Investigating the relationship between operation of electricity storage for economic and carbon reduction incentives

Contents

1.Background 1

2.Methodology 1

3.Results 4

4. Conclusions 7

5. Further Work 8

6.References 8

1.Background

The U.K. energy storage market is rapidly increasing and hence questions about how storage should and will be best operated are now being discussed. A big question is should we incentivise profit making in the market or should we incentivise carbon reductions on the grid? Of course, an even better outcome would be to do both.

The uses for storage are well known, so it will be clear from the data obtained, whether storage would reduce peak cost or peak carbon emissions [1]. One of the key drivers for this report is currently policy towards energy storage and carbon reductions. It is important to assess how current policy is affecting grid carbon intensity. If the efficacy of our current policy is poor, then it will be useful to have an idea of how we can change it to produce better results, whether that be through carbon reductions or profit-making.

This project came about after Craig Wooton noticed a discrepancy between the grid carbon intensity stated on building regulations and the grid carbon intensity being reported by Elexon. To better understand this grid carbon intensity, he developed a program that takes the data produced by Elexon and converts it to an easy to analyse format. It can tell you at any given 5-minute interval how much electricity was produced and what the carbon intensity of the electricity produced is, among other variables.

If the relationship between grid carbon intensity and wholesale/balancing prices of electricity is understood, which it currently does not seem to be, then this can be used as a tool to craft an optimised techno-economic system. My key interest here is the role of storage in this system.

2.Methodology

Using the program developed by Craig Wooton, grid data was obtained for a single week in December 2015. Winter was chosen as often energy use can be at its highest and therefore trends may be easier to spot. This data was then formatted in excel to produce a more manageable format detailing the grid carbon intensity ($kgCO_2/MWh$), instantaneous demand (GW) and a new variable, carbon intensity per unit demand ($kgCO_2/MWh/GW$). To achieve the goals of the project, data on the cost of electricity needed to be obtained. This was done by using the UK grid balancing data provided online by Elexon. From their website, it was simple to download the balancing buy price and balancing sell price of electricity for the dates necessary. This data is then intercalated into the excel spreadsheet containing the grid data, creating the final worksheet necessary to start analysis.

The first set of variables that was interesting to look at, were the relative generating powers of the different energy sources. These were formatted into a layered graph, to make fluctuations between energy sources easy to interpret. An example of this is shown in figure 1.

