Department of Mechanical and Aerospace Engineering

# Electrical energy system in 2030:

# The case of United Kingdom

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## Copyright Declaration

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Signed: Nuttanon Boonra Date: 20-Aug-2017

# Abstract

In 2016 United Kingdom electrical system supplied 57.4% of electricity demand by fossil fuel (45.2% gas, 9.3% coal, and 2.9 % oil) and 20.3% by nuclear generation and only 22.2% by the renewable source, even though there are more possible renewable source of energy in the United Kingdom. As global warming and uncertainty of fossil fuel price, it imperative to plan the future energy scenarios for matching electricity demand and supply in the future by utilizing the different amount of renewable energy in the system. Therefore, this thesis investigates the prospects for realizing of the UK electricity system in 2030 by using EnergyPlan as the modelling tool. Initially, a 2016 model of UK electricity system was created for validation and reference. Then the four different scenarios have been created which have different amount of demand and supply due to economic, political, technology, and environmental factors. Although, the result of the simulation reveals that every scenario is possible for UK electricity system in the future, the strength and weakness of each scenario are different. Thus, the weakness of the future system needs to state for prevent the undesirable situation for UK electricity system in the future.

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# 1. Introduction

As nowadays human race is facing serious environmental challenges such as global warming, pollution, and energy source depletion. The energy source is important to the well-being of human kind because it makes the production and distribution of all goods and services (Incropera, F, 2016). In modern society, the type of energy which uses in human daily life is electricity. In United Kingdoms, approximately 57 % of the energy used for electricity comes from fossil fuel (UK department for business, energy and industrial strategies, 2017). The fossil fuel is the major cause of an increase in greenhouse gases level which leads to global warming problem (Dinçer, 2010). From this reason, the fossil fuel does not seem to be the sustainable solution for all living thing on this planet. In contrast, the electricity can produce by various kinds of sources which not produce a large amount of greenhouse gas as fossil fuel. From UK department for business, energy and industrial strategies data (2017) around 43% of the energy used for electricity come from non-fossil fuel source which is renewable sources (23%) and nuclear (20%). In fact, UK has an abundance of renewable energy sources (Chmutina, K., & Goodier, C., 2014). With this in mind, the fossil fuel consumption for electricity in the UK can be reduced if UK identifies the most effective way to use fossil fuel mix with renewable energy system (RES).

Even though the RES is a solution for reducing greenhouse gas emission. But in reality, there have many factors that limit the growth of RES. For instance, economic, political, technological, social, and environmental issue (National grid, 2015). Therefore, to evaluate the most effective way of the energy mix for the UK. It has to consider in many dimension as well. Hence, this thesis has created 4 future scenarios which different demand and energy mix base on various factors. To determine the carbon emission, import, export, and grid capacity of UK in 2030. Then use these data to analyses the strong and weak point of each scenario in different seasons and also provide some possible solution for each scenario.

This project is an excellent laboratory for the experiment the different energy mix to planning the large scale electricity system and predict the possible result and solution. Lessons learned from this will help for creating a better understanding of data collecting, modeling, and analysis skills for large scale electricity planning.

## 1.1. Aims and objective

The overall aims of this project are to investigate the possibility of the UK electricity trends with the different type of energy mix to meet the future energy demand. And the potential of electricity generation in different seasons. The objective of the project is:

- Analyze the possible energy demand and supply in the future depends on a various factor.
- Modelling the UK future energy system by using modeling tools which called “EnergyPlan” to determine the future electricity situation and also include environmental issue.
- Evaluate and offer the possible solution for the scenarios which have a problem.

## 1.2. Scope

The core of this project is to investigate the feasibility of matching various types of UK electricity demand and supply in 2030 and proposing the appropriate solution for the scenarios which have a problem.

Within the scope are:

- UK electricity demand
- UK renewable potential
- Import and Export of electricity
- Grid capacity
- Carbon emission
- Stabilization of the grid
- Storage size

Out with the scope & possible future work are

- Cost
- Interconnection electricity demand
- Type of storage
- The improvement of grid stabilization

# 2. Methodology

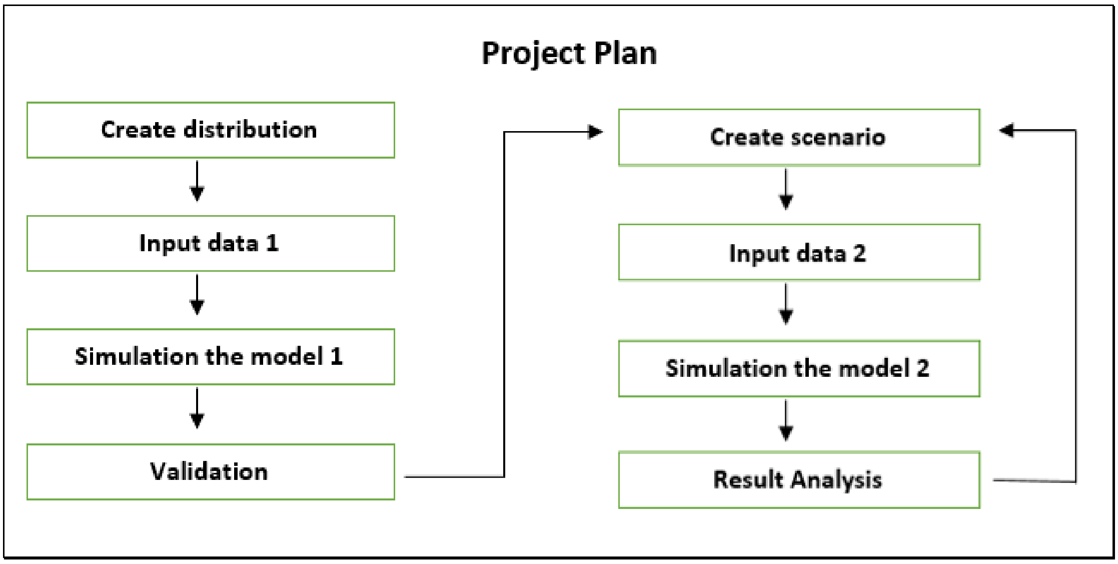


*Figure 1 Project Plan*

In order to observe the 2030 UK electricity situation. The plan of this project is shown above in figure 1 as:

**Create distribution** - Collect the needed data and change form to the set of numbers that can use in the modelling program.

**Input data 1** - Input the size of 2016 UK electricity demand and supply to the program.

**Simulation the model 1-** Simulation the program by using Energy Plan program that will show in chapter 2.2.

**Validation** - Compare the simulation result with government result and validate them together.

**Create Scenario** - Predict the size of demand and supply of 2030 UK electricity by using various factor.

**Input data 2** **-** Input the size of 2030 UK electricity demand and supply to that made from previous part to the program

**Simulation the model 2-** Simulation the program by using Energy Plan program that will show in chapter 2.2.

**Result analysis** **-** Analyze the result and then repeat to the create scenario step to run the next possible scenario.

## 2.1. Create distribution

In this step, the various data that needed to be put in the program have to collect and create into the set of 8784 numbers. In each number represent the status of each hour in a year. Therefore, the set of numbers will represent the rate of change of each value for the whole year. The value that use to create distribution comes from the average of historical data which come from Data Explorer of National Grid (2017), Great Britain grid watch (2017), and 4 documents of UK department for business, energy and industrial strategies (2012, 2014, 2016, and 2017).

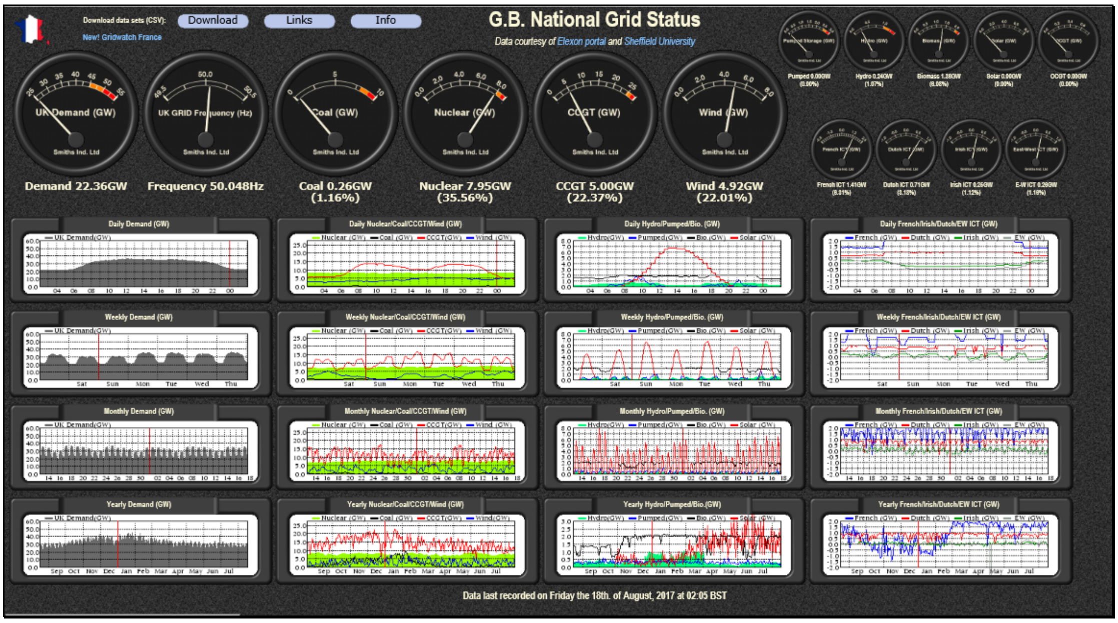


*Figure 2 Great Britain grid watch*

### 2.1.1 Demand Data

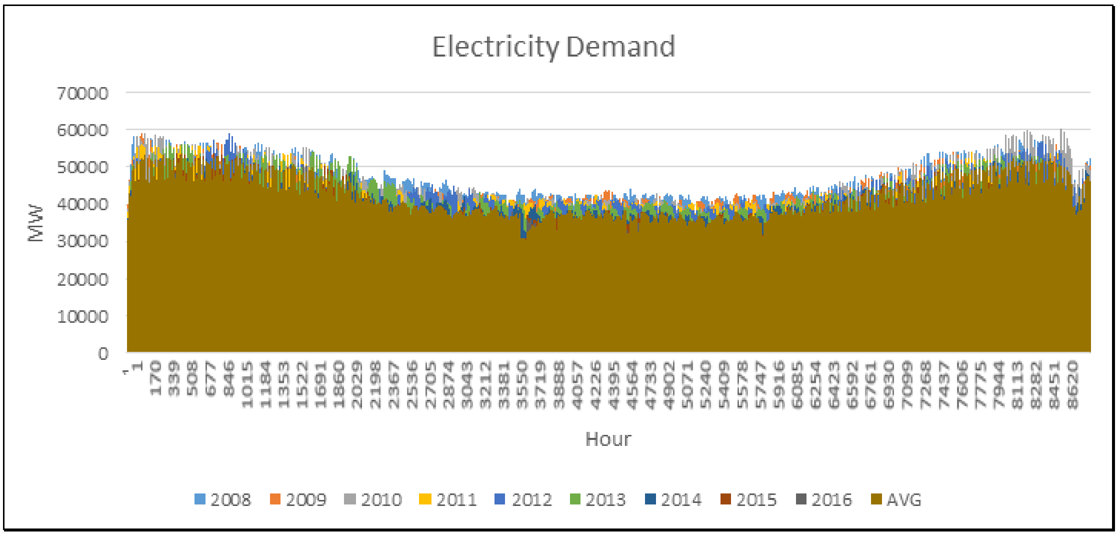


*Figure 3 UK electricity demand data*

From above figure which represents the UK electricity demand from 2008 to 2016, it has shown that the trend of UK electricity is similar. Overall, the electricity consumption is around 50000 to 60000 MW from hours 1-1600 and 7500- 8784 which greater when compared to the rest of the year. Because it is winter time, most of the people stay inside the building and might use electricity for heating also. And the electricity consumption will drop to 30000-40000 MW in middle of the year which represents to the summer. Moreover, when analyzing into 24 hours basis. It has found that the electricity demand is lowest around 8 AM and climb to the peak around 8 PM of every day. In summary, the average value of this graph will use in simulation as electricity demand distribution data. By using the following equation.

$$\% \text{ Of electricity use at one time} = \frac{\text{Electricity use at one time (MW)}}{\text{Maximum of electricity use over the year (MW)}}$$

After that use the value of % Of electricity use at one time to create the demand distribution and use as input in modelling program. The shape of this distribution has been shown in figure 4.

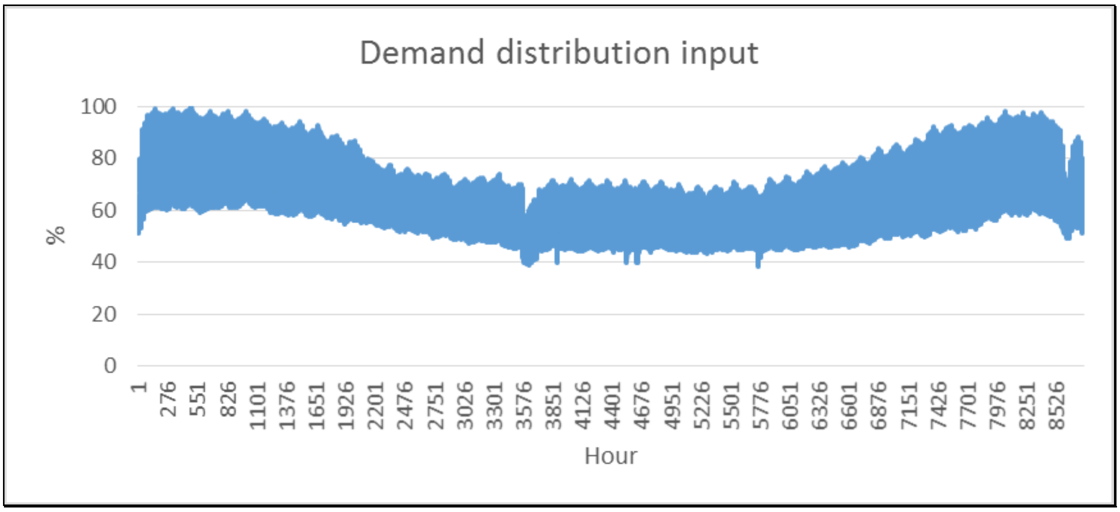


*Figure 4 Demand distribution input*

### 2.1.2 Wind data

In order to get wind distribution curve it has to put in term of capacity factor of the wind turbine but the raw data which come from Data Explorer of National Grid (2017) is not in term of capacity factor but they are in term of embedded generation and installed capacity so the capacity factor of the wind has found by the following equation:

$$\text{Capacity factor} = \frac{\text{Embedded generation}}{\text{installed capacity}}$$

From above equation, the capacity factor in every hour from 2008 to 2016 of UK wind and the average value is plotted as shown in the figure below.

