Evaluation of Energy Storage Options for 100% Renewable Energy Generation in Scotland by 2020 using EnergyPlan Software Package

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Abstract

EnergyPLAN intervene between the variable sources and the variable loads. However, if there is no provision for storage, energy generation most be equal to the energy consumption. In this study, the current share of energy mix and the UK energy demand was scaled up to the energy need in 2020. The cost of investment, life time, the potentials of some Renewable energy sources and storage technologies were also evaluated. To determine the Scottish energy demand, generation, and the storage capacity for 2020; EnergyPLAN 13.0 software package was used. From the analysis, Pump Hydro Storage technology was found to be a viable option. Though, it has relatively high cost of initial investment but it worth it considering the life time and the subsequent charges per KWh. On the other hand, inter connection could be another option which can help in archiving the 2020 target.

Key Words: *EnergyPLAN, Demand, PHS, Storage, scenario, Scottish, SSE, SP*

1.0 Introduction

EnergyPLAN intervene between variable sources and variable load. However, if there is no storage energy generation most be equal to the consumption. Energy storage works by taking energy through a time [1]. Energy generated at a time can be used at another time through the storage. They are different types of storage technologies in use;

1. Pump hydro storage (PHS)
2. Compressed air energy storage (CAES)
3. Thermal storage
4. Super conducting Magnetic energy storage(SCMES)
5. Batteries (Lithium-Ion, Lead acid, etc.)

It is assumed that by the 2020 Scotland will achieve 100% energy generation from renewable energy sources. Therefore, the current energy mix was scale up to meet the energy need in 2020 as given in the Table 1 below as provided by the [2].

Table 1. shares of energy mix 2016 **shares of energy mix 2020**

Technology	Installed capacity (MW)	Percentage	16GW Inst. Cap. For 2020	CFs	Annual Electricity prod.GWh
Onshore wind	6,135	70.99051	11.35848	0.28	27860.08424
Large scale hydro	1,339	15.4941	2.479056	0.35	7600.785003
Solar PV	312	3.610275	0.577644	0.11	556.6178199
Small scale hydro	279	3.228419	0.516547	0.35	1583.733395
Plant Biomass	198	2.291136	0.366582	0.69	2215.767091
offshore wind	187	2.163851	0.346216	0.47	1425.441148
Landfill gas	116	1.342282	0.214765	0.55	1034.738255
Anaerobic didestion	30	0.347142	0.055543	0.87	423.3020134
Municipal solid waste combustion	18	0.208285	0.033326	0.53	154.7241842
Animal Biomass(non-AD)	13	0.150428	0.024069	0.53	111.7452442
Shoreline Wave/Tidal	8	0.092571	0.014811	0.26	33.73441333
Sewage sluge digestion	7	0.081	0.01296	0.55	62.4411016
TOTAL	**8,642**	**100**	**16**		**43063.11391**

The capacity factors/Load factors used in this report was provided by [3]. Therefore, to obtain the annual energy production of 2020, the average capacity factor of each renewable energy source was multiplied by hours the year and the installed capacities of 2020. The annual electricity production for the year 2020 is 43.03TWh with wind, Hydro, Biomass, and landfill gas having the largest shares (Wind 73%, Hydro 18.7%, Biomass 2.44%, Landfill gas 1.34%). Below in Figure1 are the installed capacities for various renewable energy sources in Scotland as in the energy mix in the Table 1. above