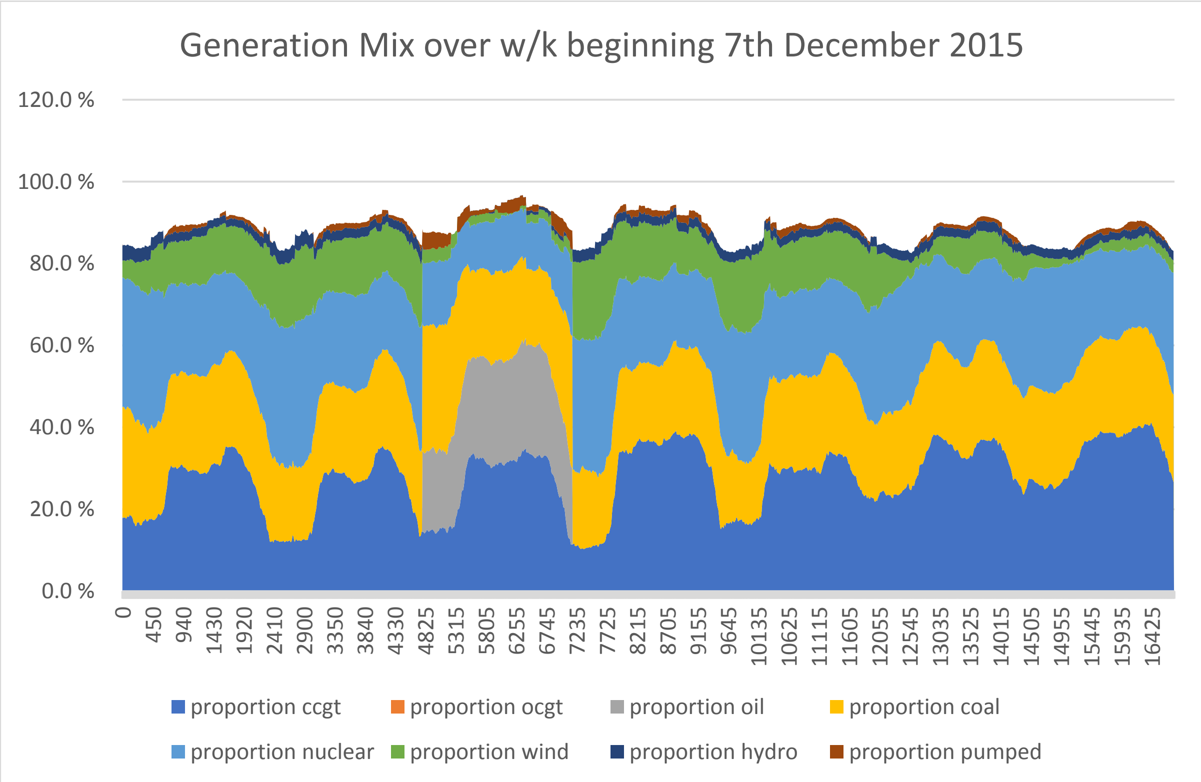

Figure 1: A graph to show the fluctuations in generation mix over a week in Winter 2015.

The next stage of the project was to try and get an initial understanding of the potential interconnection (or lack of) between energy prices and grid carbon intensity. System Buy Price was used as the energy price metric, as it details how much money National Grid is willing to pay balancing suppliers who have a net deficit of imbalance energy. This has been achieved by plotting the two variables on a multi-axis line graph, as shown in figure 2.

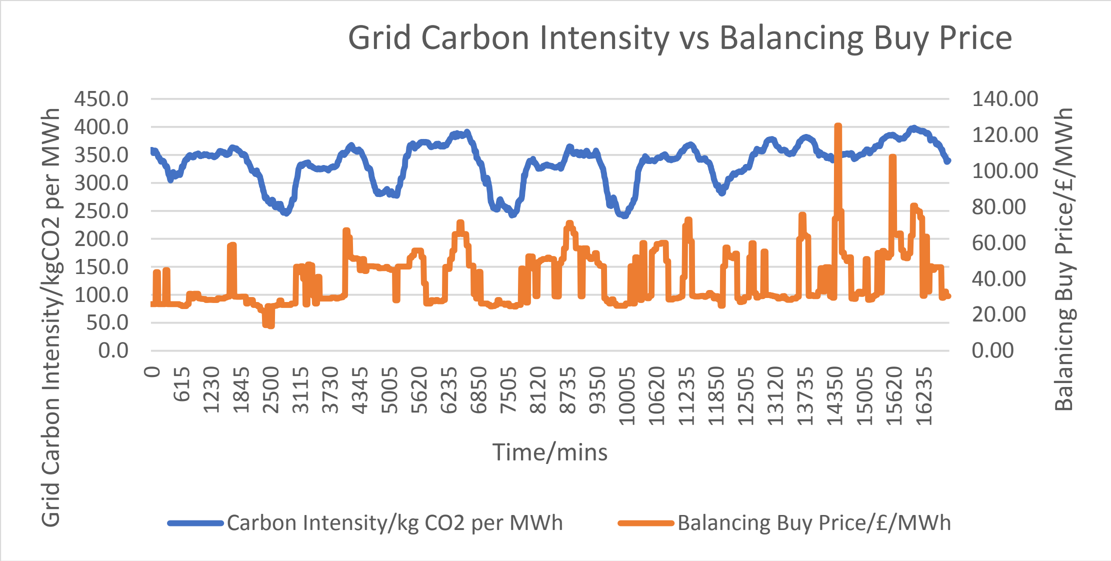

Figure 2: A graph to show the relationship between electrical grid prices and grid carbon intensity.

The above graph has its uses, but to fully understand the relationship between the two variables, it was necessary to do some data analysis. For this purpose, regression analysis was deemed to be the most useful tool. Regression analysis was also used to study the link between demand and system prices.