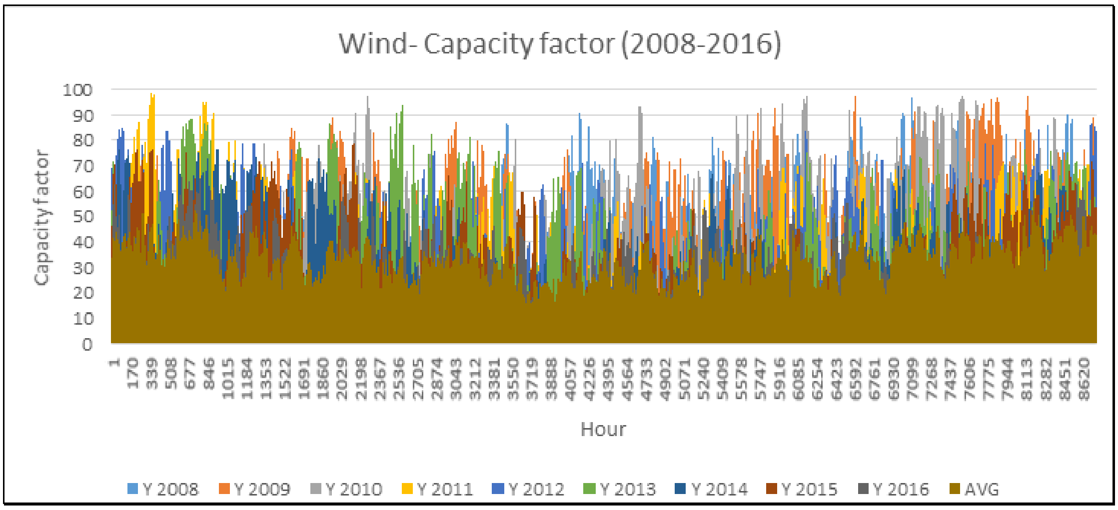


*Figure 5 Wind capacity factor*

However, the average value that comes from the previous figure cannot use in modeling program because it is combined with two type of wind farm which is onshore wind farm and offshore wind farm. Both of them have different whole year capacity factor which is 0.23 for an onshore wind farm and 0.37 for an offshore wind farm (UK department for business, energy, and industrial strategies, 2016). Hence, the average value from the previous graph is used as mean and reference to offset up and down to make the input data for modeling similar as government data as shown in figure 6 below.

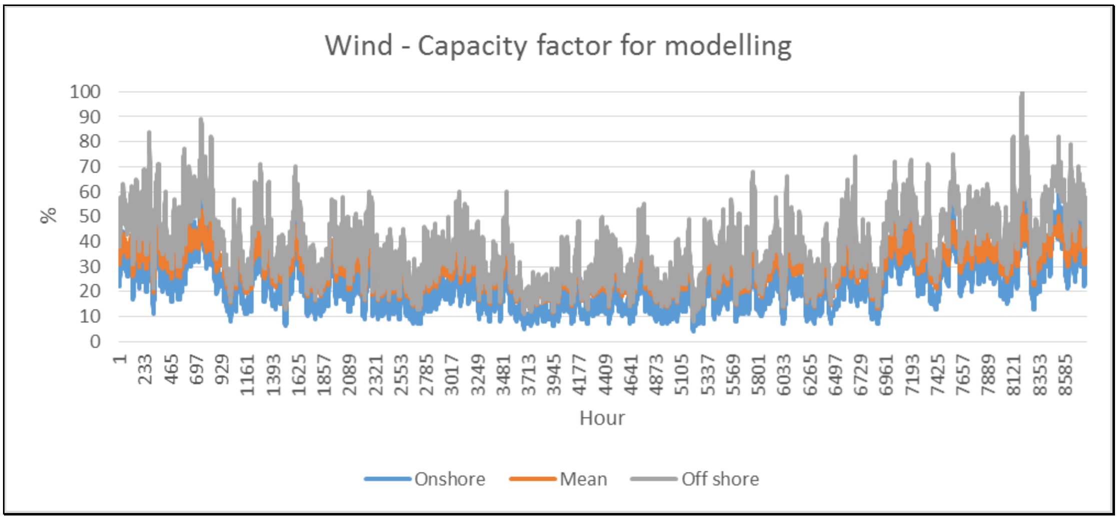


*Figure 6 Wind capacity modelling distribution input*

From figure 6 it has shown that the ability to generate electricity of wind farm very fluctuates. It might reach 100 % in one or two hours and it can drop to 30-40 % in the following hour. Overall, the wind farm is work very well in winter and drop a little bit in summer with similar to the demand curve.

### 2.1.3 Solar PV data

For the solar PV, the method for obtaining the capacity factor is a similar way to the wind farm but not need to offset the value. Only use the capacity equation for each hour from 2011-2016 and average the value. After that use the average value as solar PV distribution for simulation

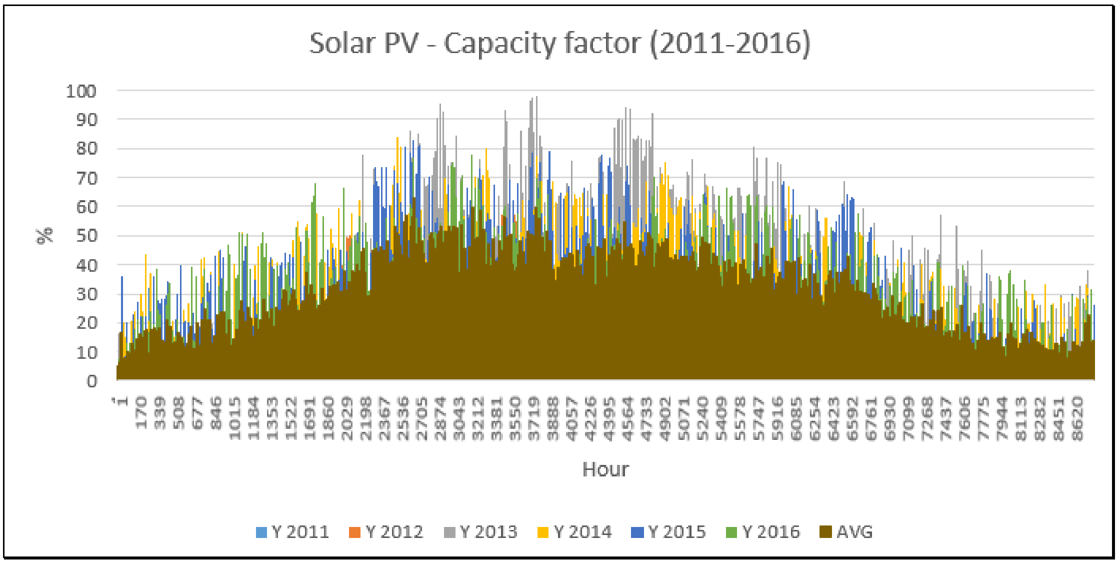


*Figure 7 Solar PV capacity factor*

From figure 6 it has shown that the solar PV will generate well from hour 1500 – 6000 which represents to the summer. During the summer time, it can generate around 50 % of installed capacity. When compared to the rest, the ability to generate might drop to 10 -20 % in winter. Moreover, when analyzing into 24 hours basis. During the winter the PV power plant can operate only 4-5 hours per day. In contrast, during the summer it can operate up to 20 hours per day. From these reasons, the overall capacity factor of solar PV is quite low when compared to other kinds of RES. The overall capacity factor of UK solar PV is around 16 %. The input data which use for modelling is use the average data from year 2011-2016 as showing in figure 8.

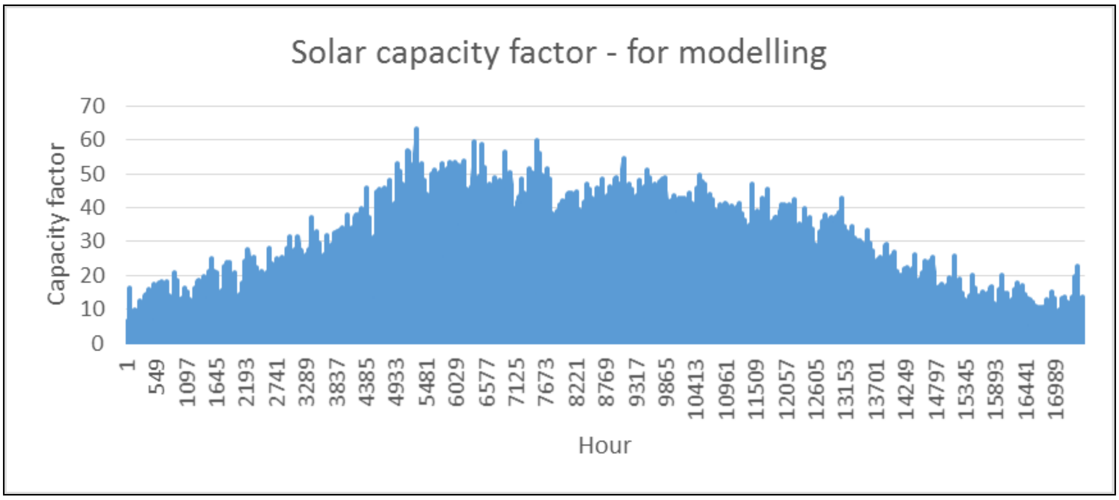


*Figure 8 Solar capacity modelling distribution input*

### 2.1.4 River and large hydro data

For another form of RES, UK government has not published a real time data as wind and solar. But it publishes in term of the capacity factor in every quarter of the year. Hence in this project is use data from UK department for business, energy and industrial strategies (2014, 2016, and 2017) as four point reference and find the average value then line each point together as shown in figure 9 below. Then convert the average line in to set of 8784 number by using excel as shown in figure

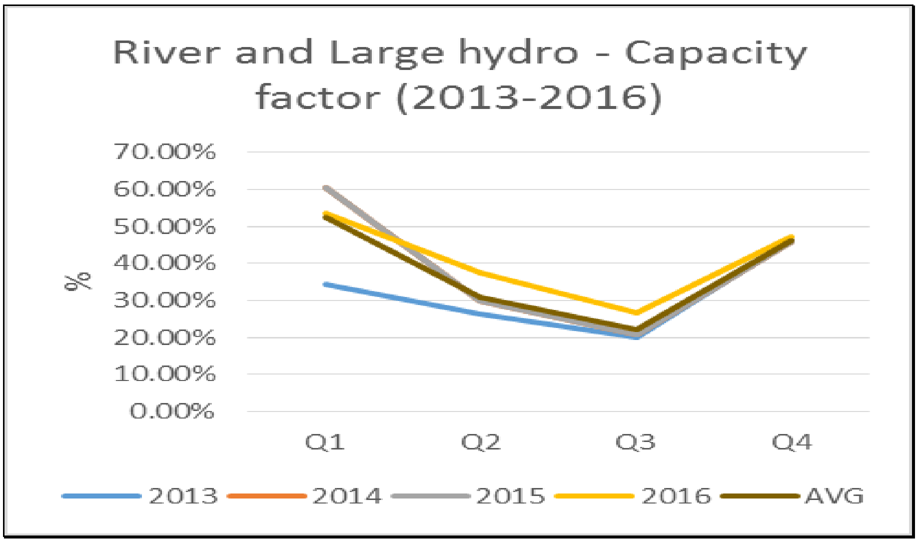


*Figure 9 River and large hydro - capacity factor*

Then convert the average line into a set of 8784 number by using excel as shown in figure 8 for making this data eligible for put in energy plan software.

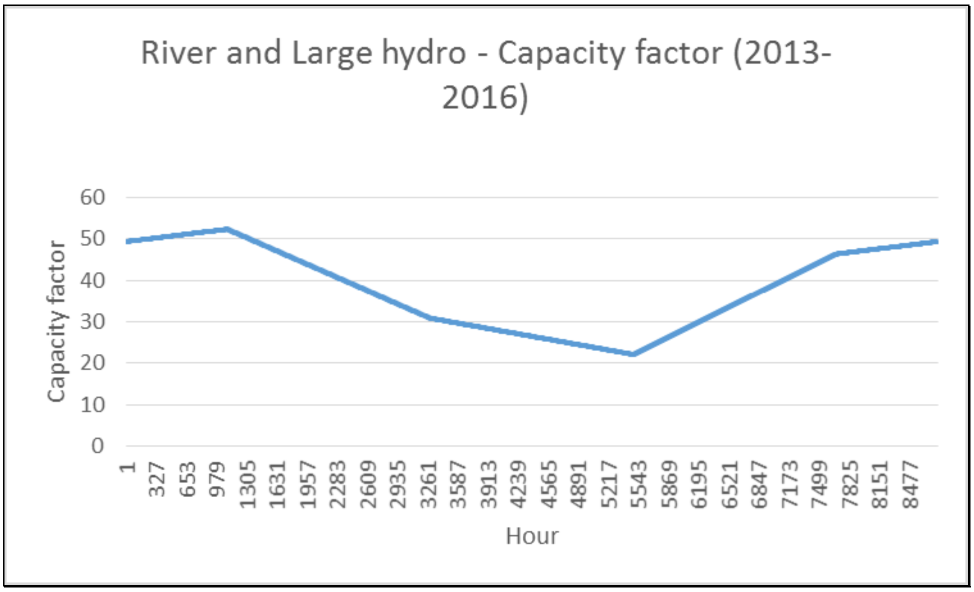


*Figure 10 River and large hydro- capacity factor for modeling*

From figure 8, the main reason of fluctuation of the hydropower comes from the rain. It has shown that the hydro power generates well in the first quarter of the year and drop around 50% in the second quarter of the year. Then still decrease to 22 % in the third quarter of the year and dramatically growth to 50 % in last quarter.

### 2.1.5 Other RES data

For another form of RES is calculate by the same method as river and larger hydro calculation due to lag of real time generation information as mention in chapter 2.1.4. The raw data of other type of RES in each type is showing below.

