DEPARTMENT OF MECHANICAL & AEROSPACE ENGINEERING

University of Strathclyde Engineering

A Future Wind Based Energy Tariff in a Carbon Neutral Energy System

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Copyright Declaration

Signed: Megan Gill

Date: Thursday 25th August, 2022

Abstract

The key aim of this project was to propose a methodology in which to predict a future energy tariff based on renewable generation, particularly wind. This tool was proposed within the context of retrofitting UK homes to reduce demand, and covering demand further by renewable means. This was achieved by creating a tool which took existing parameters - wholesale energy costs, the peak time premium, the price cap - and introduced the wind factor which represents the wind generation via the UK wind capacity factors. This work was carried out to address a gap in the field as currently there is no such tool in place for a specifically wind based energy tariff.

It was found that by analysing the effect of the wind generation for high and low wind periods in multiple scenarios, it was possible to modify and manipulate the tool to suit the user's needs. For high wind periods it was found that a wind-based tariff would carry great benefits for the customer, as on average it proved to be cheaper than the baseline tariffs. The opposite was true for low wind periods, in which a wind-based tariff was always more expensive on average. An important relationship that was observed was that between the wind generation and the tariff price, increasing wind generation saw the the wind tariff price falling for all periods. This is particularly crucial moving forward due to the current energy crisis

This tool works successfully, and is fully modifiable. Every variable and element can be changed to model countless possible future scenarios. The tool has established the base for a future wind tariff, and this predictive tool has the potential to grow into a route towards changing the way that energy companies calculate their prices. Given the fast paced nature of the energy market it is recommended that this tool be modified to keep up with trends.

Acknowledgements

I would like to take this opportunity to thank my supervisor, Dr Paul Tuohy, for his invaluable guidance and unfailing support throughout this project, in addition to Dr Andrew Lyden and Dr Graeme Flett for their insight and support.

I would also like to thank my partner Maks, my parents, and my brother, Gareth, all without whom I wouldn't be where I am today.

Special thanks to the MSc RESE cohort who have made this masters an absolute delight, I will treasure our time together.

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1 Introduction

1.1 Background and Context

As we divest from fossil fuels to renewables, this shift has to be reflected in the way energy suppliers price energy for their customers. By creating a method of calculating an energy tariff that takes wind generation directly into account then consumers will be able to see a more significant effect of wind in their energy bills.

This proposed tariff is unique due to its nature of considering wind generation on a national scale and not just through wholesale market costs or feed-in tariffs.

Research has shown that by retrofitting existing UK homes to the EnerPHit Passivhaus standards that the energy demand from the domestic setting can be reduced by as much as 90% [1]. It is feasible that this new lowered demand could be covered entirely by renewable means, making way for the potential decarbonisation of the energy system, particularly, heat and transport. When this shift is made there will be a need for a tool to calculate energy prices for the consumer – an energy tariff based on both generation and demand. To reach current climate goals of net zero, monumental shift from fossil fuels to renewable energy is required.

The importance of flexibility within the energy system cannot be understated. Variable tariffs are particularly attractive as they reward those that can flex and make investment in flexibility such as batteries, thermal stores, and smart controls. Through tariffs and personal use of smart devices, this will promote the use of energy from renewables at the domestic level. Therefore, a tool is needed by energy suppliers and their customers to predict a wind-based tariff ahead of time. Such predictions can mitigate the uncertainty introduced by wind's intermittent nature. This tariff can be used in conjunction with an app similar to IFTTT (If This Then That) which gives the consumer a great amount of flexibility and freedom. This app, which can currently be used by Octopus Energy customers, allows the user to connect their smart devices to their energy prices [2], meaning that customers can benefit from the changes in the tariff prices in real time. An example command could be “if the wind tariff drops below 15p/kWh then set thermostat to come on”.