Once all these methods had been studied, the scope of the project was expanded to look at one week in each season of 2015. Weeks in April, July and October were formatted in the same way as the week in December, described above. This allowed the project to take on greater accuracy in determining trends and relationships.

Having built this core knowledge up, the next stage of the project is to understand and analyse where storage can fit into this data, i.e. how can we best operate it to either maximise cost reduction for the end-user or to maximise carbon emission reductions. This is done by selecting, at random, one day from each week studied. These days are then studied to see where we could charge and discharge a domestic battery to obtain the two scenarios described above. The domestic battery used in this simulation was a Tesla Powerwall. The specifications for this are shown below in table 1.

Variable	Powerwall
Capacity/kWh	13.5
Power (continuous) /kW	5
Power (peak) /kW	7
Charge Time from 0%/ hours	2.7

Table 1: A table to show the specifications of a Tesla Powerwall

3.Results

3.1 Generation Mix

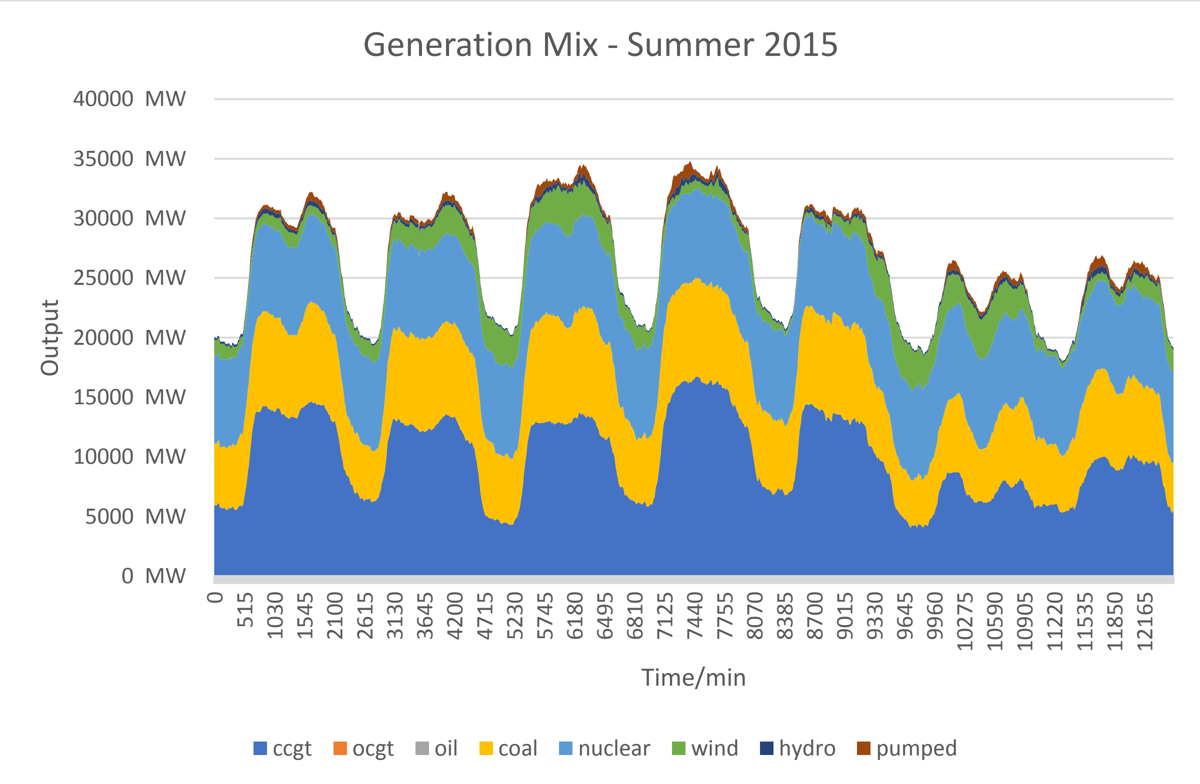

Figure 3: A graph to show the generation of electricity by source in the UK for 1 week in July 2015.