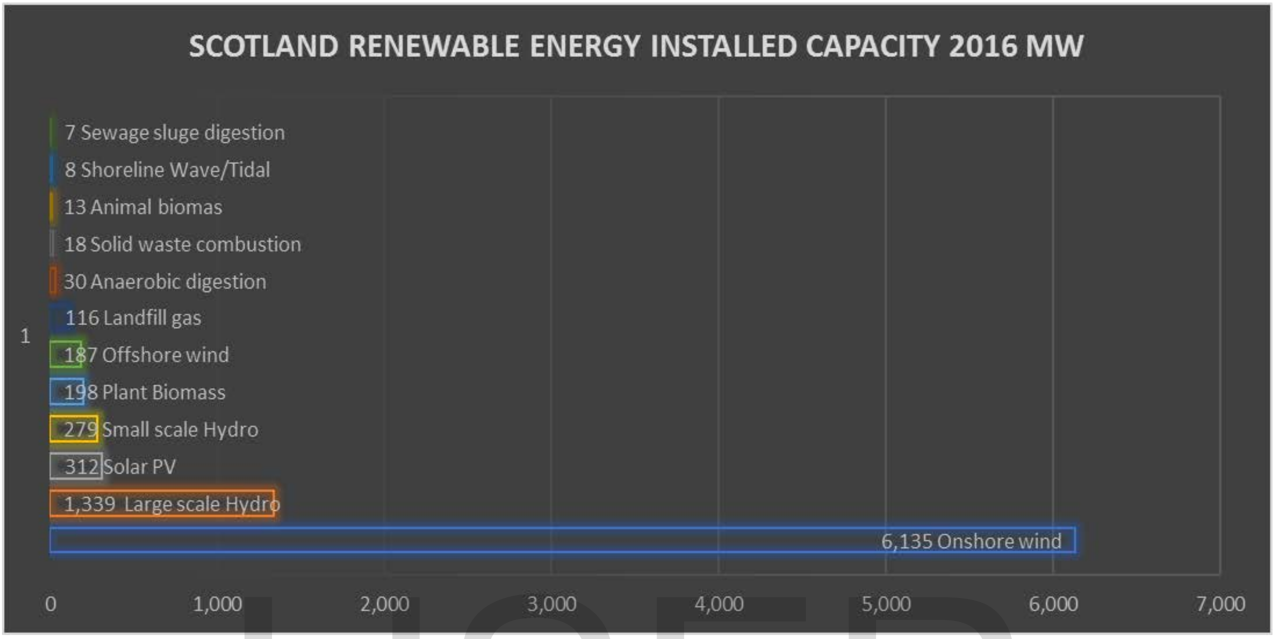

Figure 1. Scotland Renewable energy mix installed capacity in 2016

1.1 Generation Characteristics

The electricity demand in Scotland varies with, Hourly/daily, seasonal, and year to year. To achieve 100% electricity generation from Renewable energy sources as proposed by the Scottish government, the generation characteristics of Renewable energy sources with high share in the 2020 energy is mix should be known in other to predict the consumption and the storage capacity for 2020. The graph in Figure 3 below represent the monthly generation characteristics of Onshore and Offshore wind energy for UK for the year 2015 and 2016 respectively, the assumption made using UK output data was vital since the Scottish data is not readily available to know when the energy output is high or low within the year.