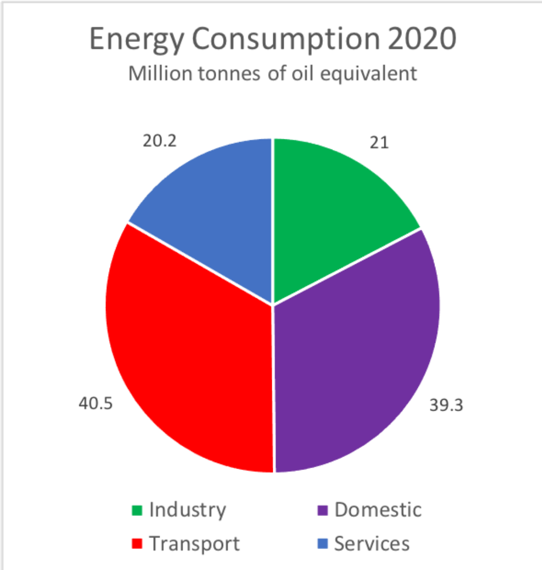

Figure 1.1: Energy Consumption Distribution 2020

This chart demonstrates clearly the impact of the energy demand from the domestic sector as it has the largest demand on the grid behind transport. This shows the domestic setting is a key area to consider in regards to climate change. Reducing this demand via retrofitting and covering the demand with renewables will be a large step on the road to net zero. This is based on the data from the UK Energy in Brief 2021 from the UK Government [3].

1.2 Project Scope

This project looks to investigate current energy tariff pricing, future energy tariffs, wind generation, wholesale market cost, and the energy price cap. In particular, how these elements influence one another was investigated.

1.3 Aim and Deliverables

The aim of this project is to investigate the influence of renewable generation on energy tariffs and propose a methodology for predicting future tariffs for various renewable generation scenarios. The key deliverable of this work is a tool capable of predicting a future wind-based energy tariff, which can be deployed with flexibility to differing energy scenarios.

1.4 Method

The following approach was taken to achieve the goals of this project:

1. Carry out a detailed literature review to establish knowledge base and available data sources i.e. previous work of others to predict future tariffs; current and future generation mixes for the UK; the wholesale electricity markets; current tariffs including Octopus Go and Agile; methods of analysis (excel, python etc); summary of findings and outline of methods that will be used.

2. Gain an understanding of historical data and establish correlations or relationships that can potentially be used to inform future tariffs.

3. Use the relationships and propose a methodology to predict the future tariffs; encapsulate this within a tool and then apply this to some future scenarios with different generation mixes and assumptions and present results.

4. Discuss the outcomes in the context of the project aim and the work of others; identify and discuss any limitations; propose future work; and draw conclusions.

2 Critical Review of Literature

This critical review chapter aims to synthesise key learnings from analysing existing literature and practice, in order to fully inform the methodology proposed and tested in this thesis.

2.1 Previous Work to Predict Future Tariffs

There has yet to be extensive work done within this field, however in [4] the potential for a wind-based tariff for proposed. While this was not the main subject area of the paper, it was suggested that a future renewable tariff could be modelled in the program PyLESA [4], requiring the use of Python. This was modelled in a way that the wind would only effect the tariff for the top and bottom 20% of wind generation to account for low and high wind.

In 2015 Philipp Grünewald et al. considered how effective a time-of-use tariff would be in high wind periods [5]. This paper discussed more in depth the significance of flexible demand side management with the increasing levels of renewable generation. Through their research they found that while wind generation may have effect on the tariff price trend, the peak period still has significant impact. Note that this paper was published in 2015, and in 2018 Octopus Energy UK announced their Agile tariff [6], which incorporates many of the themes within this paper.

As previously mentioned there has yet to be significant, tangible work done in renewables based tariffs. In the research where mentioned, it is never the primary focus of the work [7, 8, 9, 10],.

These works often lack a clear proposal for a renewables based tariff, or a route towards that. This could be for many reasons such as the intermittent nature of renewables, therefore this could mean a unpredictable energy tariff. There are also a great many elements to consider when trying to predict a renewables based tariff, all of which would be difficult to consider in one piece of work.

2.2 Energy Generation Mix

Considering the current and future energy generation mix within the UK is paramount to understanding the influence it has on the tariff prices.

The current energy mix in the UK relies heavily on fossil fuels, as seen in figure 2.1 below. Fossil fuels still make up 45.4% of the generation mix, with renewable generation only accounting for 27.7% of the mix, 19.1% of this coming from wind generation [11].

