therefore the decision was made to start by focusing our research on these two areas.

### 2.1 Energy Costs

Information on the costs of installing solar photovoltaic cells is extremely accessible as many people have looked to install small scale solar projects into their homes. However as we would be looking to install large scale solar farms with the scope of this project these price estimates may not scale accurately. To ensure we were making accurate estimations we ensured that any sources we used could be cross-referenced with another accurate source. We found that the Renewable Power Generation Costs in 2019 report published by the International Renewable Energy Agency (IRENA) reported costs for everything we would need to know, reporting for Solar PV a cost of £1210 per kW on a commercial scale [1]. This would appear to be a very reliable source as it comes from a reputable agency trusted to keep track of many different aspects of renewable energy. Nevertheless, we ensured that these numbers were consistent with a report published in 2019 by the UK government which estimated installations between 10-50kW (the upper end of their scale, so most relevant to a large scale commercial project) cost an average of £1139 per kW, and that this number had fallen to £1088 per kW by 2021.[2] This suggests to us that the IRENA report has accurate numbers to reference for costs overall even if prices will be slightly lower due to the year that has past since publication.

The IRENA report also reports costs of installing onshore and offshore wind farms, with similar cost breakdowns of cost per kW to the solar reports. The reported cost of an offshore wind farm was reported as £3432 per kW in 2019 which is significantly more than installing solar panels. Onshore wind is not as expensive as offshore to set up but again is more expensive than a solar equivalent capacity at £1349 per kW in Europe.[1]
However when you compare the levied cost of electricity from the generator, which is calculated by considering the operations and maintenance costs, lifetime capacity and the economic lifetime of the project (IRENA) we see that onshore wind is significantly cheaper than the other options at a cost of £0.0503 per kWh, compared to the £0.1403 per kWh and £0.0907 per kWh of solar photovoltaic and offshore wind respectively [1]. This number does vary across different countries reported and solar may have a higher cost due it being relatively unused on a large scale in the UK and with increased adoption this may get better but currently this shows wind being the most efficient option to consider cost wise.

## 2.2 Locations

We found that generally with solar farms the location impact is fairly minimal over a small area like the UK, as the only impacting factor ends up being the levels of sunlight over a day. As such we decided that the due to location not being a huge factor in their performance we would narrow the scope to ignore solar power as it would only add complication to the end system without being a interesting problem to solve.
When looking into suitable locations from wind farms another question comes up regarding the difference between offshore and onshore wind. In 2019 the UK had a slightly higher generation capacity of onshore wind than offshore, however the actual generation amounts were equal with both generating 9.9% of the UK's total power each.[3] This is due to offshore farms having access to more suitable weather conditions resulting in a higher average load factor (average percentage of generation capacity actually generated) of 40.5% compared to the 26.5% of onshore wind[3]. From this it may appear advantageous to focus on offshore wind, and the increasing proportion of capacity being offshore over the last few years would also support this, but considering the levied cost of onshore wind farms being cheaper per kW generated [1] and that historical weather data is more readily available around onshore farms we will aim to focus on allocating onshore farms initially with this project with offshore being an area for expansion later.

Choosing a potential site to build a new wind farm is a difficult task as not just the generation can be considered, a perfect site may not be usable if you are not allowed to build there. Many wind projects get rejected as seen in 1 which shows all wind farm applications that have been refused recorded in the Renewable Energy Planning Database [4]. As such when deciding on locations we have decided to accept some limitations by only considering existing locations and suggesting the project finds the best of these existing projects to expand upon. This is a limitation that can be easily amended in future work if a list of suitable new sites is created. We will also be making use of locations that have been approved but are under or awaiting construction which expands our potential sites vastly as shown in 2.