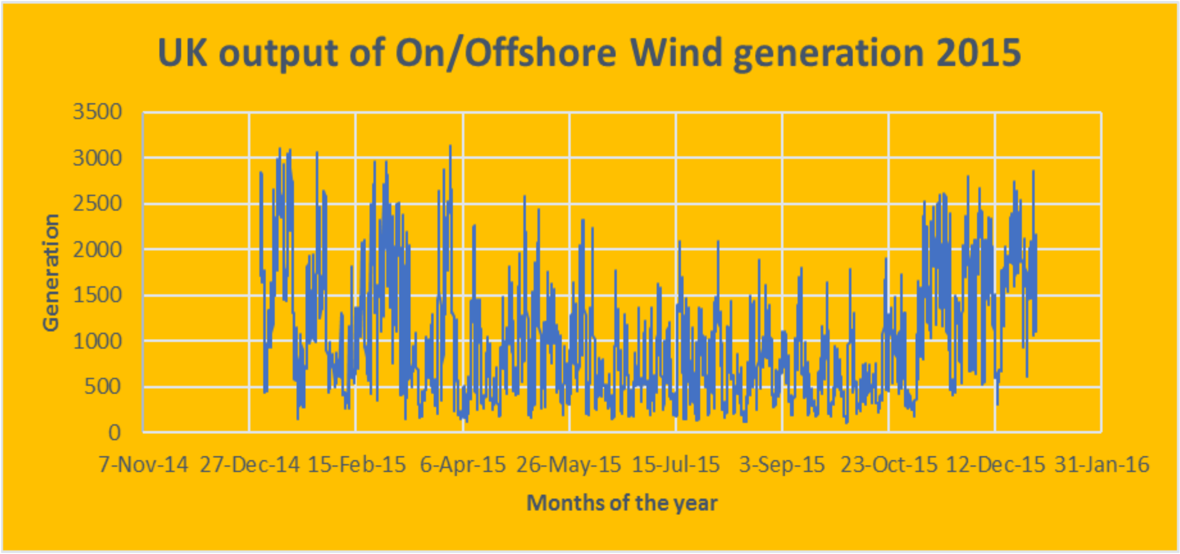

Figure 2 Monthly generation characteristics of UK wind 2015

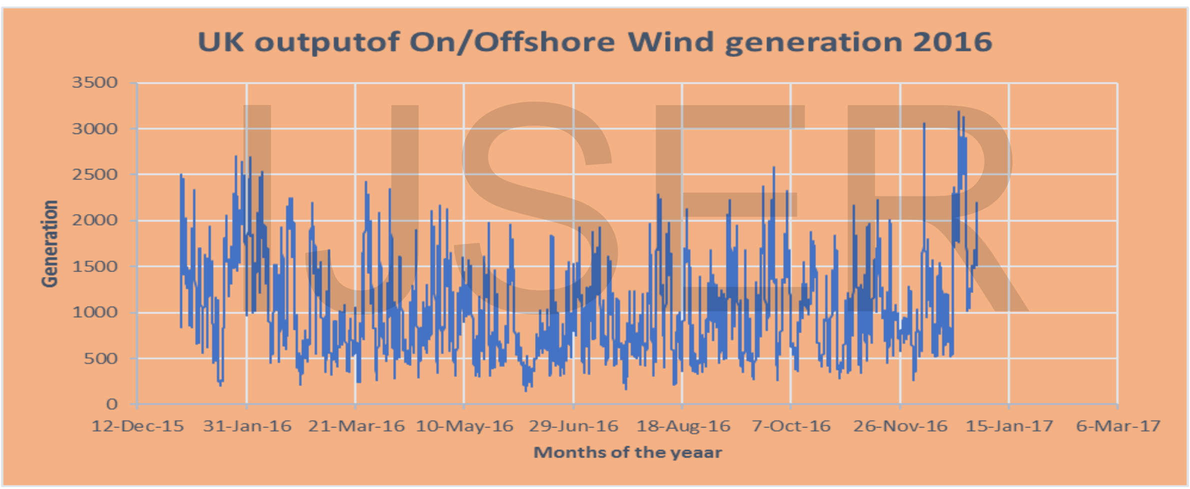

Figure 3 Monthly generation characteristics of UK wind 2016

From the generation curves above, it can be observed clearly that Wind energy output was much higher in 2015 as compared to 2016 as reported by [4], that Wind energy generation has reduced by 10% in 2016.

1.2 The UK and Scottish energy demand

Since the annual energy consumption data for Scotland is not available, the UK annual monthly energy demand curve was plotted including Scotland to give an over view of how the system works as in Figure 4 below.