From analysis of the generation mix, we can come to multiple conclusions about the UK electricity market. Firstly, that CCGT seems to be the energy source that fluctuates the most. This is to be expected, as CCGT is very versatile in how much energy it can produce and in many countries, is used to meet high electrical demand. In contrast, nuclear energy has a very stable output, with its share of the generation only shrinking slightly at high demand. This is to be expected, as it is difficult to vary the output of nuclear energy, hence nuclear energy is often referred to as supplying the baseload of the electrical production.

3.2 Relationship between Grid Carbon Intensity and System Buy Price

Two methods were used to determine the relationship between grid carbon intensity and system buy price. The first is to plot the two variables against each other on a line graph and see if there is any obvious correlation between the two. An example of this is shown in figure 4.

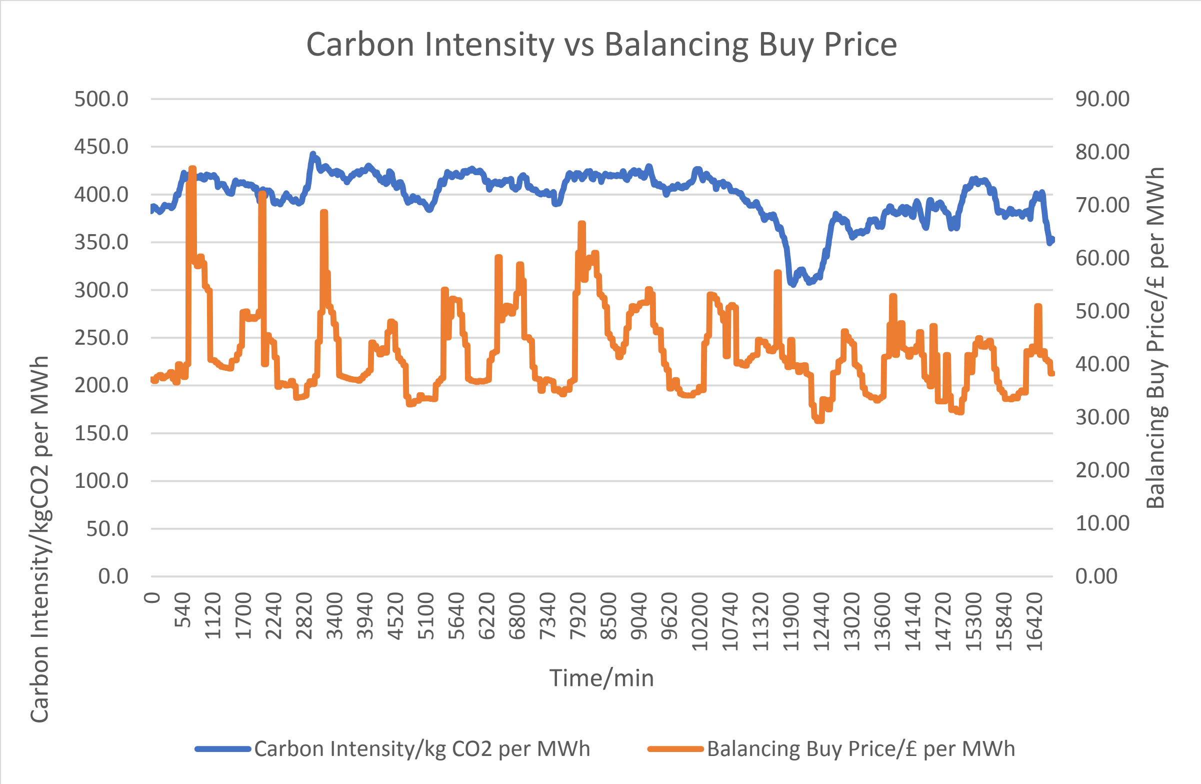

Figure 4: A graph to show the relationship between Grid Carbon Intensity and Balancing Buy Price

From this graph, we can see that there is relatively poor correlation between the two variables. carbon Intensity doesn't fluctuate very much throughout the week, compared to the fluctuations in electricity price.

To explain this relationship more precisely, a second method is used. This method is regression analysis. This will tell us how closely correlated the two variables are by producing a number between 0 and 1. The closer to 1 the value is, the more closely the variables are correlated. A summary of the regression analysis done in this project is shown below in table 2.