## 2.3 Generation Prediction

As we found that generation rates for wind power vary depending on a variety of weather conditions we decided that the first idea to consider would be to use regression to predict an amount of power generated. This will allow us to train a model against weather data for each day with a target being the generation a wind farm actually produced on that day. By training this on numerous wind farms over a large set of days, we hope to be able to accurately estimate the power generated by a wind farm for any weather pattern. We will then use this to predict a generation on an "average" day

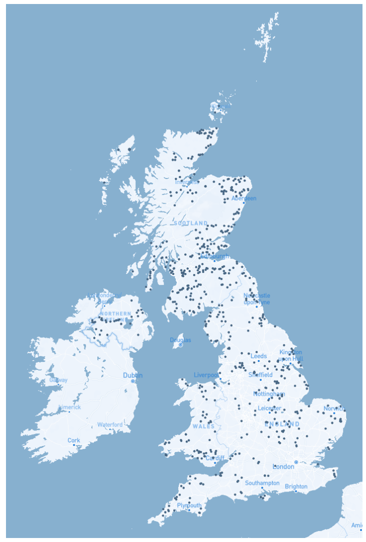


**Figure 1:** *Rejected Wind Farms UK 1990 - 2021, [4]*

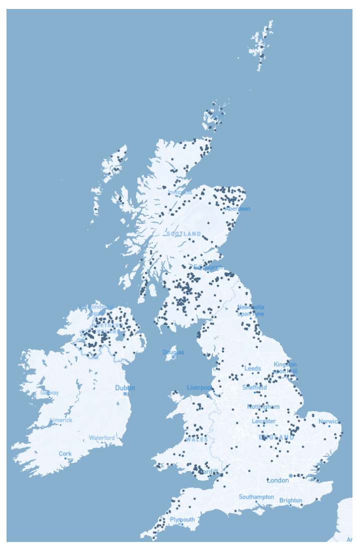


**Figure 2:** *Operational or Approved Wind Farms UK 1990 - 2021,[4]*

for every location to predict the performance of the proposed wind farm.
Currently the plan is to evaluate a few different regression models to see which finds the best fit, and in the next few weeks we will begin work on constructing the data set and conducting any feature engineering required to extract latent features from the data provided. This may not be necessary and a simple regression model against weather data may be sufficient but by testing a variety of approaches we aim to find the best result possible.

# 3 Technical Progress

With the majority of the time up to this point focusing on the research aspects of the project there have not been many technical developments. The main one technical aspect though is the collection of data and a start to the building of our training and testing data sets.

## 3.1 Data Collection

From the research stage we now have a better idea of what data we are going to require to achieve the aim we set out at the beginning. There are two main things we now know to consider, a comprehensive weather breakdown for a given location at any point in time over the span of our training time range and an actual generation amount for every onshore wind farm on every day of that same training time range.

### 3.1.1 Historic Weather

In the process of searching for a good source of this weather data we came across a few potential sources. The first was the Met Office historic station data sets[5]. This gave us access to a selection of 37 stations across the UK, each having the the following information for every month since it's opening: [5]

- Mean daily maximum temperature
- Mean daily minimum temperature
- Days of air frost
- Total rainfall
- Total sunshine duration

Unfortunately this did not give us the resolution we needed nor any information on wind speeds that would seem inherently important to a discussion on wind farm performance.
The option we discovered next was visualcrossing.com [6], this website provided access to data for any location in the UK based on the closest weather stations it has access to. It gives the resolution and span of dates we need to create a comprehensive training data set. We are able to query any date and time range, at an hourly resolution getting information about:[6]

- Air pressure
- Cloud cover
- Humidity
- Precipitation
- Temperature
- Wind speed
- Wind direction
- Wind gust speed

This amount of information should make for a plentiful feature set, hopefully allowing for a accurate prediction model to be found. The weather API system allows us to automate the data collection process although their free model limits to 1000 records a day, so we are planing carefully what dates and areas we require for our data set before making any large requests.

### 3.1.2 Historic Generation Amounts

Finding values of actual generation produced by wind farms was a bit more of an involved process, from our research we have been unable to find any one specific source that gives us the full information we need. However after a bit of searching the National Grid online data portal [7] and the

Elexon Balancing Mechanism Reporting Service (BMRS) [8] we were able to obtain a list of all wind farm Balancing Mechanism Units Ids (BMU_IDs) which allows us to query the BMRS dashboard to obtain an actual generation amount at half hour intervals for any date it was operational.
This allowed us to compile a list of all the BMU_IDs and in the next few weeks let us start to match a location, a date-time and a power output, which can be used in combination with the weather data gathered to build our data set.