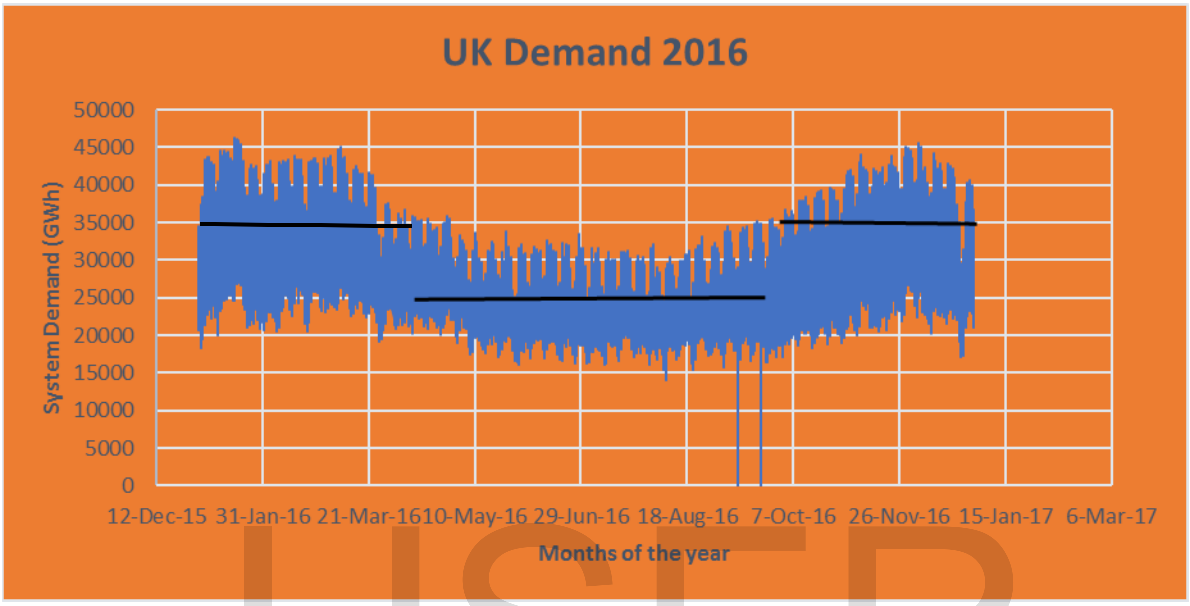

Figure 4. Monthly UK electricity demand curve 2016

From the graph in Figure 4 above the demand for electricity increases during the winter time and decreases during the summer. This give us a clear clue that the year is divided into high and low demand. To be able to predict the exact electricity demand for Scotland, a separate data is needed from the Scottish grid. Given in the Figures (a) and (b) below is a four days' Scottish load curve from [7], showed the measured and the predicted demand during the Winter and Summer time for the year 2003.