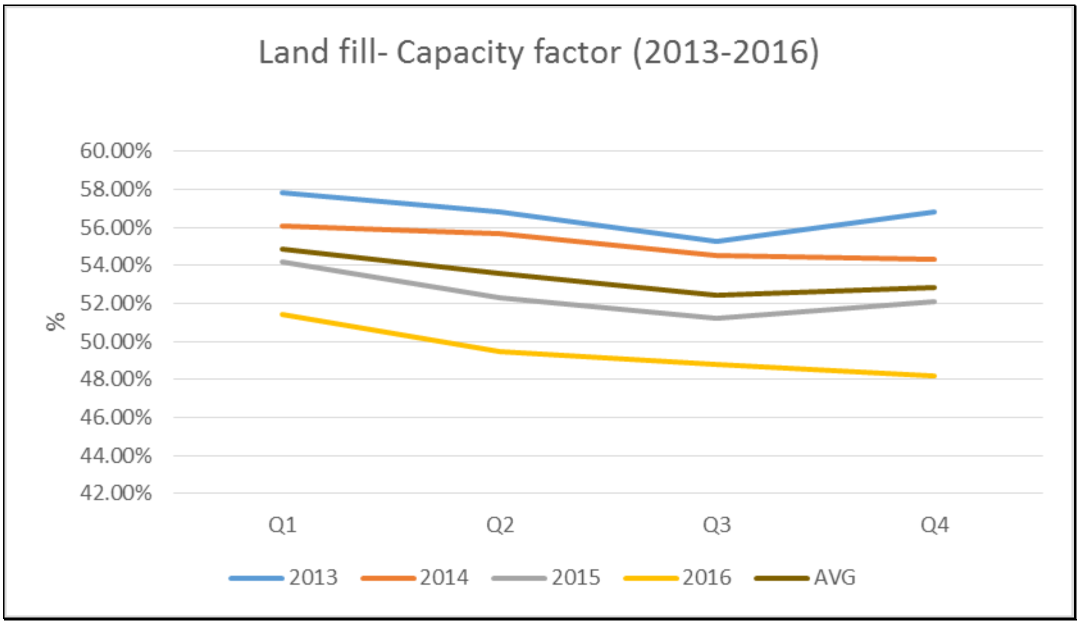


*Figure 11 Land fill - capacity factor*

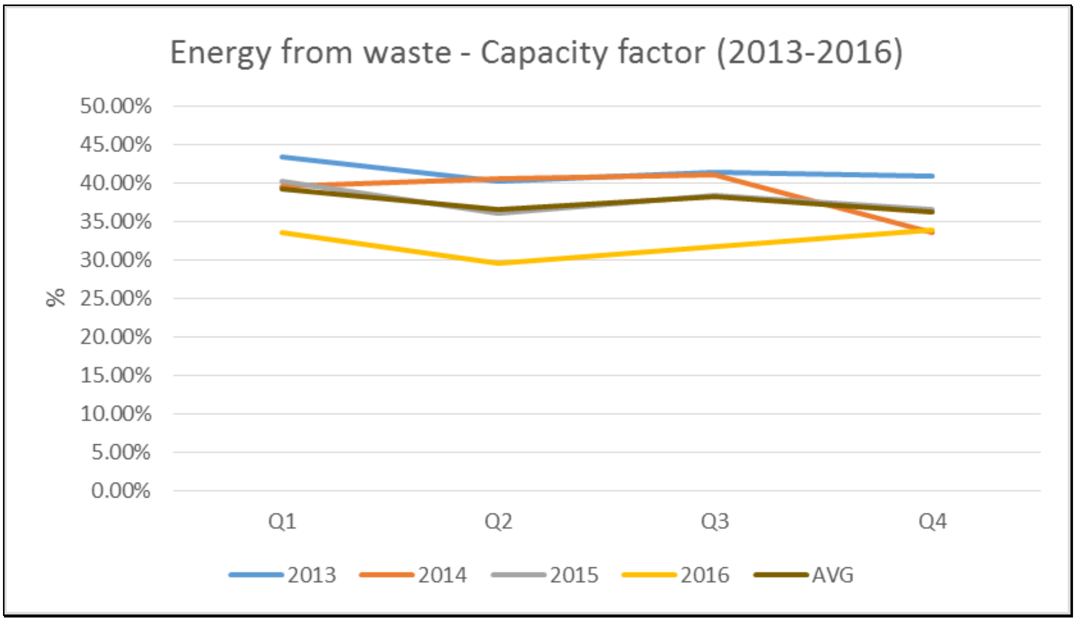


*Figure 12 Energy from waste - capacity factor*

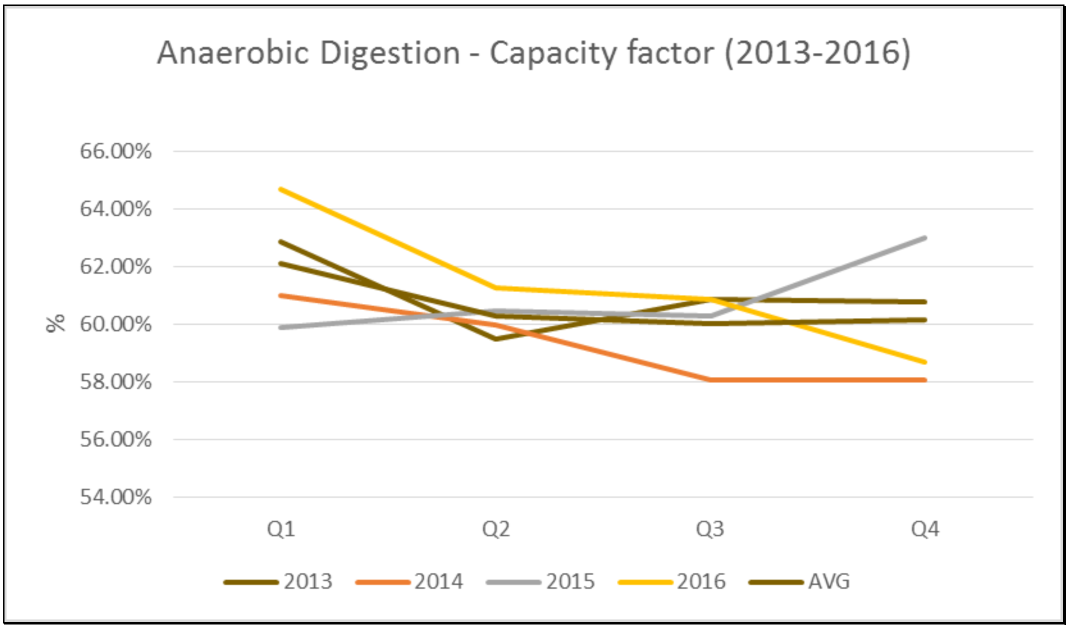


*Figure 13 Anaerobic Digestion- capacity factor*

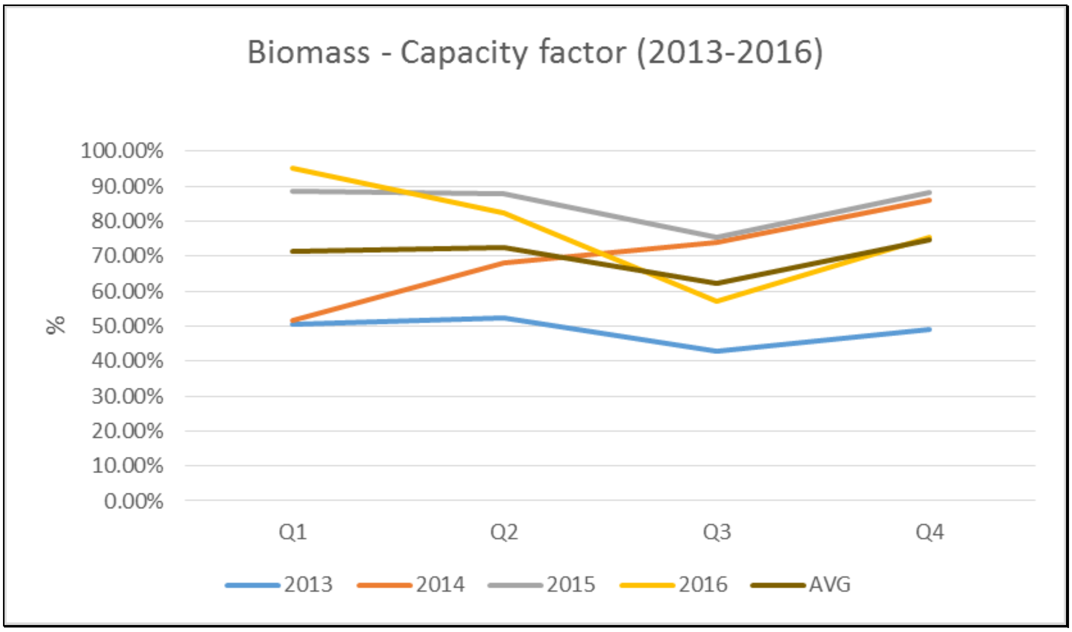


*Figure 14 Biomass - capacity factor*

Then convert all of above average data to set of 8784 numbers same as 2.1.4 then use these sets of number as a distribution of Land fill, Energy from waste, Anaerobic digestion, and Biomass respectively.

### 2.1.6 Non-RES data

For Non- RES data, the other power plant is divided into 2 groups which are Nuclear and Fossil fuel. Both of them have different distribution profile as follow:

**Nuclear** **-** The new clear power plant in modeling is operated 24-7 with constant capacity factor the efficiency that uses for modeling is 33%

**Fossil fuel** **-** In modeling program when all of the parameters have been set. The fossil fuel will run automatically to make demand and supply meet together. But it will also run under grid stabilization condition. In this modeling, the grid stabilization has been set to 0.3 which means 30 percent of electricity supply must come from the central power plant which means nuclear, large hydro, and gas.

## 2.2. Input and simulate model 1

For the first model is run for validating data with 2016 data. Hence the input data of this model has used 2016 government data from UK department for business, energy and industrial strategies (2017).

In 2016, all electricity demand (include loss) is around 352 TWh per year. The hydro storage is around 14 GWh. And the UK installed capacity has shown in figure 13 below.

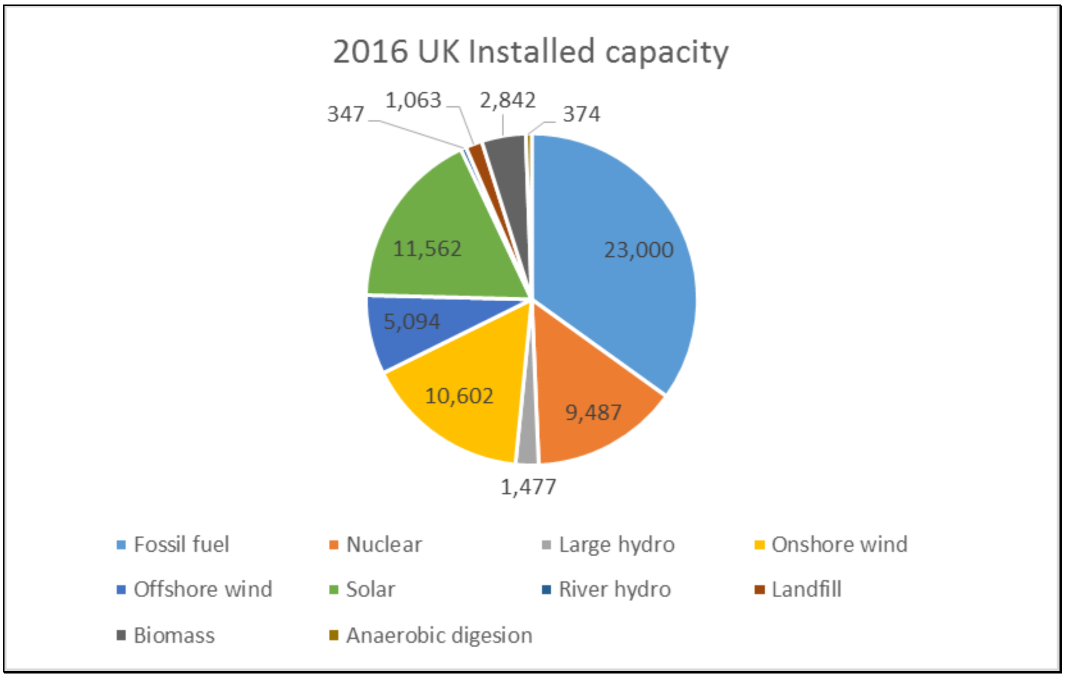


*Figure 15 2016 UK Installed capacity*

Then, use all distribution data which has been made in chapter 2.1 to run the model. The structure of model has shown in figure 13 below.

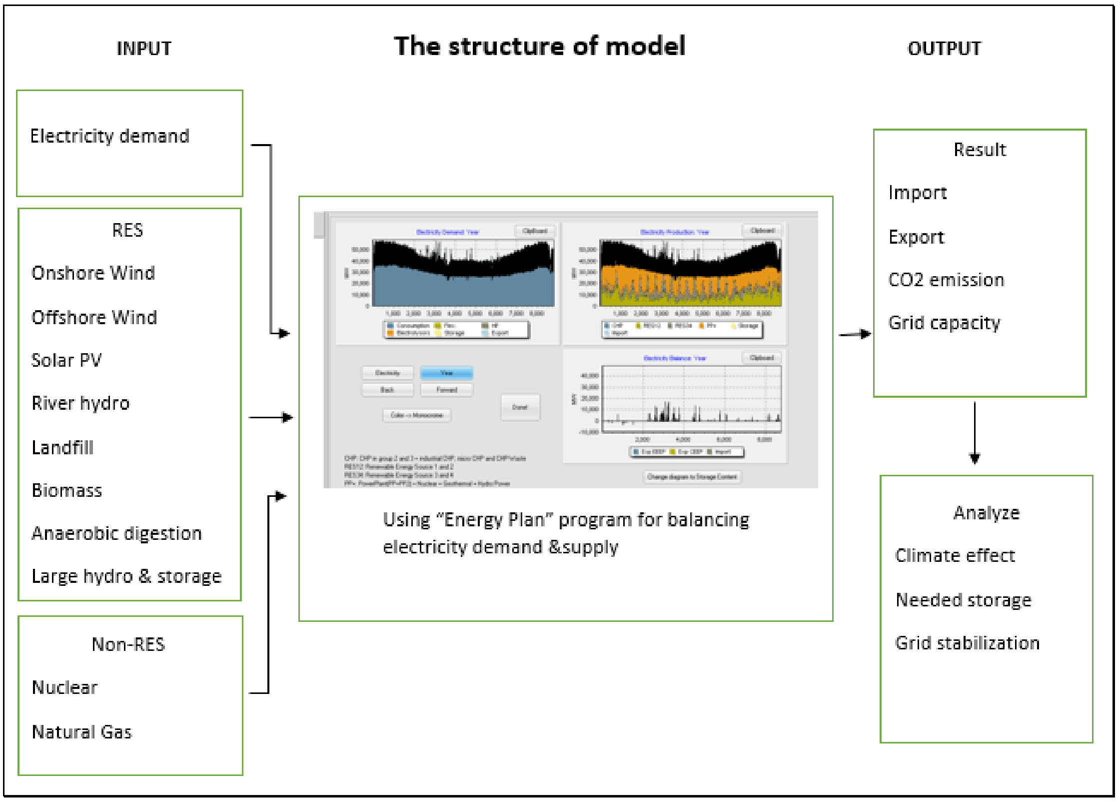


*Figure 16 The structure of the model*

In order to find the result of this project, in this project use the "Energy Plan" software for run the simulation.

## 2.3. Validation

Energy Plan result is come out in 2 from. The first form is a graph type as shown in Figure 15: Electricity production and 16: Import and export of UK in2016.