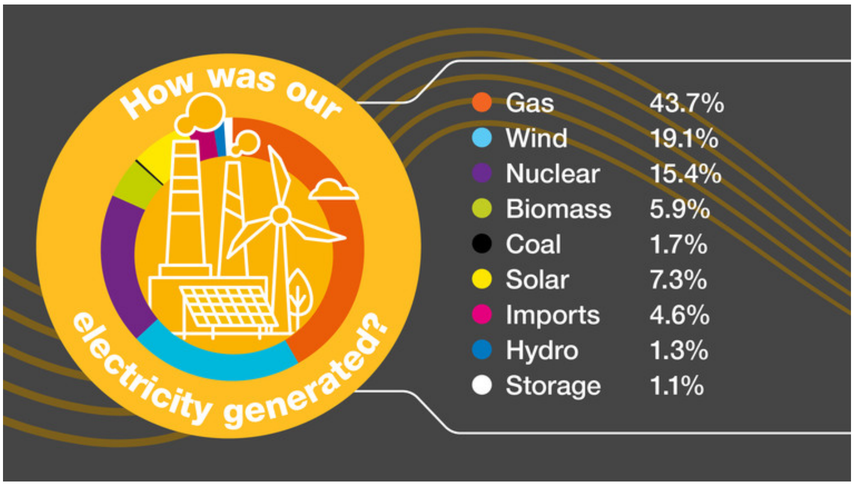

Figure 2.1: UK Energy Generation Mix July 2022 [11]

A large percentage of the UK's wind generation comes from Scotland, given the high levels of wind. The current potential output power from wind in the UK can be seen on the map in figure 2.2 below.

While this thesis is focusing on the UK as a whole it is important to consider where the energy from wind is being generated, due to political climates and transmission costs for example.

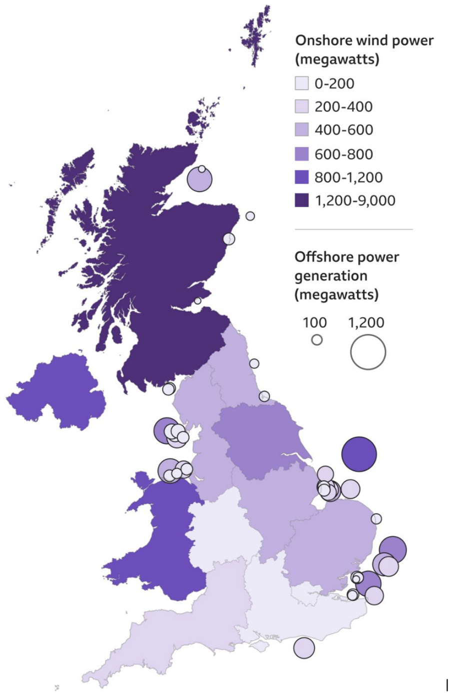

Figure 2.2: Potential Output Generation from Wind [12]

This brings attention to wind generation in Scotland. The figure below shows the renewable generation in Scotland. While it dropped in 2021 the overall trend is positive and increasing. It can be estimated that wind, both offshore and onshore, account for 73.4% of the renewable generation in Scotland [13].

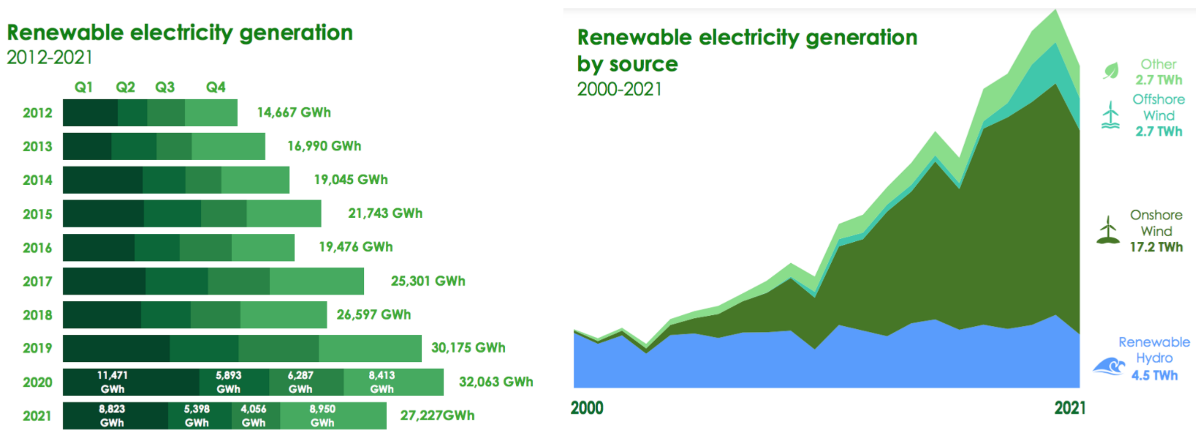

Figure 2.3: Scotland Renewable Electricity Generation [13]

With the cost of building wind farms falling the opportunity to increase wind generation has never been greater. The current climate change goal to be 'Net Zero' by 2050 has motivated the

UK government to invest further in wind and renewables. Prime Minister Boris Johnston stated that the UK would be aiming to 'quadruple' the offshore wind capacity [14]. It is said that by 2030 offshore wind should make up a third of the UK's electricity generation [15].