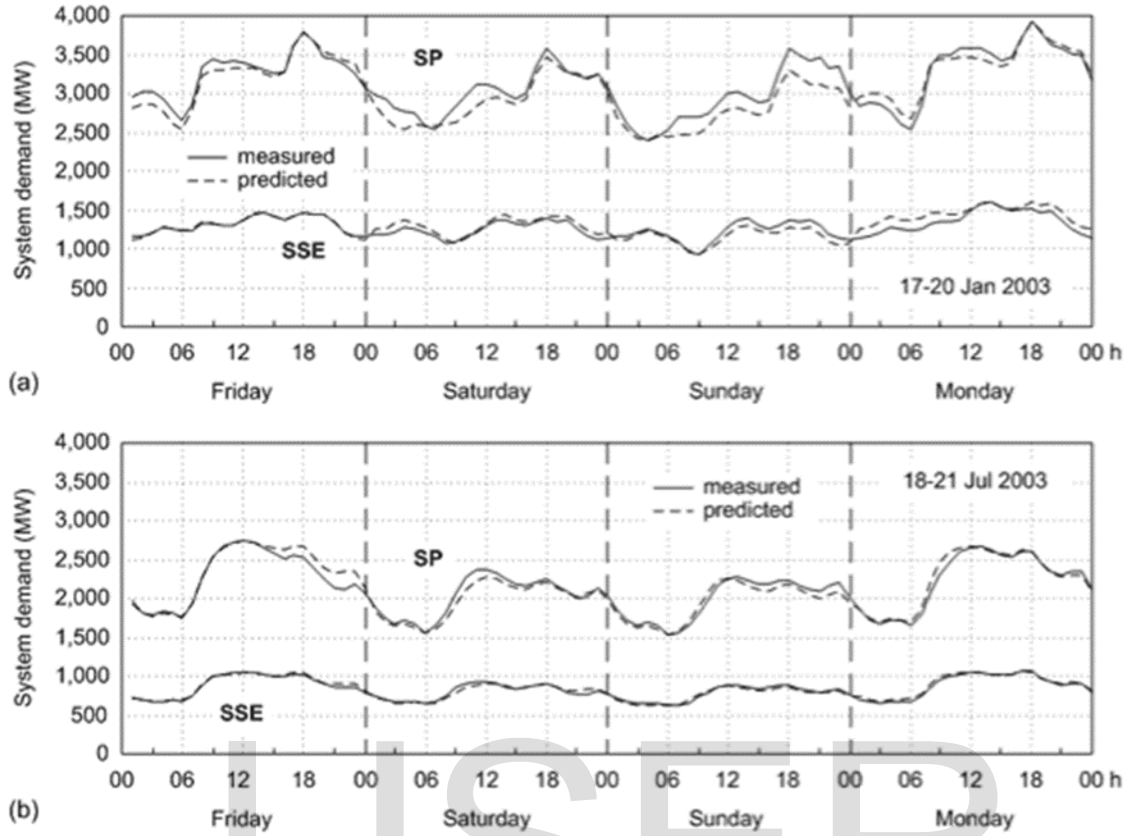

Figure 4.1 Measured and predicted hourly system demand from [7]

Due to the rapid development in renewable energy generation in Scotland, a new target was set by the Scottish government to have an approximate installed capacity of 16GW by 2020 with an average annual of output of 33,122GWh. To stabilize the 4% energy demand growing rate, the is a need for effective energy storage.

2.0 PUMPED HYDRO STORAGE

Pumped hydroelectric energy storage is very large, mature and commercially satisfying technology that has been used over the years in different parts of the world. Pumped hydro use off-peak electricity to pump water from a lower reservoir to another reservoir at a higher elevation. Whenever there is an increase in electricity demand, water is released from the upper reservoir through a hydroelectric turbine to the into the lower reservoir for electricity generation.

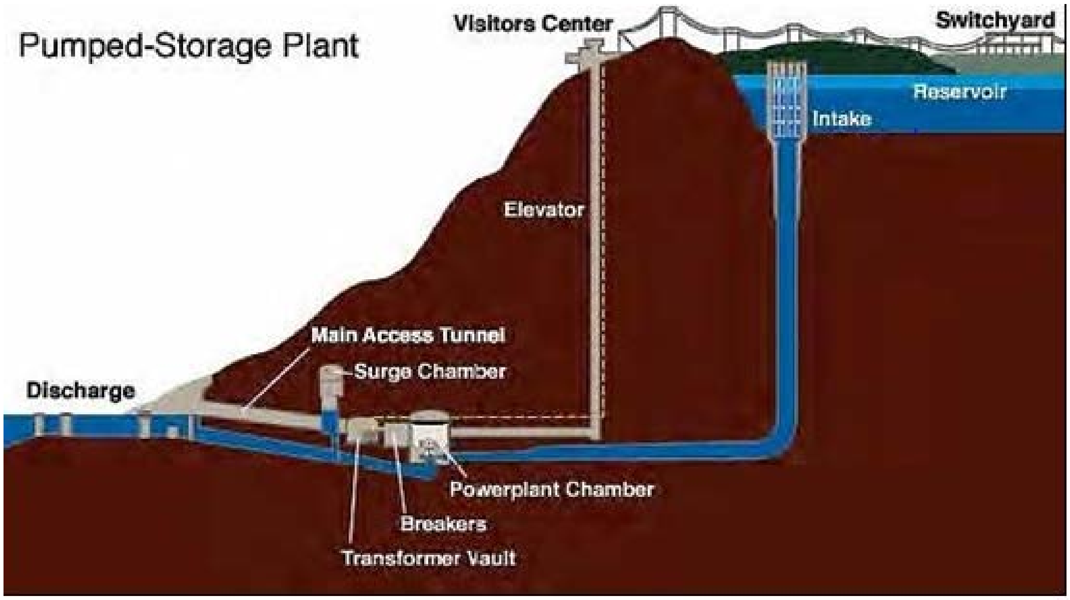

Figure 4.2 Cutaway diagram of a typical Pumped Hydro storage [1]

A pumped hydro storage may be practically sized up to 4000MW and operate at bout 76-85% efficiency, depending on the design. Pumped hydro plant normally have a life span of about 50-60 years [1].