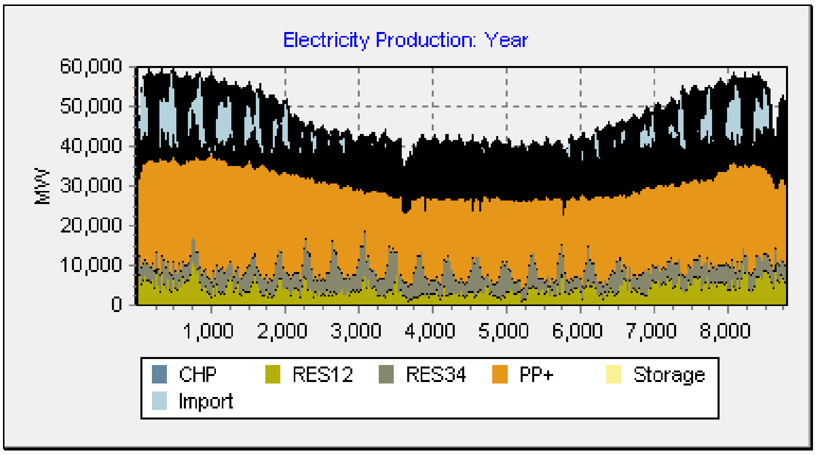


*Figure 17 EnergyPlan graph: 2016 UK electricity production*

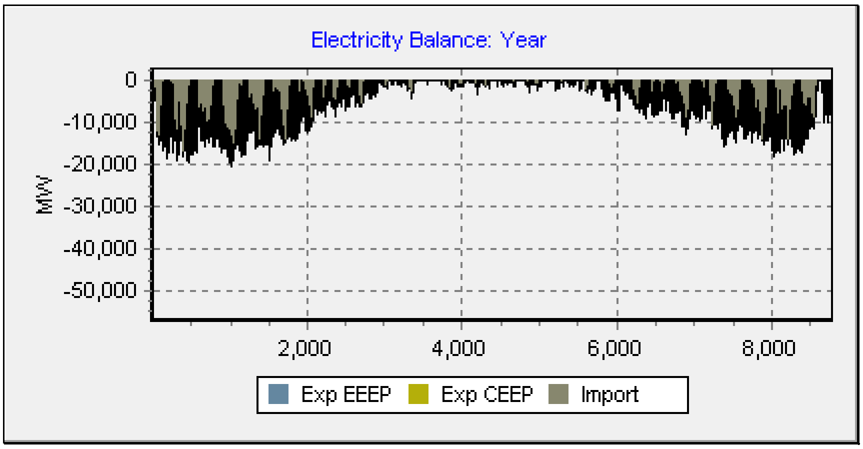


*Figure 18 EnergyPlan graph: 2016 UK Import and export*

But for validation, it has to use the all year summary that shows in a spreadsheet which is another form of result. The comparison of government and simulation data will show in following figure.

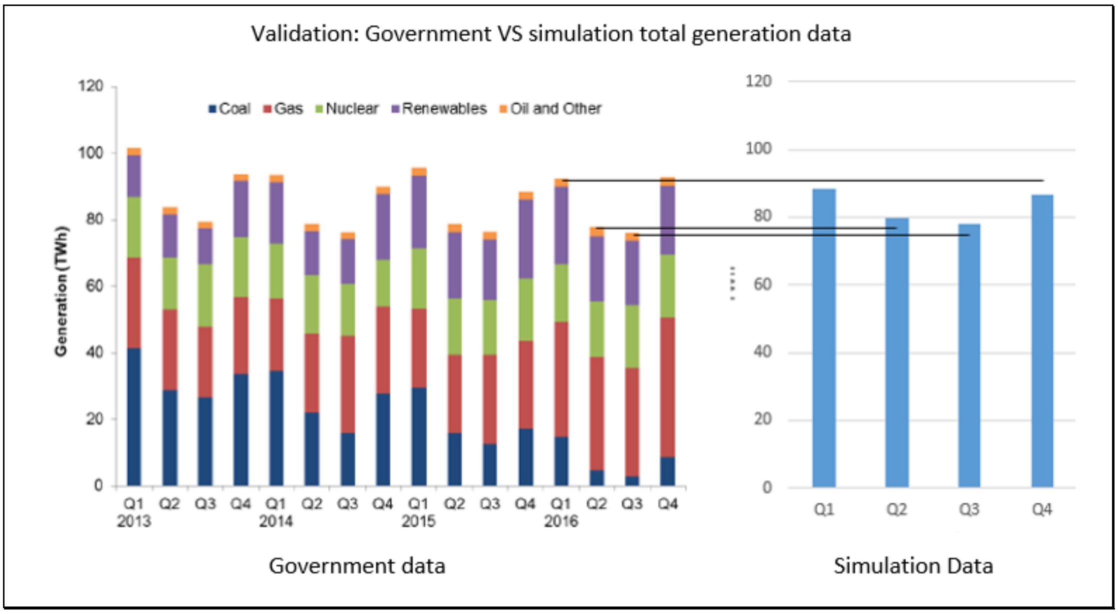


*Figure 19 Validation Data: Simulation VS Government generation data*

In this part is trying to compare the result from energy plan and government data. The government data that use for this comparison comes from the Energy trends July 2017 document (UK department for business, energy and industrial strategies, 2017). From above figure is show that both of them have similar trends in term of electricity generation. But the first and last quarter of the year the amount of the electricity production from government data is greater than the simulation. In contrast, the second and third quarter the value of simulation is greater than the government data. The reason of this error comes from the input distribution of the stimulating program. Because the input distribution comes from the average value that has shown in the previous topic which not exacts the same value as 2016 data. For an overall summary of Simulation result and government data will show in the following figure.

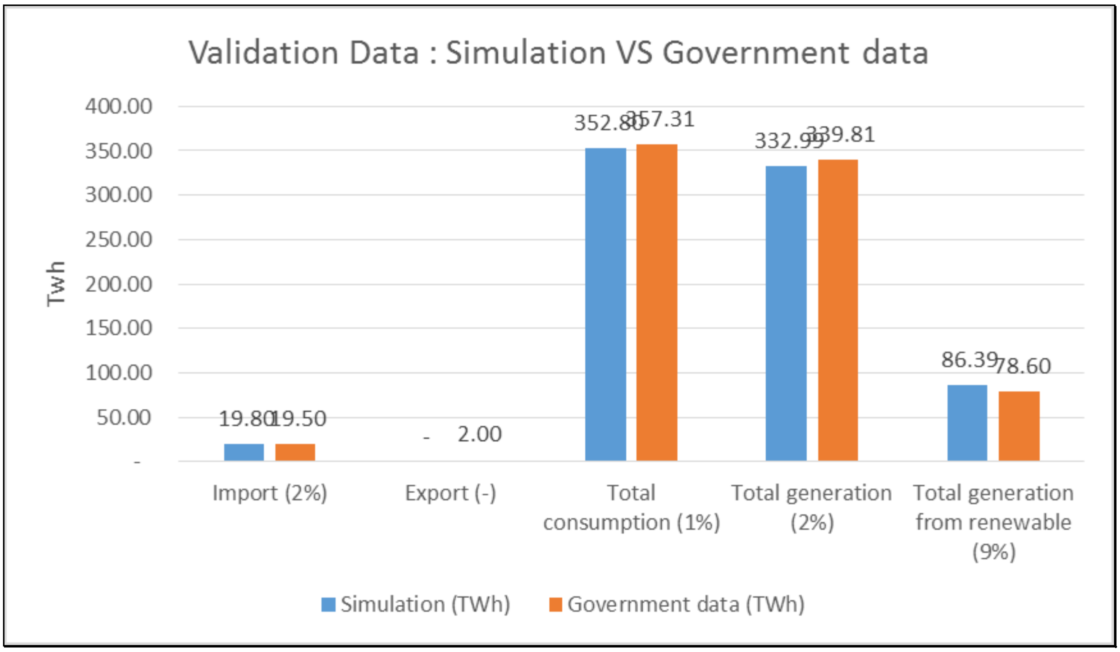


*Figure 20 Validation Data: Simulation VS Government data*

From figure 20 it has shown that the error of all data is less than 10% except the export data. The reasons that in the simulation has no export because of 2 reasons. The first reason is that of all distribution come from average data for many years as explain in the previous part. Hence, sometimes it has a less high capacity factor at a time when compared to each year. For example, in one point of wind generation in 2016 has operated with 100% load but at the same time in 2014-2015 is operate only 70-80%. Hence when taking this average data to the simulation. The 100% capacity factor might not occur. Therefore it will effect to export and generation value. The second reason is in reality, sometimes the UK have to export electricity which generates from fossil fuel for politic and economic reason (UK department for business, energy and industrial strategies, 2017). Therefore, the export value might have some error.

## 2.4. 2030 Scenarios

In this project, the 2030 UK scenarios are classified into 4 groups which are Gone green, Consumer Power, Solow Progression, and Steady state. By using future energy scenarios from national grid documents (2015, 2016, and 2017) and Pathways for the GB Electricity sector to 2030 from Energy-UK (2016) as references.

Here is the information to classify each scenario by using 5 factors which are economic, political, technological, social, and environmental.

**Gone green - ** This scenario is a world that green aspiration is not limited by financial issues. More effective technologies are embraced and introduced by society.

- Economic - Moderate growth.
- Political - Have long term environmental energy policy.
- Technological - Increased focus on all green innovation.
- Social - Social activity support the green technology.
- Environmental- Ensuring that all renewable and carbon target are achieved.

**Consumer Power -** This scenario is represented to a world of relative wealth, fast develop and research to meet the customer needs for improving their life quality.

- Economic - Moderate growth.
- Political - Focus on lowering the carbon emission.
- Technological - - High level of local generation (especially solar PV).
- Social - Focus on quality of life.
- Environmental- Focus on carbon target but more relax than Gone green

**Slow progression-** This scenario presents a poor economic situation but tries to spend money on low-cost long-term solutions to achieve the carbon target.

- Economic - Slow growth.
- Political - Focus on low-cost environmental energy.
- Technological - Medium level of all innovation.
- Social - Limited choices by cost but support green technology.
- Environmental- Focus on carbon target but constrained by affordability.

**Steady stage -** This scenario is a word which focuses on only cost and security of supply. Hence, the fossil fuel is playing important role in this scenario similar to nowadays.

- Economic - Slow growth.
- Political - Lack of focus on environmental policy
- Technological - Little innovation for green technology.
- Social - Focus in living cost for here and now.
- Environmental- The attention on carbon target has been ignored.

From above study, the 4 scenarios have been created for represent the possibility of 2030 UK electricity situation. By assume the possible installed capacity of each type of power plant and also predict the possible demand for each scenario. The input data and summaries of all scenarios are present in figure 21 and 22.

| | | Year 2016 | Gone greeen | Consumer power | Slow progression | Steady state |
|---|---|---|---|---|---|---|
| Demand | Electricity (TWh/year) | 352.8 | 363.3 | 347.55 | 333.9 | 338.1 |
| Supply | Installed Capacity (MW) | | | | | |
| | PP2 (GAS) | 23,000 | 27,000 | 32,000 | 29,000 | 36,000 |
| | Nuclear | 9,487 | 13,500 | 13,500 | 13,500 | 13,500 |
| | Onshore wind | 10,602 | 19,000 | 17,000 | 16,500 | 13,500 |
| | Offshore wind | 5,094 | 29,000 | 14,000 | 23,000 | 16,000 |
| | Solar PV | 11,562 | 23,000 | 28,000 | 17,500 | 12,000 |
| | Large hydro | 1,477 | 3,229 | 1,683 | 2,920 | 1,477 |
| | River hydro | 347 | 759 | 395 | 686 | 299 |
| | Landfill | 1,063 | 2,324 | 1,211 | 2,101 | 915 |
| | Biofuel | 2,842 | 6,213 | 3,239 | 5,618 | 2,445 |
| | Anaerobic digestion | 374 | 818 | 426 | 739 | 322 |
| | Demand (TWh/year) | 352.8 | 363.3 | 347.55 | 333.9 | 338.1 |

*Figure 21 Data of 2030 Scenarios - Installed capacity and annually demand*

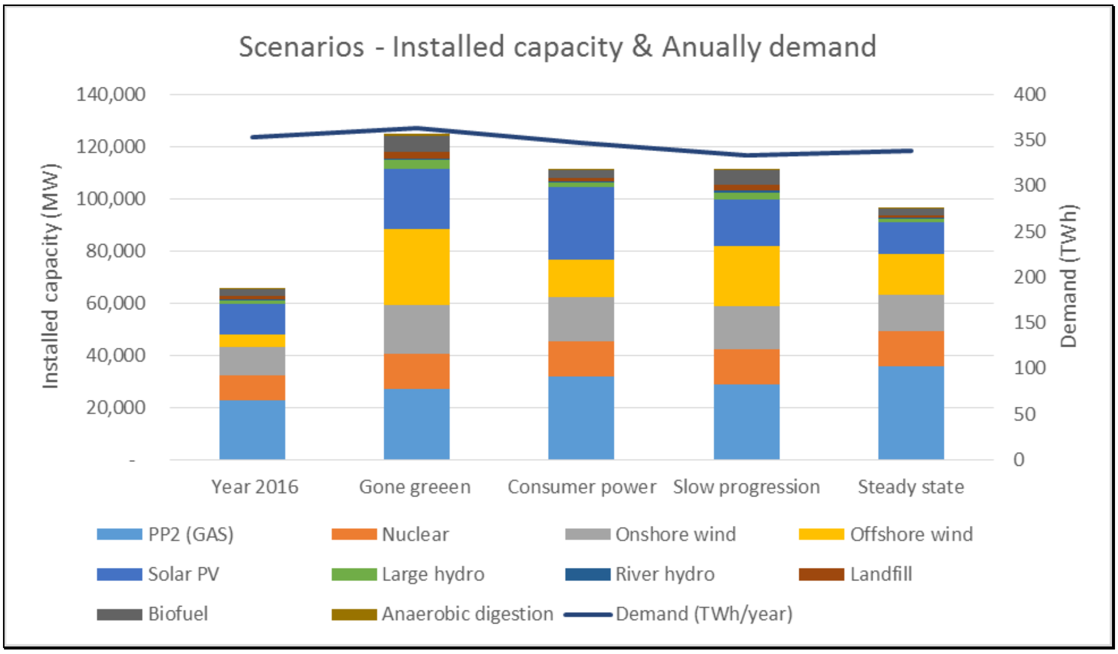


*Figure 22 2030 Scenarios - Installed capacity and annually demand*

From above figure, it has shown the capacity mix and annually demands in 2016 and four possible 2030 UK electricity situation. In Gone green scenario, the amount of gas is similar to 2016 situation but the size of new clear is increasing to 13500 MW due to the Energy department plan (Energy-UK, Ibid) for every scenario. The size of the offshore wind farm is increasing around 6 times and double the rest renewable installed capacity when compared to 2016. For the demand part, in this scenarios have highest electricity demand due to EV car and electrification for heating. In Consumer power scenarios, due to focus on local generation, the largest renewable installed capacity is from PV roof top which should increase around 2.5 times but the rest type is increased by 15-50% when compared to 2016. In Slow progression scenarios, due to focus on cost and carbon target, hence the most amount capacity factor for the green generation which is offshore wind farm is the best option. Therefore, the installed capacity of the offshore wind farm is increasing 4-5 times but the rest type is also increasing around 10-90% depends on the type of energy. Moreover, the demand in this scenarios is also smallest compared to all scenarios because of the economic problem. Lastly, the steady state scenarios. Steady state scenarios are not mean the same amount of installed capacity as the present. But it means fossil fuel plays a really important row for the electricity system. In this scenarios, the only one type of renewable supply that plan to build more is the only offshore wind farm. In contrast, the rest of renewable supply might be increase or decrease around only 20% due to unwell maintenance and expansion of existing size only. From this reason in this scenarios have to have the biggest fossil fuel power plan when compared to the rest.

# 3. Result & Analysis

In this chapter will show the result of 4 scenarios simulation and try to state the problem of each scenario by observing the 3 days in different seasons. In the following graph will show overall demand and supply of each scenario.