# 4 Updated Plans & Project Management Decisions

## 4.1 Narrowed Scope

Now we have the research completed we have a better idea of exactly what is possible for this project. Over the course of this document we have discussed some of the areas we have narrowed the scope to improve the quality of the product we do produce. For example by restricting our predictor to work initially on strictly onshore wind power we hope to ensure that our prediction accuracy can be better than if we were split across different generator types having to consider a variety of different features.
We believe this decision is for the best of the project as the concepts demonstrated by this more limited project will allow for expansion in the future to more easily implement other sources and locations.

## 4.2 Next Steps

From here our project will consist of 2 main targets, the predictor system and the efficient allocation algorithm. Originally our specification planned the order such that we would implement and research the allocation algorithm before tackling the performance predictor but through the research section it became clear that this would be extremely counter intuitive. Both these components are key areas requiring a lot of focus, and they should be tackled when required instead of preemptively designing the allocation system with no performance heuristic to use with it. As such, the immediate focus now is on designing tests for the first iteration of development focused on the predictive model and then compiling the data highlighted in section 3.1 into one large training data set.

## 4.3 Managing the project

To keep track of each iterations development we will make use of a Kanban style board designating a iteration backlog of tasks to be done. This will help us evaluate the progress being made through the project and aim to keep a constant rate of work to ensure the project can be completed within the time frame given. In keeping with the original plan laid out in the specification most of the development work will be conducted throughout term 2 due to a reduced workload outside of the project allowing for a larger time dedication to development work.

# References


[1] I. R. E. Agency, "Renewable power generation costs in 2019." `https://www.visualcrossing.com/weather-history`, Jun 2020.

[2] D. for Business Energy Industrial Strategy, "Solar photovoltaic (pv) cost data." `https://www.gov.uk/government/statistics/solar-pv-cost-data`, May 2021.

[3] D. for Business Energy Industrial Strategy, “Energy trends: March 2020, special feature article - wind powered electricity in the uk.” https://www.gov.uk/government/publications/energy-trends-march-2020-special-feature-article-wind-powered-electricity-in-the-uk, Mar 2020.

[4] D. for Business Energy Industrial Strategy, “Renewable energy planning database: quarterly extract.” https://www.gov.uk/government/publications/renewable-energy-planning-database-monthly-extract, Nov 2021.

[5] “Met office - historic station data.” https://www.metoffice.gov.uk/research/climate/maps-and-data/historic-station-data. Accessed: 28-11-2021.

[6] “Visual crossing - weather history.” https://www.visualcrossing.com/weather-history. Accessed: 28-11-2021.

[7] Datopian, “Eso data portal: Home: National grid electricity system operator.” https://data.nationalgrideso.com/. Accessed: 28-11-2021.

[8] “Actual generation output per generation unit.” https://www.bmreports.com/bmrs/. Accessed: 28-11-2021.

# CS310 Project Specification:
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## 1 Problem Statement

One of the most substantial threats to the modern world is the ongoing climate crisis. With a need for more renewable technologies and energy being one of the key paths forward, the problem becomes where best to site these new energy sources. With so many possible locations to choose from and a finite budget the automation of these decisions would be an obvious help.
AI is a powerful tool in tackling optimisation problems such as this, where the number of variables affecting the outcome make the best choices difficult for a human to comprehend. As discussed, with such a wide range of varying locations across the country the choice of where to allocate funds quickly becomes a complicated one. Especially so when considering the statistically uncertain factors such as maintenance and most importantly for renewable energy, weather.
When considering a choice of location and energy source there are a range of factors to consider in evaluating the value of the decision. The costs of a choice will be impacted by the setup and connection costs, the initial production cost and the cost of repairs, meanwhile the output of a location will vary depending on the weather of any given day. This exposes the other area of the problem, the need to consider the statistical uncertainty of events such as faults requiring repair and ”profitable” weather patterns occurring when evaluating a choice.