Time of Year	Correlation between CO_2 Intensity and Balancing Buy Price	Correlation between Demand and Balancing Buy Price
Spring	0.377	0.665
Summer	0.356	0.533
Autumn	0.289	0.590
Winter	0.434	0.730

Table 2: Regression Analysis of multiple variables

From table 2, we can see that there is a poor correlation between CO_2 intensity and balancing buy price. This confirms what was suggested by the graph previous. The second set of regression data is very interesting. It would be expected that there be a strong link between demand and the price of electricity, however, this data seems to suggest that this link may not be as strong as thought.

3.3 Operation of Storage

Here, we will discuss two scenarios for operating storage. The first of these is operating storage for financial gain of the end-user. This is where electricity is stored when electricity is cheap and then that stored electricity is released during the hours of the day where electricity is most expensive. We will call this the profit-making scenario. The second scenario is one where storage is operated to minimise carbon dioxide emissions. This is done by storing electricity when the grid carbon intensity is low and then using that stored electricity to avoid having to use grid based electricity when grid carbon intensity is high.

For this section I assumed that the battery would be completely discharged and completely charged, which may be slightly unrealistic. However, it would be easy to make the calculation needed to work out a way around this (multiply by ~0.8 or whatever depth of discharge you wish). A second difficulty with this method is the number of charge/discharge cycles done during a day. With a 5.7 hour charge/discharge cycle, there should be 4 complete cycles in a day. This is not the case, however, as there are limited fluctuations in price/carbon intensity during a day. Usually there is a fluctuation that can be exploited between 7am and 10am, presumably when people are waking up and preparing for work, and then a fluctuation between 5 and 10pm, which correlates nicely to when people arrive home from work. This mean the days I have studied have only 2 charge/discharge cycles.

	Profit Making		CO_2 Reduction	
Time of Year	Money Saved/£	CO_2 Saved/kg	Money Saved/£	CO_2 Saved/kg
Spring	0.14	0.31	0.09	0.54
Summer	0.44	1.36	0.22	1.85
Autumn	0.39	0.93	0.32	1.26
Winter	0.72	1.30	0.53	1.56
Total	1.69	3.90	1.16	5.21

Table 3: A Table to show the results of modelling electricity storage scenarios

Table 3 shows the data obtained by modelling the two scenarios. Interestingly, this shows that CO_2 emissions are not always at their lowest when prices are at their lowest. This seems to agree with the point made in section 3.2 about the poor correlation between the two variables.

To fully understand how useful storage can be, the data from table 2 was extrapolated to detail how much of a change these savings would make annually. In the profit-making scenario, this was then compared to how much the battery would need to cost to be cost-neutral after 10 years and hence what the price per kWh would need to be. For the CO_2 emission reduction scenario, the yearly emission savings were compared to the 1990 emissions base level. This could then be used to work out the yearly contribution to emissions targets. These findings are shown in tables 4 and 5.

Scenario	Amount Saved Per Year/£	Minimum cost for 10-year payback/£	Necessary Battery Cost per kWh/£
Profit Making	154	1543	114
CO_2 Reductions	106	1059	78

Table 4: A table to show the required cost of energy storage solutions, based on annual savings

Scenario	Carbon Reductions Per Year/kg	# of Households in UK	Total Carbon Reductions per Year/kg	1990 Base Level CO_2 Emissions/kg [3]	% of Base Level CO_2 removed per year
Profit Making	356	27,000,000	9.62E+09	5.96E+11	1.61%
CO_2 Reductions	476	27,000,000	1.28E+10	5.96E+11	2.16%

Table 5: A table to show the effects of energy storage in the home on climate change targets

As we can see from table 3, batteries like the Tesla Powerwall would need to drop below ~£120 per kWh. Currently the Tesla Powerwall costs ~£440 per kWh [2]. This undermines the profit-making ability of energy storage in the home. A computer program could be developed to easier spot fluctuations and change between charging and discharging instantaneously to improve the efficacy of the battery for our relative scenarios. This could increase the amount of yearly savings and hence increase the necessary cost of the battery.