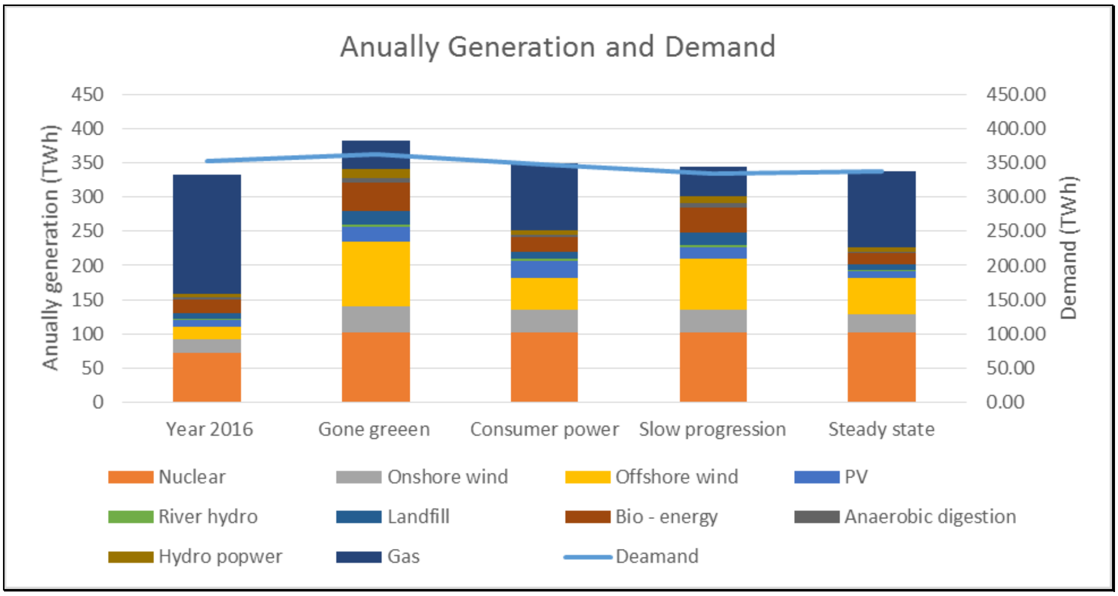


*Figure 23 Annually generation and demand*

From above figure, it has shown that in 2016 the net import of UK is around 18 TWh which means UK electricity relies on the import of other countries. In other words, the UK has low level of security of supply. When compared to the 2030 scenarios, all of them have no net import problem. All of them can export electricity by using interconnection grid more than import. Especially in Gone green scenario, the net import is around 30 TWh/year. For the Consumer power, Slow progression, and Steady stage the next export is 1, 10, and 0.2 TWh/year respectively.

## 3.1. Grid interconnection capacity

From the previous figure which shows that in 2030 scenarios. The UK can produce electricity more than consumption demand. Hence, the UK can sell this electricity to other countries through the international grid connection. Therefore the surplus &deficit energy has to be observed as shown in figure 24 to find the minimum size of interconnection to carry these energies as shown in figure 25.

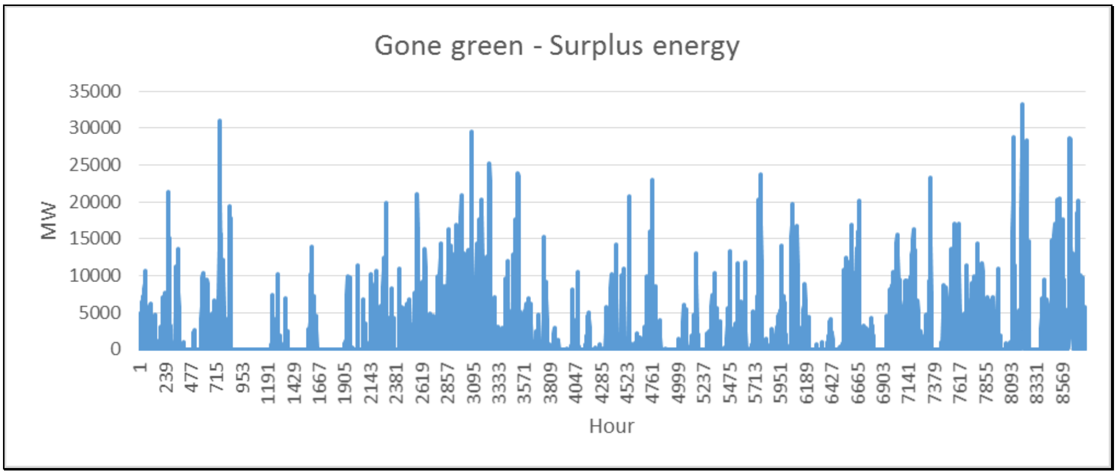


*Figure 24 Gone green - surplus energy*

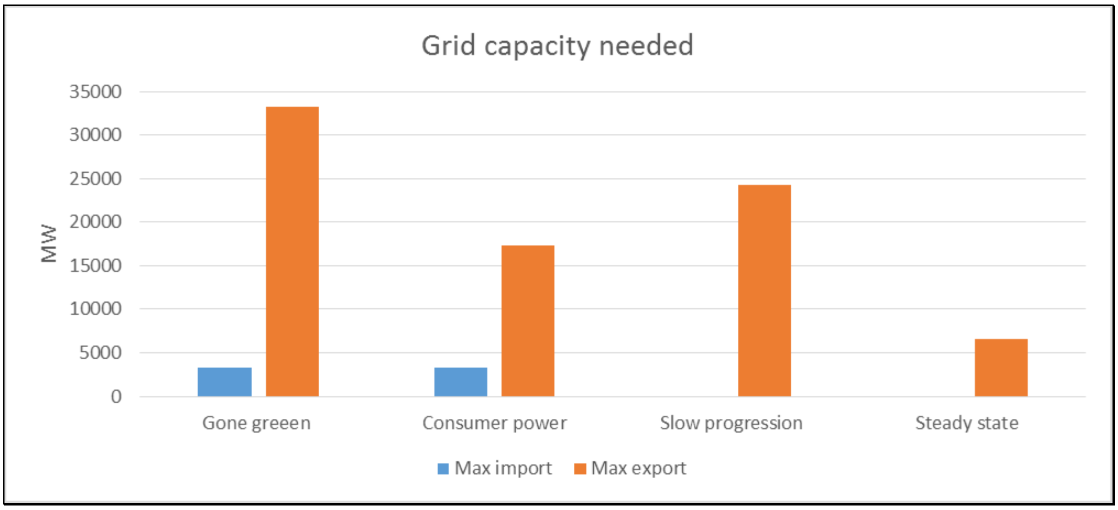


*Figure 25 Minimum Interconnection size*

From figure 25 it has shown that the Gone green and Consumer power needs some import. The reason will show in chapter 3.3.

## 3.2. Carbon emission

For environmental perspective, the carbon emission has to observe. Because it is the major cause of global warming problem. The figure below shows the amount of carbon emission in Mt/year.

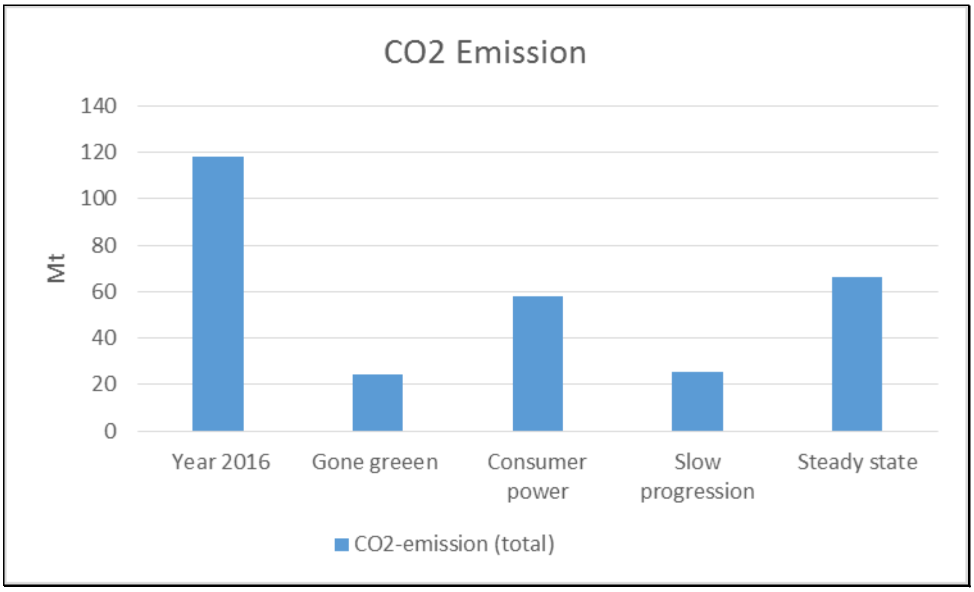


*Figure 26 Carbon emission*

From above figure, the amount of carbon of all 2030 scenarios will be smaller than 2016. The carbon emission of Gone green, Consumer power, Slow progression, and Steady state are 24.48, 57.86, 25.35, and 66.33 respectively. The result of carbon emission is also a direct variation with the using of fossil fuel which shows in figure 23. From this reason, the Steady stage scenarios that rely on fossil fuel has the largest amount of carbon emission among all 2030 scenarios. But the Consumer power scenarios which try to engage people to use green energy still have the similar carbon emission level as the Steady stage. The reason that why Consumer power scenario has really high number when compared to Gone green and Slow progression will show on the following topic.

## 3.3. Depth analysis

In this part will try to analyze the result from energy plan by observing every 2030 scenarios to find the reason that why Gone green and Consumer power have to import as shown in figure 25. And why the consumer power has high level of carbon emission same as Steady stage scenarios as shown in figure 26. Moreover, in this analysis is also looking for other possible problem of the UK electricity grid.

The depth analysis uses the spread sheet data result from EnergyPlan to plot a graph and observe the problem. The length of timing that observes in this analysis is 72 hours or 3 days. These are the reasons and information of observation period:

- February: Using data from hour 957 to 1031, the reason that picks this month to observe because in this month the ability of the wind and solar PV generation is lowest among 12 months.
- May: Using data from hour 3100 to 3174, the reason that picks this month to observe because in this month the ability of solar PV generation is highest among 12 months.
- December: Using data from hour 8186 to 8260, the reason that picks this month to observe because in this month the ability of wind generation is highest among 12 months.

From above reason, all of the scenarios have been plot to observe the problem as shown in figure 21 to 34