## 2 Objectives

The aim of this project is to create a program that will be able to take a user’s budget as an input, and make decisions in allocating that budget to different energy sources in different locations. These decisions will be made using a range of different techniques to ensure that the allocations are made result with the most efficient spending possible.

### 2.1 Core Objectives

The program itself will be made up of a few different components and in order to be successful should meet the objectives below:

1. A ”performance” function will be able to evaluate a location for a given energy source type, using uncertain variables such as wind speed, sun light time and sun intensity.

2. A ”cost” function will evaluate a cost of choosing a location according to the production cost of the energy source, transportation and connection costs for a given location, and an evaluation of repair costs against the chance of a fault occurring.

3. A ”solver” function will implement a yet undetermined optimisation problem algorithm suited to an allocation problem of this type, and will make use of the ”cost” and ”performance” functions as heuristic values.
4. The program be able to access a data set of locations, curated to be viable for allocation.
5. Given an input budget value the program will return the user a set of allocations chosen as it deems to be the most performant based on the performance function defined in objective 1.
6. The program will run under a fixed time condition such that the user should not be waiting more than 30 seconds for a result.

These are the core parts of the project which are required to have successfully implemented the goal of this project. However these objectives have some areas for expansion which could potentially be investigated given the core aspects are implemented successfully with additional time to spare.

### 2.2 Potential Areas of Expansion

1. Extend the ”performance” function to consider long term trends in the weather to all for the program to make allocations based on future worth.
2. Evaluate more than one of the most relevant algorithms, benchmarking performance on time taken, accuracy, and consistency.
3. Extend the location set by allowing users to input their own location data set, allowing the program to be used in different countries or more specific areas in the future.

## 3 Methods

### 3.1 Development Methods

The development process of this project will follow an agile iterative model of development. The project will be broken down into core sections that need to be implemented, with the aim to complete a new version of the project, including a new core feature, every 3 weeks. This give regular target milestones in the development and ensures that the order of development is structured with each prerequisite feature completed before work begins on a new one. This agile style will also allow for flexibility as it is likely that the initial plans for this project will change in the future if certain implementations do not perform as expected.

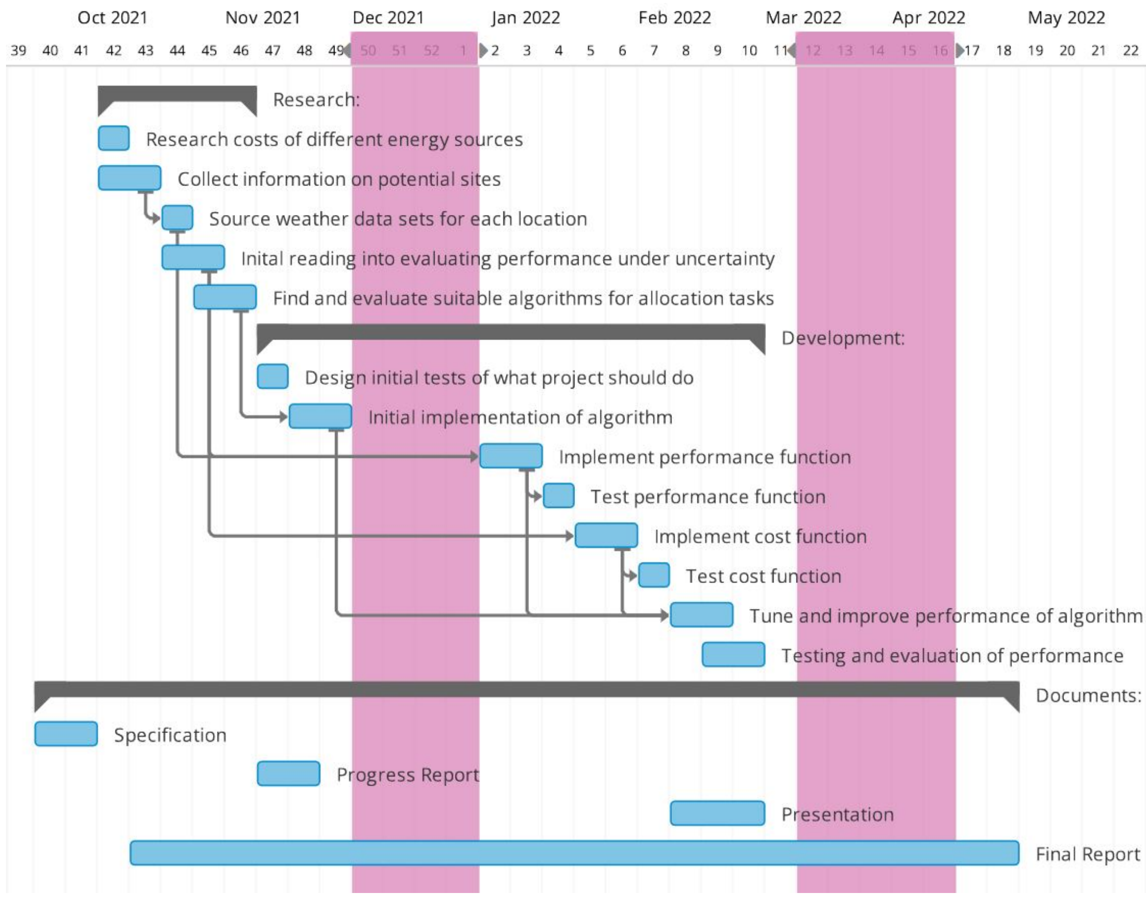
The project will make use of Git to separate the code base into versions throughout development, this will allow for different functionalities to be developed separately if needed, and give access to easy rollbacks to previous versions should some area of the code cause problems.