Table 4 seems to suggest a more positive result. The UK needs to reduce its CO_2 emissions to 80% below base level by 2050 and by 2020 this should already be 30% [3]. Getting an energy storage solution into every home is however, unrealistic. A more realistic target would be to get it into 10% of homes, with automatic installation into social housing being a good way of doing this. This means that in an ideal scenario, residential energy storage could contribute a reduction of 6% on base level CO_2 which is 12% of the reductions needed by 2050.

3.4 Strange Results

In figure 1, you can see a strange spike in the use of oil as a source of electrical energy. This corresponds to a huge drop in the amount of wind energy being obtained from wind. Days like show very clearly, the intermittency of wind. Clearly there were not enough CCGT or coal plants available to ramp up production so the electricity had to be found from other sources, of which oil is the only real option. Burning oil for electricity is very inefficient and hence should be avoided at all costs. This strengthens the case for situating more energy storage on the network, especially alongside renewable energy generators.

4. Conclusions

To summarise, the knowledge gained from this project should help others who wish to study this area of the electrical grid in the future. Different techniques have been utilised to help break down the large amounts of data and hence make it easier to understand. The relationship between grid carbon intensity and balancing buy price has been studied over the 4 different seasons of the year and it has been found that there is a very poor correlation between the two. Studying the four different seasons allowed a greater certainty than studying just a single season as initially planned.

Multiple scenarios of energy storage in the home have been developed, focusing on energy storage for profit and energy storage for CO_2 emission reductions. Using a Tesla Powerwall as an example energy storage unit, it has been found that energy storage applications will need to drop below ~£150/kWh for residential applications, for end-users to make even small amounts of profit over the battery lifetime.

Carbon emission reduction, on the other hand, were effectively reduced by residential energy storage. Through extrapolation of the data gathered in this project, it was possible to quantify how much of an effect residential energy storage would have on the carbon emission targets for 2050. If energy storage were to be present in 10% of homes, 6% of the necessary 50% of CO_2 emission reductions could be achieved.

5. Further Work

Due to time limitations on this project, there is great scope for expansion. The main area of expansion would to format the rest of the yearly data that I have not. One of the reasons this project required so much time spent formatting data, is because there was not a simple way of identifying what was important to know. Due to the knowledge gained through this project, I now believe the best way to proceed would be to do one of two things.

The first solution would be to develop a program to sift through the data as I mentioned in section 3.3. This could enable greater control of the energy storage model and hence a more favourable outcome on the scenarios suggested. The second solution would be to develop some association learning methodology [4]. This could easily spot any relationships between variables if they were to arise. It also enables us to sift through the large amounts of data very quickly.

This project would also benefit from an updated set of data. There has been plenty of change in the U.K electricity sector in the last two years, not least the collapse of coal as a major energy source [5]. Having CCGT as the only major source of CO_2 emissions in the electricity market could have changed the way storage is operated.

Work should be done on how the findings within this report should/will influence policy, i.e. do we want to focus on carbon reductions by getting energy storage solutions into at least 10% of homes, and how do we do this? (social housing?). Another aspect would be to look at incentivising purchasing of these systems, by providing cheap loans to buy them for example. Another way of looking at this would be to see how these savings change for people with solar panels and other generating sources in their homes.

It would also be interesting to look at how energy storage could be used to change the residential heat market, i.e. if people installed air/ground source heat pumps, how would this change some of the parameters studied in this project. Could greater carbon reductions be made by using heat storage over the current gas network.

6.References

1. B. Dunn, H. Kamath and J-M. Tarascon. “Electrical Energy Storage for the Grid: A Battery of Choices”. Science, vol. 334, issue 6058, pp. 928-935.
2. https://www.tesla.com/en_GB/powerwall
3. United Kingdom. Department of Energy and Climate Change. “2010 to 2015 Government Policy: Greenhouse Gas Emissions” May 2015.
4. S. Kotsiantis and D. Kanellopoulos. “Association Rules Mining: A Recent Overview”. GESTS International Transactions on Computer Science and Engineering, vol.32, issue 1, pp. 71-82, 2006.
5. S. Evans. “Analysis: UK wind generated more electricity than coal in 2016”. Carbon Brief, January 2017 [online]. Accessed online at: https://www.carbonbrief.org/analysis-uk-wind-generated-more-electricity-coal-2016