2.1 Potential of Pumped Hydro Storage in Scotland

In other to meet the 100% generation from renewable energy sources in 2020 as targeted by the Scottish government, there is a need of 1050GWh storage capacity. As recommended [5], suggested that a storage capacity should be 2-8% of the annual energy demand, this makes the result to fall within the recommended range. Now, they are only two installed Pumped Hydro storage plant in Scotland which are, Gruachan power station with capacity of up to 440MW and Foyers with a storage capacity of 300MW which are not quite enough to meet the 16GW target by 2020.

2.2 The economics of PHS in Scotland

The cost of pumped hydro storage is site dependent. [8], made a detailed assessment of two potential site in Scotland, but the specific cost projection has not been reviled [8]. Apart from the cost of construction and maintenance, effort is needed to ensure that the plant does not cause any environmental or social impact. Though large scale energy storage is expensive as describe above, pumped hydro storage are generally seen as the most cost effective way of storing electrical energy. Other technologies are still on the development process, while some like batteries are developed to some extend but still expensive. The energy that needed to be stored as stated above about 1050GWh for Scotland to have a stable electricity supply by 2020.

The cost of building a in Scotland is within the range of (1500-4300$/Kw) and (250-430$/Kwh) at an efficiency of 80-82% [8].

Considering the exchange rate of US dollar to GBP

1$ = 0.78£ (Exchange rate, 2017)

Which gives 1170-3354£/Kw taking the average cost will give an estimation of 2,262€/Kw, then the cost of storing 1050GWh

If 1GW = 10^6Kw, then 1050GWh = $1050*10^6$ = $1.05*10^{10}$Kwh = 1,198,630Kw

The Total cost of storing = 2262£/Kw*1198630Kw =271millionGBP

2.3 Aims and objectives

This study aims at providing information on the UK'S current Renewable energy share mix, generation, energy demand, and then scaling up to determine the storage capacity for 2020 target.

2.4 MATERIALS AND METHODS

The parameters used for this study was the UK'S energy generation, generation characteristics, energy demand for two years 2016 and 2017 respectively. To determine the energy demand, investment cost, the type and size of energy storage technology for 2020 target; the available data were all fed into the EnergyPLAN 13.0 software package, and then a simulation was carried out using all the input data.

3.0 ENERGYPLAN SIMULATION

This part of the report explains how the simulation was carried out using the input data on the energy plan, the obtained result and how to stabilize a Scottish electricity grid with 100% generation from renewable technologies by 2020. The investment cost of electricity as in the energy plan data as changed to GBP in other to match with the Scottish data in the EnergyPLAN. Below in the cost of investment and life time for Scottish grid scenario.

Table 2. Cost of investment and life time for Scottish grid scenario.

Prod. Type	Price MGBP/unit	Period (years)	% O&M
Wind	1.32	20	2.97
Solar PV	1.3	20	0.6
Hydro storage	7.5	50	1.5
CSP solar power	5.98	20	7.7
Hydro power	3.3	50	1.5

Though the initial cost of investment may look big as is Table 2 above. However, considering the maintenance cost and the number of years each resource will take in operation, it is cost effective and worth investing to achieve 100% electricity demand using renewable technologies in Scotland.

3.1 The Scottish electricity grid scenario

For this scenario, the data that was used was obtained from Table 1 to generate an annual electricity that will meet the Scottish energy demand. Below are the simulation results as obtained from energy plan software.