While this is a step in the right direction, further wind projects could be in place if it were not for the current restrictions in place for future onshore wind development. Despite onshore wind farms being cheaper to develop, it has become difficult to gain permission to build them [16]. Currently in England most, if not all, onshore wind developments are rejected as with the UK's planning regulations, a new development can be stopped by one person [17]. There are many calls for reform so that more onshore wind developments can go ahead, which is much needed for the UK to decrease its reliance on fossil fuels.

2.3 Wholesale Energy Market

It is necessary to understand what drives the wholesale energy market costs, this is primarily supply and demand [18]. As demand fluctuates so too must supply to create balance, therefore, as demand increases so does the levels of supply. Due to the fact that demand is traditionally inflexible therefore the supply has to be. This demonstrates the importance of the electricity generation mix, if supply is coming mostly from fossil fuels during a high demand period then the wholesale costs will be higher.

A large factor in the wholesale prices is gas prices [19], which recently has become increasingly more expensive partially due to the Russo-Ukraine war. As the UK continues to rely on gas to generate electricity and supply heating with these increasing prices then the wholesale costs will also continue to rise, which is directly reflected in the tariff prices. This prediction can be seen in figure 2.4 below.

However, there are many other factors which have influence over the wholesale prices not just the costs of generation. Elements such as weather, currency rates and political events can have an effect on the wholesale prices [18].

While the price will increase as we continue to use expensive fossil fuels, the cost of renewables is very low [19], so it can be said that as renewables begin to make up a larger percentage of the UK's energy generation mix this would be reflected in the wholesale market prices [21].

Figure 2.4: UK Wholesale Price Projection for Winter 2022 [20]

2.4 Current Energy Tariffs

Understanding what tariffs are currently on the market was essential to establishing a potential gap in the market. Of particular interest are Octopus Go and Octopus Agile which are cutting edge examples of flexibility in modern energy tariffs.

2.4.1 Octopus Go

Octopus Go offers cheaper energy prices overnight between 00:30 - 04:30, which would benefit in particular customers with electric vehicles who charge at home [22]. Customers on this tariff can see prices of $7.5p/kWh$ overnight [23]. While this has great benefits for the customer, battery electric vehicles only make up for 10.9% of the newly registered cars in 2022 [24]. It can be said that this is a more niche tariff with a much smaller reach.

2.4.2 Octopus Agile

The Octopus Agile tariff is an example of a time-of-use tariff, which means customers will be subject to flexible energy prices. This tariff uses the introduction of a ‘peak premium’, which will be charged to customers between 16:00 - 19:00 to account for high levels of demand [25]. This encourages customers to use less energy in this period to avoid that premium, thereby reducing peak time demand and reliance on fossil fuels.

This tariff has even offered customers negative pricing on multiple occasions [25] - referred to as ‘plunge pricing’. When there is an excess amount of energy on the grid, suppliers are paid to use this energy and this saving is passed on to the customer with negative pricing [26]. Currently there is no other tariff on the market doing this, setting Octopus ahead of its competitors.

From the research carried out it appears that the Octopus Agile tariff is the largest tariff on the market that could be modified to create a wind based energy tariff. This is favourable to bringing an entirely new tariff onto the market, as this would be expensive to implement and would come with great levels of uncertainty.

2.5 Summary of Analysis

While there is much promise in this field, it was clear from critical research that there is still much to be explored within this field, which this thesis will aim to address. Key elements which were deemed significant are; the current generation mix in the UK which is still predominantly fossil fuels; the influences driving the wholesale energy market prices which were found again to be fossil fuels.

3 Methodology

3.1 Establishing the Tool Variables

The foundations of this tool are based on a singular equation. This tool was designed to predict a future wind-based energy tariff, and it is able to predict the tariff price on an hourly basis. To determine a tariff price the equation currently used by Octopus Energy UK was selected [25], which can be seen below:

$$T = min(2.20 \times W + P, C) \tag{3.1}$$

where,

- T is the tariff price,
- 2.20 is a coefficient which includes the distribution costs,
- W is the wholesale energy costs,
- P is the peak time premium to account for grid congestion between the hours 16:00 and 19:00, and
- C represents the price cap set by Ofgem which will ensure customers are charged no more than this.