**February ( hour 957 to 1031)**

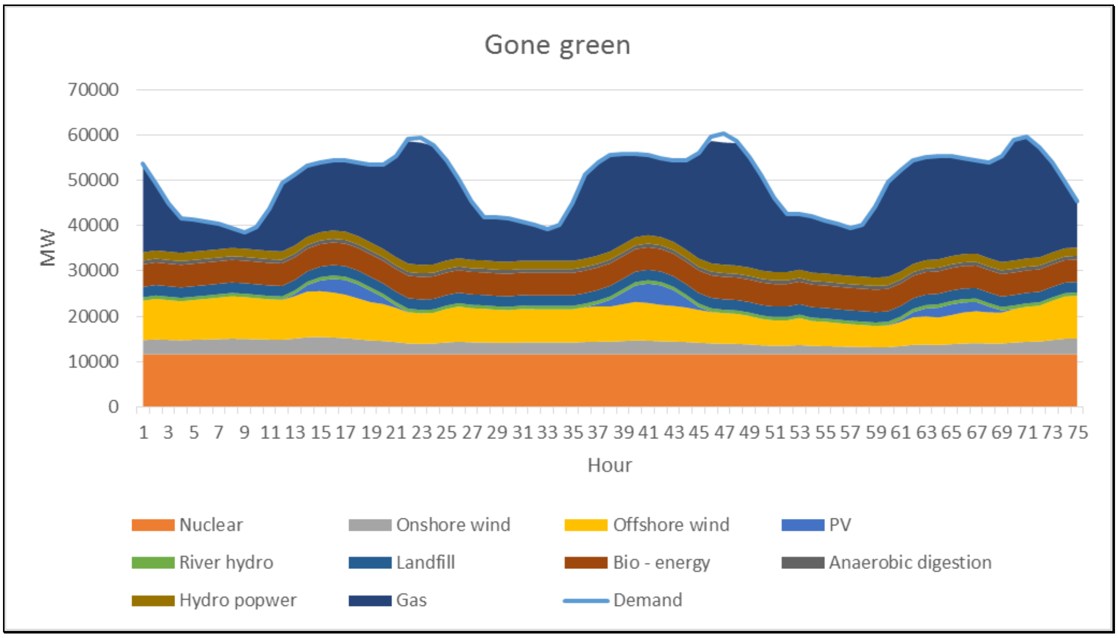


*Figure 27 February - Gone green*

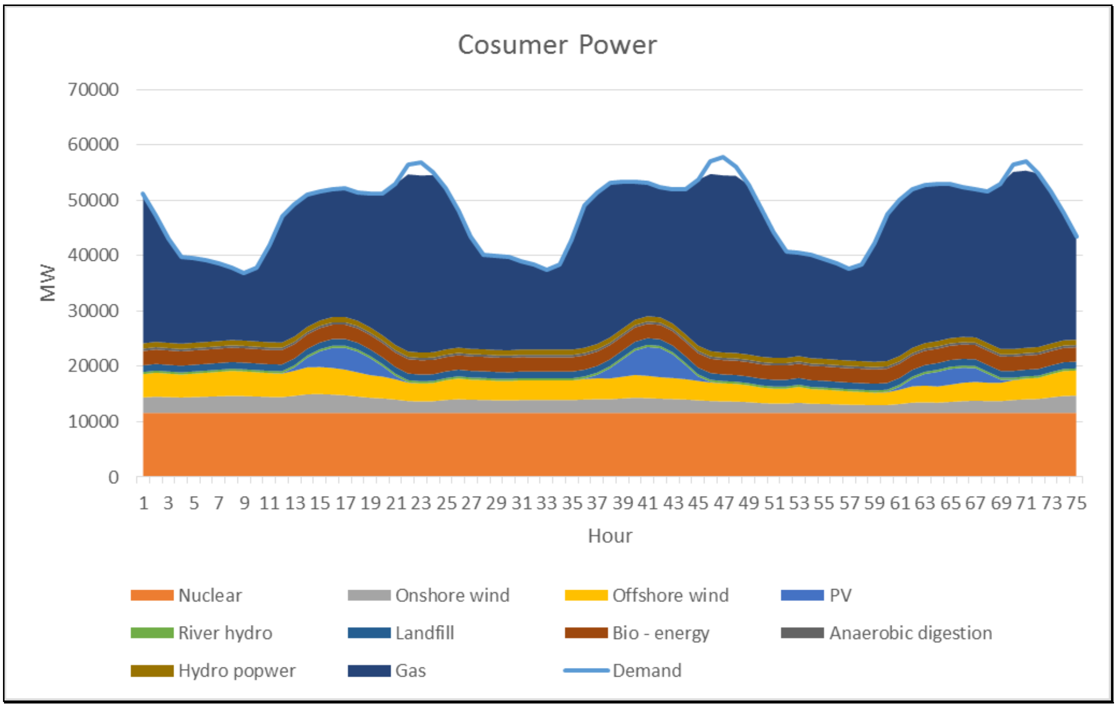


*Figure 28 February - Consumer Power*

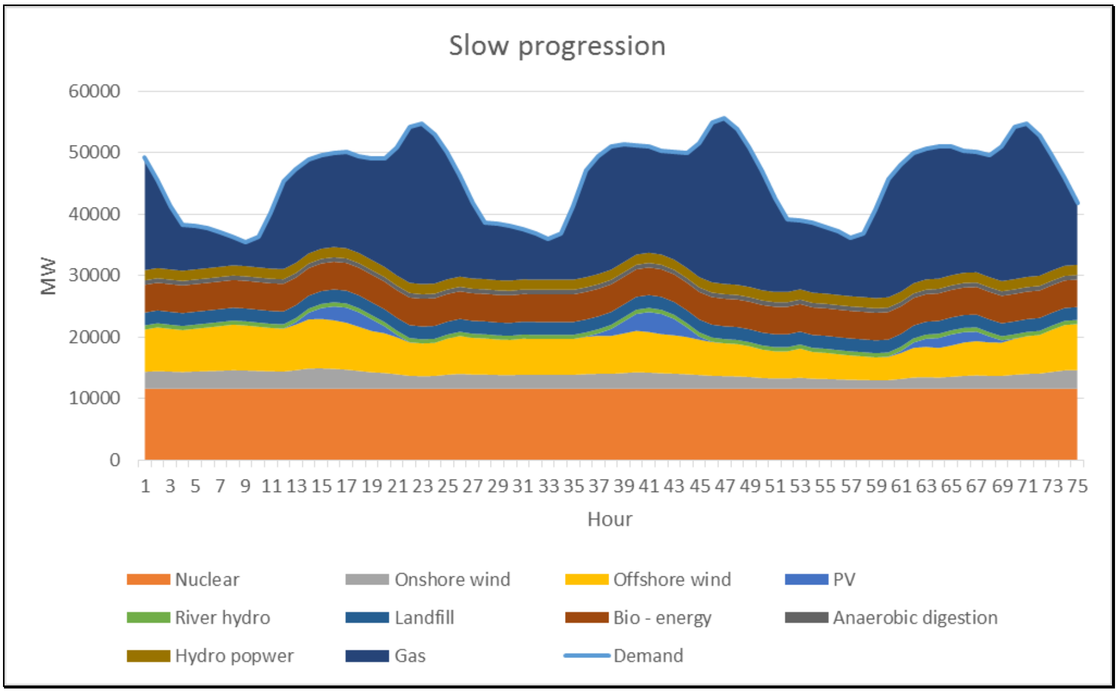


*Figure 29February - Slow progression*

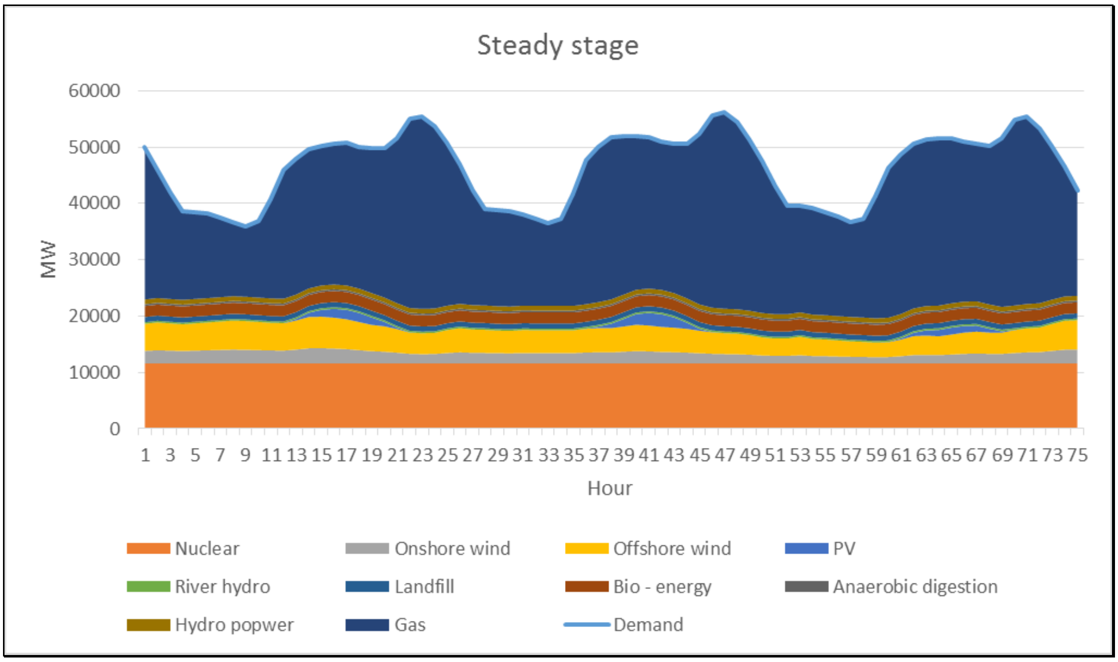


*Figure 30 February - Steady stage*

**May ( hour 3100 to 3174)**

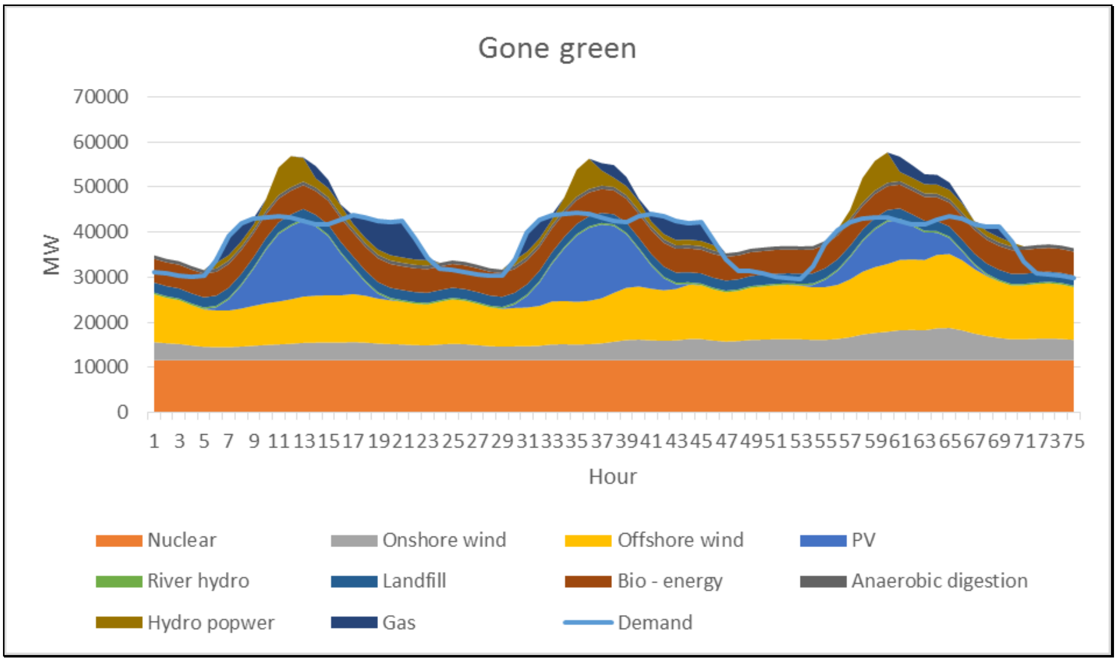


*Figure 31 May - Gone green*

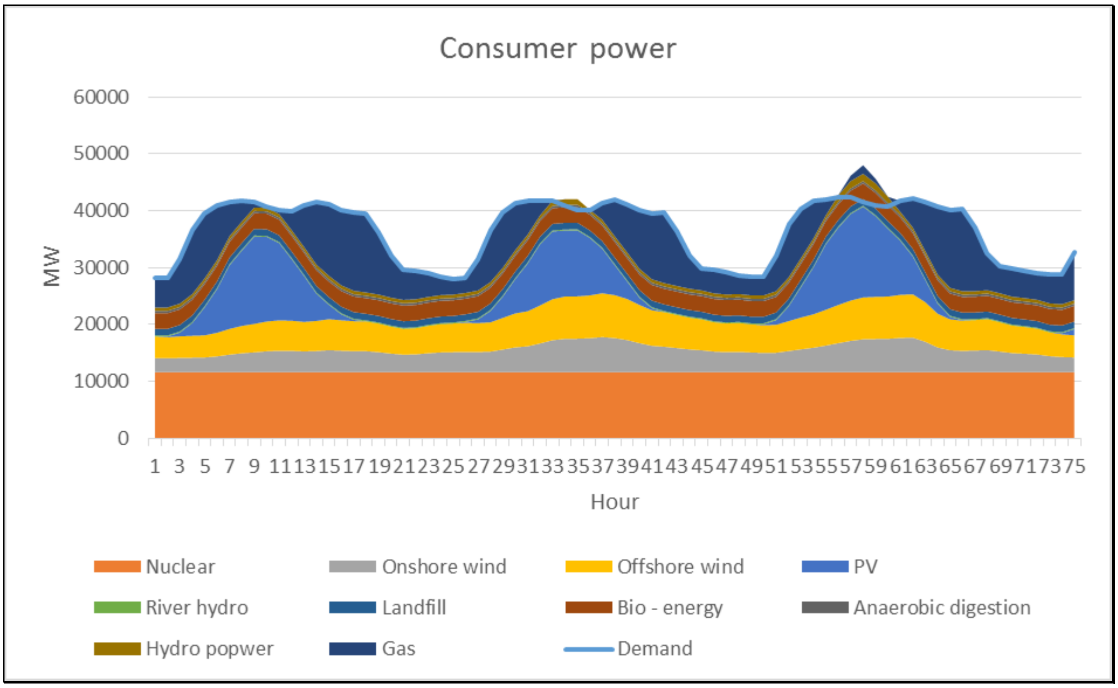


*Figure 32 May - Consumer power*

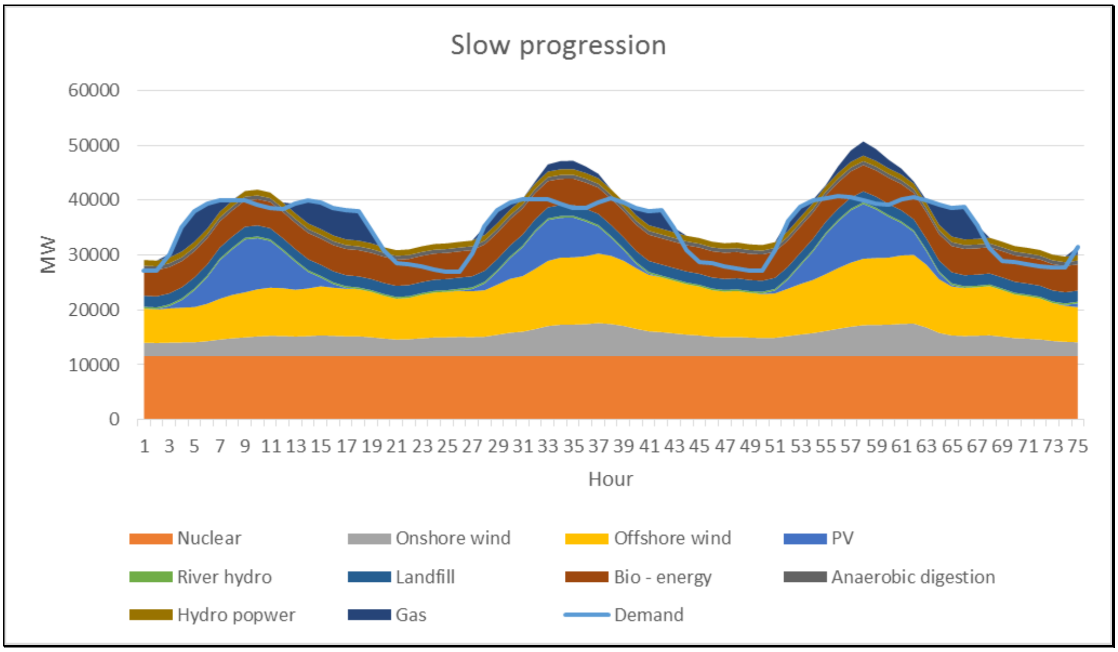


*Figure 33 May - Slow progression*

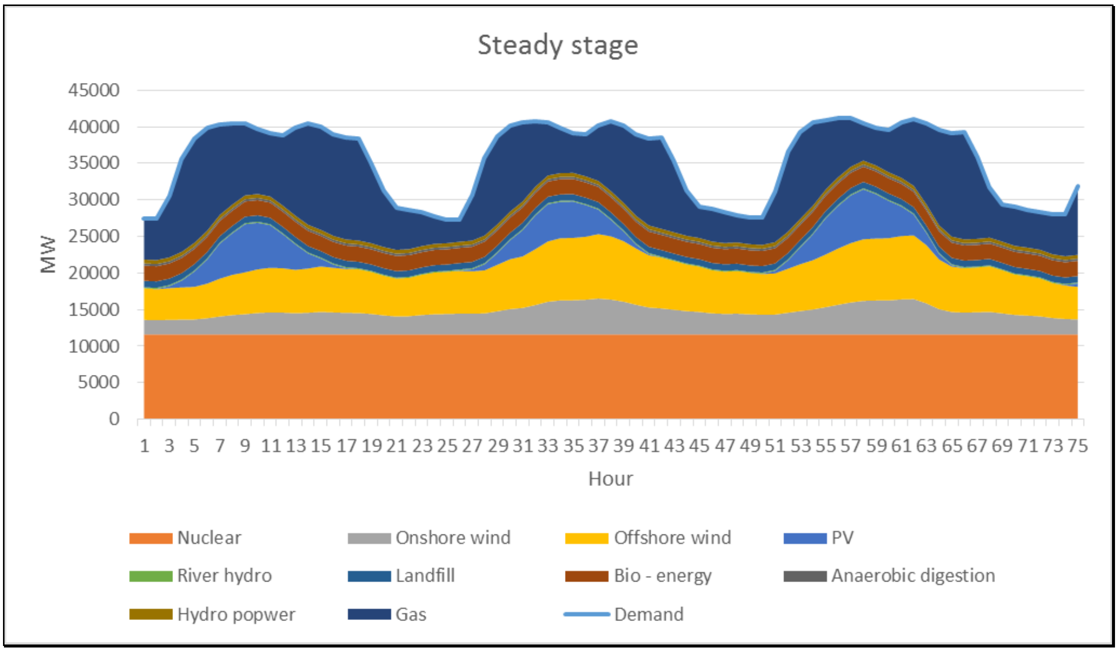


*Figure 34 May - Steady stage*

**December ( hour 8186 to 8260)**

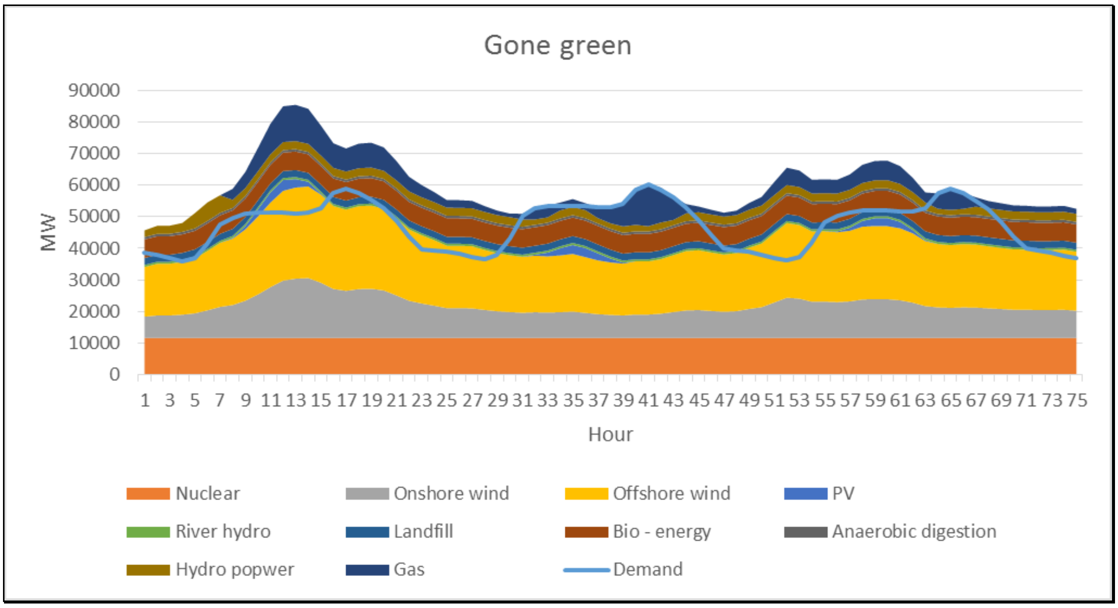


*Figure 35 December - Gone green*

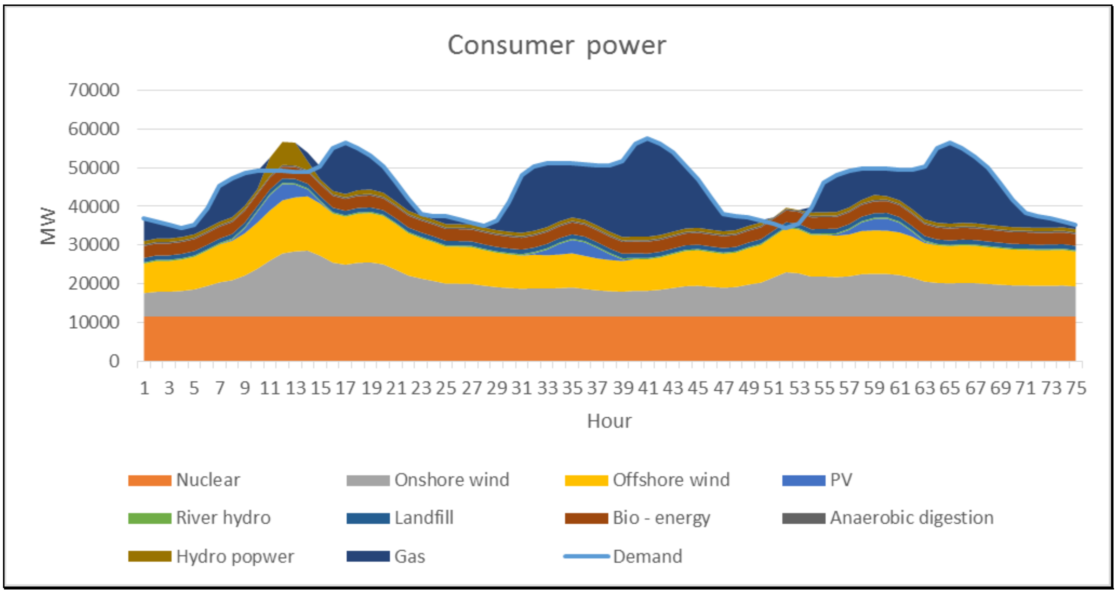


*Figure 36 December - Consumer power*

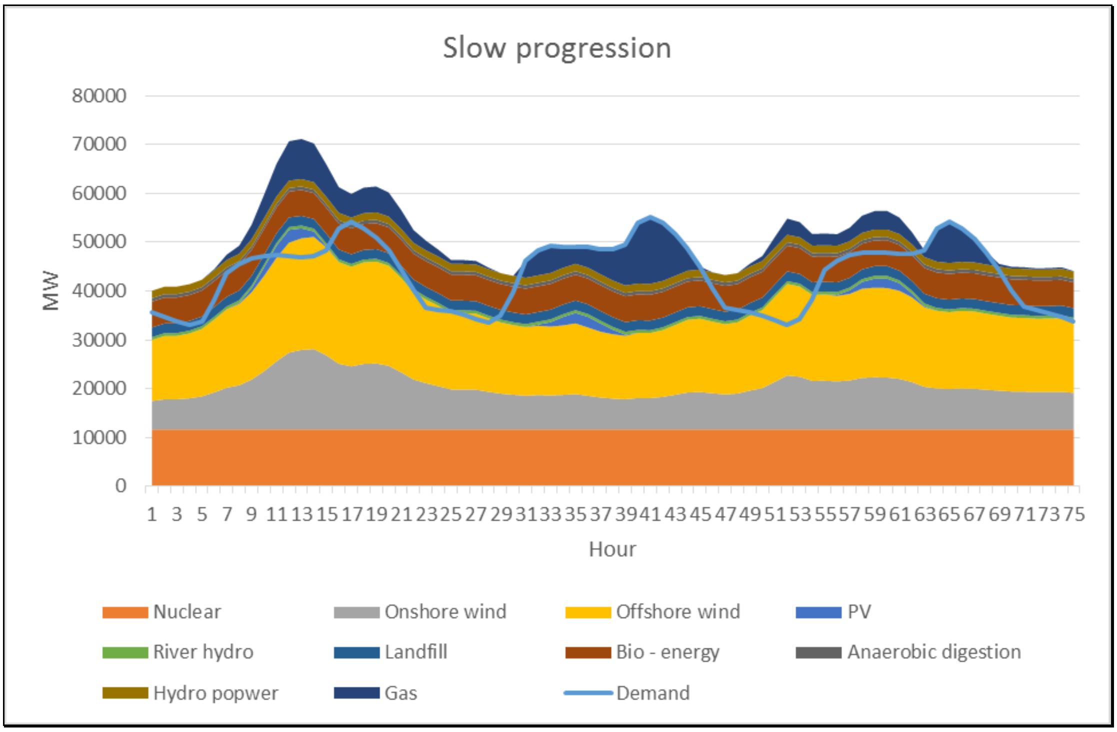


*Figure 37 December -Slow progression*

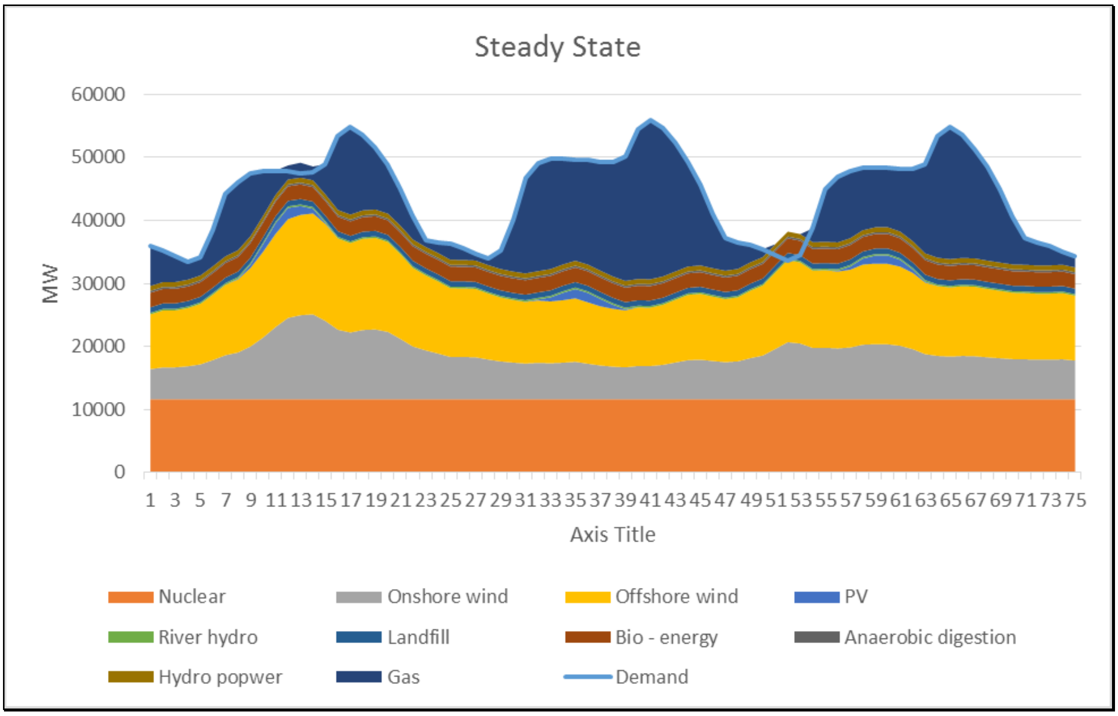


*Figure 38 December - Steady stage*

From figure 27 to 38 which show the depth analysis of 3 different months, these are the discussion of depth analysis.

- February: In this month is the worst month for clean energy such as the wind and solar. As from figure 6 and 8 which represent the capacity factor of the wind and solar PV generation. It has shown that from hour 745 to 1440 of simulation (which represent to February), the capacity factor of both types is drop in similar time. Therefore, the overall supply will drop to the critical value. Moreover, when compared to demand side which shows in figure 3.The demand side of this month is around 50000 to 60000 MW which is quite high. From these reasons, the situation that the electricity supply does not match demand might occur as shown in figure 27 and 28. In Gone green scenario, the electricity relies on renewable and the Consumer power, the electricity relies on solar PV. Hence, when the renewable supply cannot produce the electricity match to the demand both scenarios have to import some electricity from other countries by using the interconnection grid as shown in figure 25. In contrast, the Slow progression and Steady stage scenarios don't have this problem. Because although in Slow progression scenario wants to use renewable energy but it has an economic problem the proportion of the conventional power is still high same as Steady stage scenarios. Hence, when lag of the renewable supply. The fossil fuel can run to meet the demand as shown in figure 29 and 30.

- May: In this month is the best month for solar PV. As from figure 8 which represents the capacity factor of solar PV generation. It has shown that from hour 2905 to 3648 of simulation (which represent to May), the overall capacity factor of solar power in this month is really high. Therefore the ability to generate electricity during the day of this month might over the demand as shown in figure 31, 32, and 33. In Gone green scenario, the electricity supply is over the demand during the day time due to solar PV and wind. In this case, the excess electricity can export to other countries as it supposed to. The interesting point is the Consumer power and Slow progression scenarios. Although the Consumer power relies the electricity on solar PV and the amount of solar PV electricity supply is more than the Slow progression scenario. But overall the excess electricity is less than Slow progression scenario. The reason has come from the installed capacity of another type of renewable. Because although the Slow progression scenarios less solar PV power generation. But in this scenario, another type of green generation is greater than Consumer power scenario. Therefore, the overall generation performance of Slow progression scenarios is greater than Consumer power even in summer time. Lastly, in steady stage scenarios, in this state still have to use conventional generation to supply the deficit energy from green energy supply.