### 3.2 Testing strategy

In the iterative model chosen each version should be appropriately tested on completion. To ensure the end result meets expectation, at the start of each iteration a list of tests and expected results will be defined. If at the end of a version’s development the tests are not met sufficiently, the next version developed should either rework the code to ensure it meets the tests or consider if the tests originally defined should be redesigned to be more achievable. This may lead to features taking longer to implement than planned so some flexibility in timetabling should be allowed.

# 4 Timetable

To organise the time spent on this project the key steps requiring work have been broken down and scheduled over the duration of the university year. The below gantt chart visualises what will be worked on each week and how different tasks are prerequisites to each other. The highlighted weeks are kept free for university breaks, by leaving them free it will allow for any versions dedicated to failed tests in prior versions to be completed without extending the overall project beyond the deadline of completion.




The majority of the development work will be done in term two as before it can be started a full understanding of concepts learned in the research phase is needed. This also works to fit availability of time as term two will have more free time to allocate to development each week. The current plan is for the majority of work on the project to be done on Tuesday, Wednesday and Thursday with 2-3 hours scheduled each day and any more work to be completed over the weekend.

# 5 Resources

The main resources needed for this project is the historical weather data required to evaluate the suitability of different locations. Using a mix of sources from visualcrossing.com [2] and the Met Office [1], will help ensure a full range of data for each chosen location as well as acting as a fail safe in the unlikely event of either sources removing access to this information. The project will be built in the base Python 3.9 language, this is a widely supported language with no chance of becoming unavailable within the duration of this project.

# 6 Risks

The main risks this project will face are data loss and issues with falling behind schedule. In order to prevent and mitigate the problems caused by these risk we will take the following measures:

- Data Backup:
  - By using Git as a version control protocol for the project we can make use of GitHub's private repositories to keep a regularly updated backed up to a central online location.
  - To avoid the unlikely case of losing access to the repository causing any issues we will also be pulling up to date versions of the code base and project documentation to at least 2 different computers (a personal Laptop and Desktop most regularly).
- Time management:
  - As part of this document the timetable will help build an expectation of where the project should be every week.
  - Project management tools such as Kanban boards can be used to break down the tasks ensure regular progress is being made on the development.

# 7 Ethical Considerations

As this project will be using publicly available information as sources and is isolated in the development and testing of the program there are not an ethical concerns to be raised at this time.

# References

[1] Met office - historic station data. `https://www.metoffice.gov.uk/research/climate/maps-and-data/historic-station-data`. Accessed: 10-10-2021.

[2] Visual crossing - weather history. `https://www.visualcrossing.com/weather-history`. Accessed: 10-10-2021.