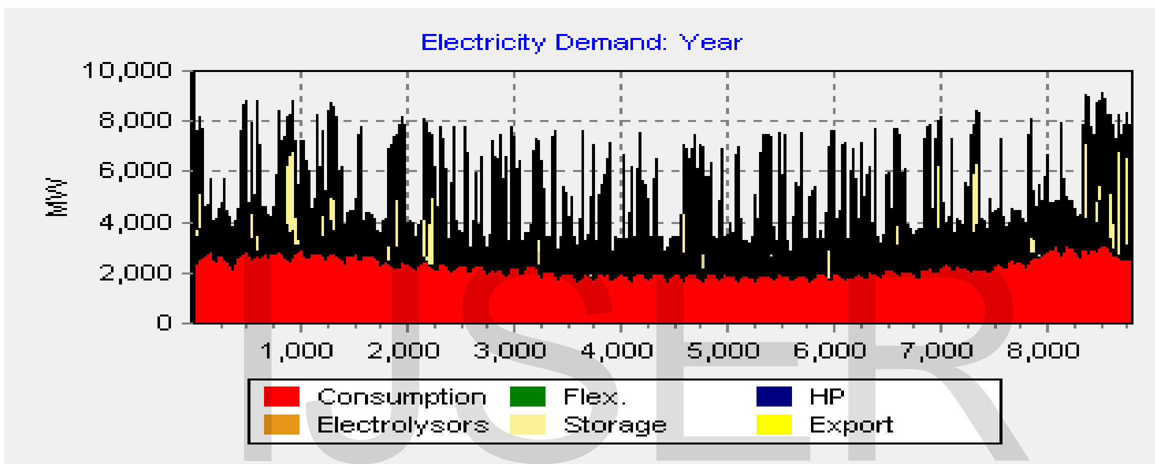

Figure 4.3 Scenario of Scottish electricity demand

On the figure 4 above, the red color indicates the annual electricity demand and the base load is approximately 2000MW as indicated on the graph.

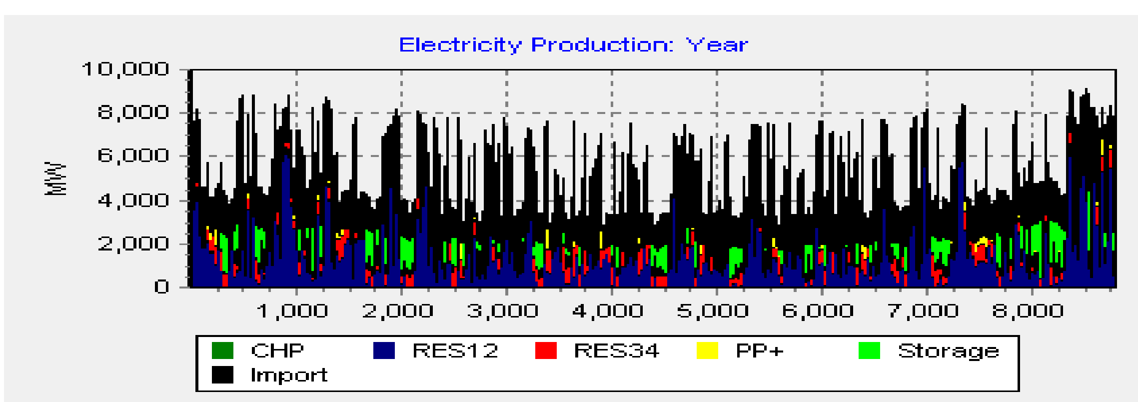

Figure 4.4 Scenario of mix renewable energy generation in Scotland

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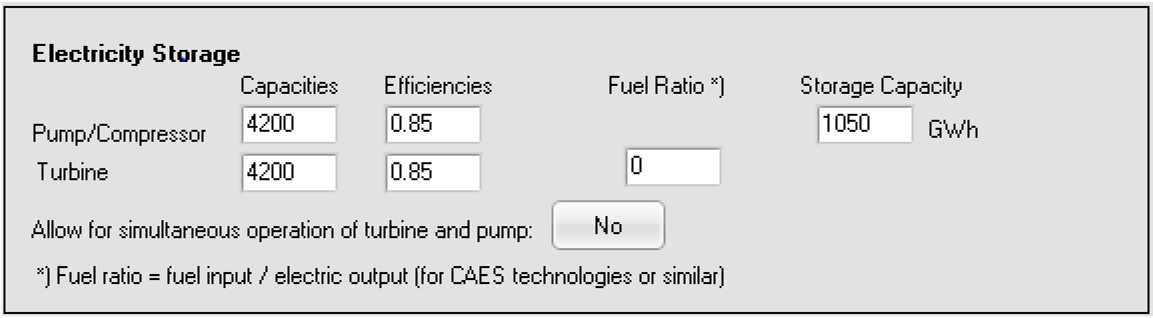

Figure 4.5 Generation and storage capacity

3.2 Scenario of Scottish energy stabilization

This research work is focused on energy generation and storage, to maintain a balance between generation and storage Scotland some factors needed to be addressed. To maintain stability in electrical grid, the critical excess in generation should be cut down as it is done within an energy plan environment were 7 represent reducing the power plant in combination with renewable energy resources 1, 2, 3, and 4 as shown in the Figure 4.5 below.