- December: In this month is the best month for wind power. As from figure 5 which represents the capacity factor of wind generation. It has shown that from hour 8041 to 8784 of simulation (which represent to December), the overall capacity factor of wind power from both types in this month is really high. Therefore the ability to generate electricity during the day of this month might over the demand as shown in figure 35 and 37. The interesting point of this month is in Gone green scenario. Because of a really high amount of wind energy generation, the proportion of central power plant generation will be less than 30% of overall electricity if not run the gas. Due to the stabilization of the grid as refer in chapter 2.1.6. The gas power plant has to operate even the overall electricity supply is more than demand as shown in figure 35. Moreover, this situation is also happening in Slow progression scenario as shown in figure 37 also. But the over needed gas generation of this scenario is less than Gone green scenario because of the amount of total RES generation is less than the Gone green scenario. Move to the Consumer power scenario. Because in December have less sunlight compare to May. Hence the generation performance of solar PV is quite low as shown in figure 8. Therefore, the consumer power that electricity rely on PV has to use gas for supply the deficit energy from green energy supply same as the steady stage scenario.

### 3.4. Possible solution/ critical issue

From depth analysis in the previous part, it has shown some possible problem that might occur in the 2030 UK electricity system. Hence, in this part will try to find the possible solution to those problems.

- **Import problem**

From figure 25, it shows that in some 2030 UK scenarios have to import some of the electricity from outside which the reasons have shown in the February month in depth analysis part. Therefore, to avoid the import need and maintain the level of demand to be the same. There are 2 possible solutions for this problem which is

**Increment of power station**

In this case, the gas power station of both scenarios (Gone green and Consumer power) have to increase around 3400 MW to solve this problem. Hence the carbon emission of both scenario has been changed from figure 26 to figure below.

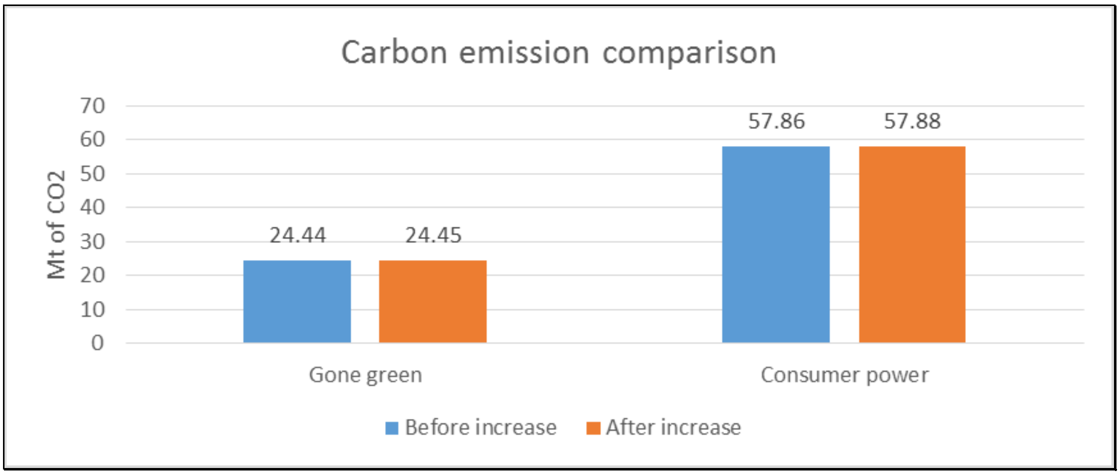


*Figure 39 Carbon emission after increase 3400 MW of gas station*

**Electrical storage**

The other solution to avoid the import is the storage. In this part, the storage in the simulation will run under the condition that the storage must store only excess RES energy only. From the simulation in Gone green and Consumer power scenarios the needed capacity size is only 6000 and 23000 MWh respectively. But the problem of both scenarios is a generator size because in both scenarios have few hour that lags around 3400 MW as shown in the figure below which show the amount of energy that store in the storage of both scenarios. Even the largest dam in the UK the generation capacity is less than 3400 MW. Hence, it has to research the other type of storage in future to solve this problem.

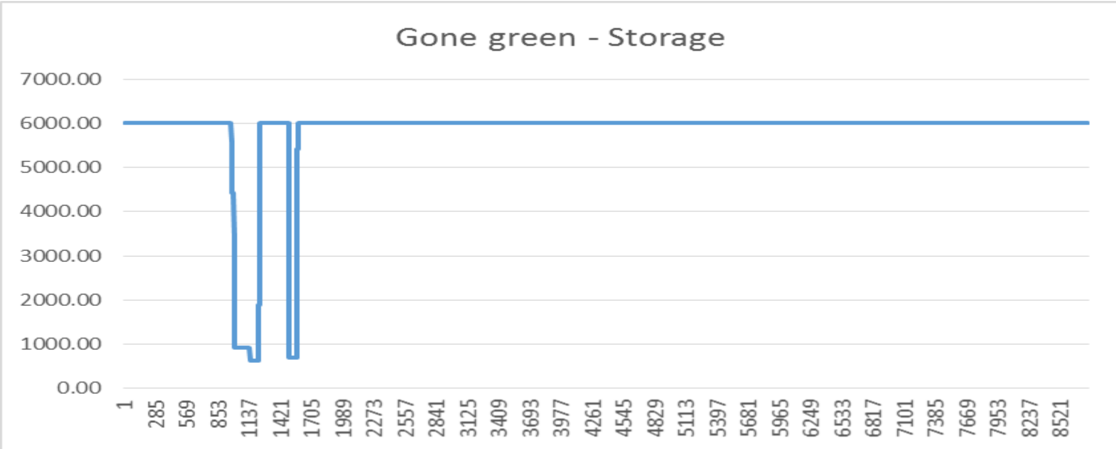


*Figure 40 Gone green storage*

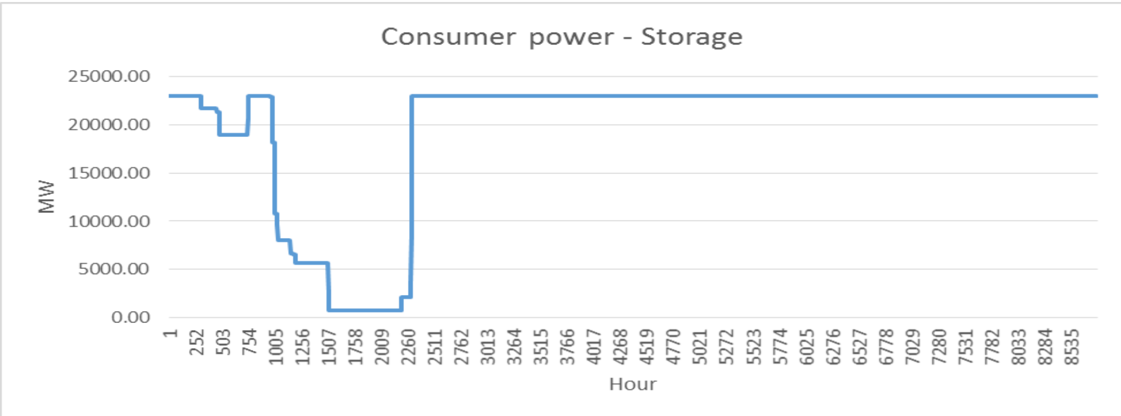


*Figure 41 Consumer power storage*

- Over needed gas generation

From figure 35 and 37 in depth analysis part, it has shown that for stabilizing the grid the 30 % of total energy generation has to come from the central power plant which not RES. From this reason, the first step towards a 100% renewable energy-system for Ireland (D.Conolly, H, Lund ,B.V. Nathiesen, M.Leahy, 2011) document is used to a reference by running the program with 0% grid stabilization. Some example of the result of this simulation is showing below in figure 42. In this figure is use the gone green scenario as the base. Then the stabilization value has been changed from 0.3 to 0 to observe the electricity from gas consumption.

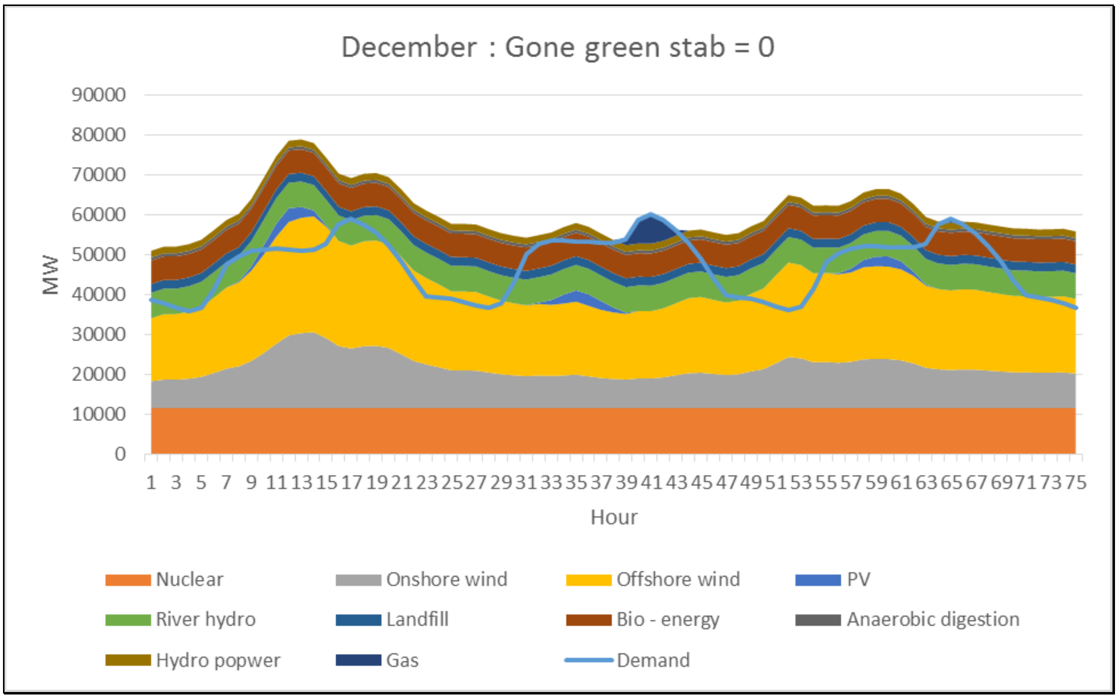


*Figure 42 December: gone green (stab=0)*

From above figure is found that when the grid stabilization has been changed to 0 they are no over need gas generation same as figure 35 which represent to the same time observation but different in stabilization value.

Therefore, when the grid stabilization has been changed the gas consumption in each scenario will be reduced. The following figure will show the amount of gas consumption in each scenario when the grid stabilization has been changed from 0.3 to 0.

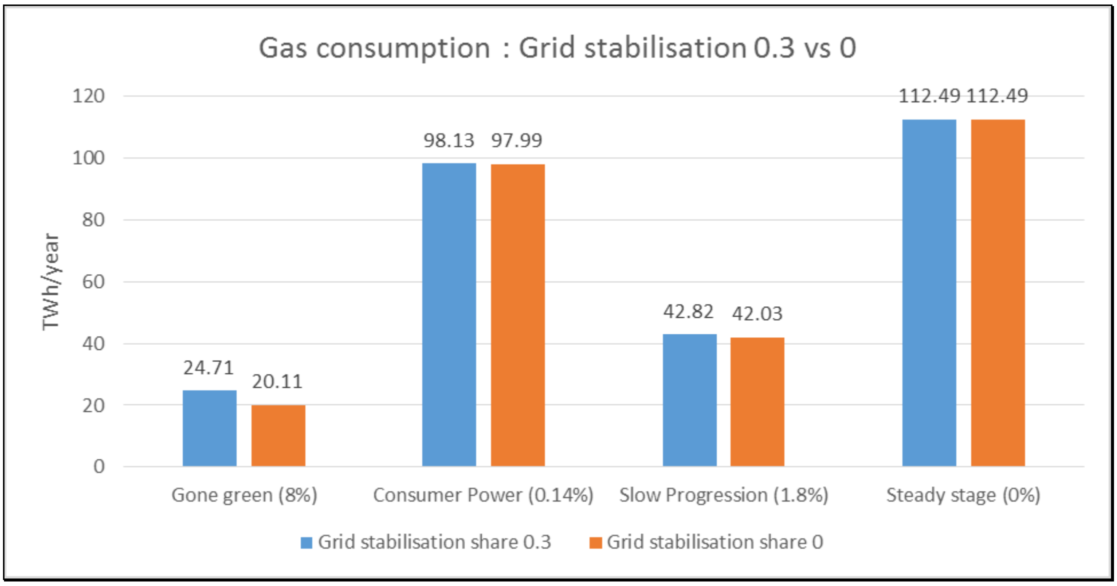


*Figure 43 Gas consumption: grid stabilization 0.3 vs 0*

From above figure, the most affected scenario is Gone green scenario. The gas consumption of this scenario has been reduced up to 8%. Because in this scenario is contain a lot of RES supply which sometimes they produce a lot more than need. The second scenario that effect to this change is the Slow progression scenario but it affects only 1.8% because of the time that over RES supply is not much as Gone green scenario. In contrast, the last two scenarios are not affected too much by this change. Because both of them most of the time the RES are not meet with 70% of total electrical production.

# 4. Discussion

In this part will discuss 4 simulated scenarios to find the best option for 2030 UK electricity system.

**Gone green**: In this scenario is the best scenario in term of an environment. As from the previous result, it has shown that the carbon emission of this scenario is the lowest among 4 scenarios. Because of a lot of electricity is generated from the green energy which accounts for 62 % of overall electricity production. But because of this reason, it has low level in the security of supply due to the uncertainty of the generation source. It is the reason that in some month (February) the electricity cannot supply enough to meet the demand. The possible solution for this problem is to build a more reliable power plant which can support the energy during the deficit time. But this power plant will increase the emission level also. The way that remains the emission level is energy storage. From previous calculation has shown that the size of storage is not a problem. But the problem of is the size of the generation. Moreover, due to the fixed grid stabilization value. The gas has to run even the green energy supplies more than the demand. If this scenario not run under fixed grid stabilization condition the gas consumption will reduce around 8% of the fixed condition. Moreover, in some type of RES which can control the operation hour such as biomass. It can shut down sometime to prevent grid stabilization problem. But due to the lag of real time information data, this can be improved in the future work.

**Consumer Power**: In this scenario seems to be the worst scenario of all. The reason comes from even people try to produce own green energy by using solar PV. But the carbon emission is still in the similar level of the Steady stage scenario. Because of the solar PV has the lowest capacity factor among all type of green energy. From this reason, it not a good idea to invest a lot of money in this type of energy. As when compared to slow progression scenario. The amount of total installed capacity is no different. But the ability to produce electricity of this scenario is worse. Even in the summer time that which the solar PV should be at peak performance. But it still cannot generate electricity enough to meet the demand. Moreover, the performance of solar PV in this scenario is getting worst in the winter time. But due to the high wind generation during this time that supports the electricity generation. However, a lot, of gas have to run to fulfill the electricity demand. Which made a large number of carbon emission as mention in previous.

**Slow progression**: In this scenario is seem to be the best option for 2030 UK electricity grid. Because even the amount of carbon emission is not the lowest one. But it similar to Gone green scenario value. And the other of advantage of this scenario is no need any import and even under the grid stabilization fixed condition. The value of gas consumption is different from non-fixed condition only 1.8%. When analyze in each season, the energy mix from this scenario seem to match proper in every season. In summaries this is the optimum scenario for 2030 UK electricity grid among 4 simulated scenarios.

**Steady stage**: In this scenario, the advantage of this scenarios is the security of supply issue. Due to a large number of gas station. It can match demand and supply perfectly in every season. The other advantage of this scenario also comes from the small amount of RES generation which cannot produce electricity up to the fixed stabilization value which is the cause of over needed gas issue. But the weak point of this scenario is the environmental issue. Which produce carbon up to 2.7 times of Gone green and Slow progression scenario.

# 5. Future work

1. Even the storage capacity has been calculated for avoiding the import, but it does not classify type and efficiency of storage. Due to large generation capacity that needs in single time, in storage part have to research more to solve the problem.
2. The grid stabilization is also a big issue because in the future the grid stabilization might be reduced due to the development of technology. Hence, the exact value of gas consumption and carbon emission might be changed.
3. In this project has not involved the cost analysis. In order to plan the future, cost analysis should be done in future work.
4. The transport and heat sector can be used for analysis the overall UK energy situation.

# 6. Conclusions

In conclusion, from all 4 type of scenarios. The slow progression and Steady stage scenario can use for the plan the 2030 UK situation under no need any import condition. In Gone green and Consumer power scenarios can also use but under some of the import needed condition unless building more power generation or storage. The critical month of UK electricity system is in February due to the low potential of the wind and solar generation.

Although the best scenario in term of environmental is Gone green scenario which can reduce carbon emission around 83% from 2016. But in Slow progression scenario seem to be a better option because it no need to build more power generation of any storage to import and carbon emission will reduce up to 80 % which similar to Gone green scenario. However, in Gone green scenario the electricity is also used in EV car that might reduce the emission from transport sector which out of our scope. In term of invest, a large amount on solar PV as shown in Consumer power scenario might be not a great idea for the UK. From the simulation has shown that it has the import problem and also produce a high level of carbon when compare to the previous scenarios. Lastly, the Steady stage scenario which has the most security of supply but in term of the environment has the most problem because it has the highest carbon emission level among 4 scenarios.

# References


Chmutina, K., & Goodier, C. (2014). Alternative future energy pathways: Assessment of the potential of innovative decentralised energy systems in the UK. Energy Policy, 66, 62.

Data Explorer | National Grid. (2017). Www2.nationalgrid.com. Retrieved 9 August 2017, from http://www2.nationalgrid.com/UK/Industry-information/Electricity-transmission-operational-data/Data-Explorer/

D.Conolly, H, Lund ,B.V. Nathiesen, M.Leahy (2011). The first step towards a 100% renewable energy-system for Ireland. Applied Energy, 88(2), 502-507.

Dinçer, I., & Springerlink. (2010). Global warming [internet resource] : Engineering solutions (Green energy and technology). Dordrecht ; New York: Springer.

Energy UK .(2016). Pathways for the GB Electricity sector to 2030. London.

G. B. National Grid status. (2017). Gridwatch.templar.co.uk. Retrieved 6 July 2017, from http://www.gridwatch.templar.co.uk/

Incropera, F. (2016). Global warming. In Climate Change: A Wicked Problem (pp. 55-79). Cambridge: Cambridge University Press.

National grid. (2015). Future Energy Scenarios. National grid plc, Warwick

National grid. (2016). Future Energy Scenarios. National grid plc, Warwick

National grid. (2017). Future Energy Scenarios. National grid plc, Warwick

UK department for business, energy and industrial strategies (2014), Energy trends December 2014. London

UK department for business, energy and industrial strategies (2016), Energy trends December 2016. London

UK department for business, energy and industrial strategies (2017), Energy trends July 2017. London