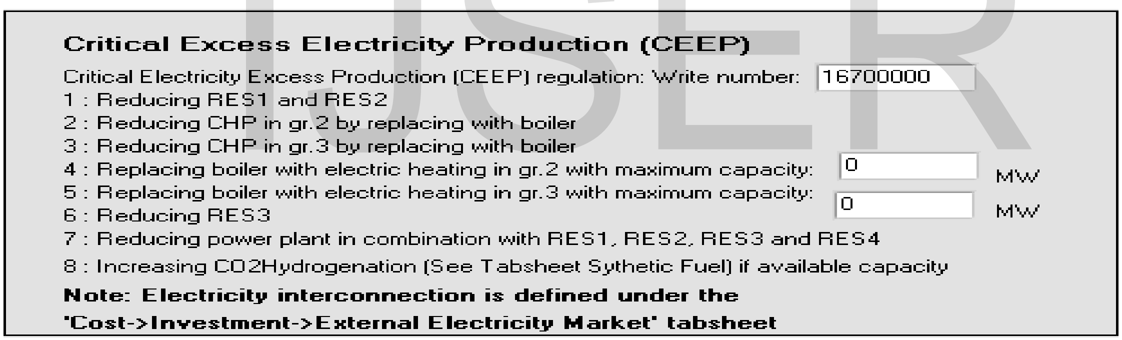

Figure 4.5 Critically excess generation

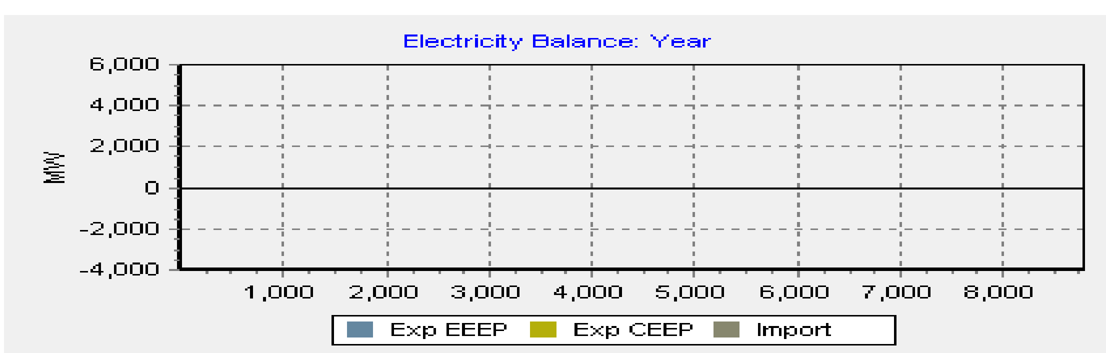

Fig 5.6 Annual import and export electricity balance.

3.3 Scottish electricity grid interconnection scenario

Creating a network with other power plants is far more economical than isolating power plants from one another. The reason is electrical loads are shared across many different power plants, in time of power crises other plants can pick up. Interconnection can contribute to Scottish grid before and after stabilization because of its cost effectiveness.

4.0 CONCLUSION

This report evaluated the Scottish target to depend on 100% electricity generation from renewable sources by 2020, from all the analysis made in this report, it indicated that it is an achievable target. In terms of energy storage, PHS is a viable option for Scotland in achieving the target. Though, the initial cost of installation for PHS is relatively high, but it worth investing on considering the life span and the subsequent charges per Kwh is cheaper as compared with the other storage technologies. Inter connection also is another option that could help the Scottish government in achieving their target as it is economically cheaper and it encourages savings.

5.0 ACKNOWLEDGEMENT

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