This calculation however does not take the wind generation into consideration in a significant way; therefore, it was necessary to make modifications to this equation to account for that. The modified equation that will be used can be seen below:

$$T = min(2.20 \times W + (P + Q), C) \tag{3.2}$$

As shown this equation remains true to the original with the addition of the parameter Q, - this represents the wind factor. This is dependent upon the wind capacity factor (WCF) at that given time. The WCF is the average power generated divided by the wind's peak capacity [27]. When the WCF is below a certain value, then there will be an additional charge to the tariff and there would be a discounted price when the WCF is above a particular value.

3.1.1 Baseline Scenario

It was decided to use 2019 as the base year for modelling the predictive tariff tool, using southern Scotland wholesale energy prices with the national wind capacity factors for the UK. The choice to model within 2019 was a calculated decision, taking into account the impacts of the 2020 coronavirus pandemic and the current energy crisis in conjunction with the inhumane Russo-Ukrainian War that broke out following the invasion of Ukraine in February 2022 [28, 29]. The baseline tariff was first determined using equation 3.1 without considering wind.

Initial Wind Based Tariff Predictions

Then, by using equation 3.2 to determine the future wind-based tariff it was possible to make a clear comparison between these tariffs, for high and low wind periods. These high and low wind periods were determined by averaging the wind capacity factors for each month of the year. From there, the windiest week in a high month and the least windy week of a low wind month were used to model within the tool.

The comparison of the baseline and wind tariff was made for every scenario modelled within this tool, so to analyse potential benefits or drawbacks of the wind tariff.

Note that for every scenario modelled within this project the 2.20 coefficient remained unchanged, and W was always the wholesale prices from 2019. The peak premium used here was $12p/kWh$ - this was decided based on Octopus' current peak premium charged to customers [25]. For this scenario, when the WCF was less than 0.2 then $Q = 10p/kWh$ and when it was more than 0.5 then $Q = -10p/kWh$. The wind factor range was not particularly large to begin with as it was paramount to determine its effect initially before further tests. The price cap here was $35p/kWh$, which was taken from Ofgem as this is the current price cap for the period 1 April – 30 September 2022 [30].

3.1.2 Future Scenarios

Once the model was showing the desired outputs from the baseline and initial scenarios, it was ready to be tested.

Increased Price Cap

The first future scenario was based on current predictions that in October 2022 the energy price cap will increase by up to 78% [31], from calculations it can be estimated that C will be $62p/kWh$. The peak premium and the wind factor were kept the same as in the baseline, which allowed for the observation of the effects of the price cap and the closely related effects of the current energy crisis in the UK.

Increased Price Cap and Increased Wind Generation

On a more hopeful note, the tariff was modelled in a scenario in which wind generation was increased in the UK by 30% in conjunction with the increased energy cap. By increasing the wind capacity factor by 0.3 in the respective formula, it was possible to model this future scenario. A key observation from this was that modifying and using the tool to suit the users' needs was straightforward. All other parameters from the first future scenario were unchanged here so as to solely observe the effects of increasing the wind generation.

Extreme Future Scenario

In the final scenario, the tool took into account current trends in the energy market which suggest that the price cap will continue to increase further in the coming years. Here, the only parameters which changed were the price cap, which was set to $150p/kWh$ to reflect these predictions, and the wind factor. In this instance the wind factor range was increased to model a scenario in which there is a high penalty for the use of fossil fuels, as the current increase in the cost of energy appears to be driven by the costs of natural gas [19]. Therefore, Q was set to $\pm 50p/kWh$, all other parameters were unchanged.

It is important to note that all of the parameters within this equation are subject to change, and this is possible to model within the tool. While it was decided to keep the 2.20 coefficient and the peak premium unchanged for these scenarios, these were strategic choices. It was unlikely that increasing the peak premium value would have any effect on the energy tariff price as for each of these scenarios the peak price was always met during peak hours.

3.2 Tool Structure

3.2.1 Current System

In the current system wind generation is only taken into consideration through the wholesale market costs, on which wind has little effect given it makes up only 19.1% of the current generation mix [11]. As the energy mix is quite varied the effects of the wind on the wholesale price is minimal. Therefore. this is not the optimal approach given the much-needed shift to renewables.

3.2.2 Proposed System

As we look to decrease our reliance on fossil fuels in favour of renewables, a smarter way to price energy is required. Currently energy is predominantly priced based on demand and supply source, however in the proposed tool the wind generation is taken more directly into consideration with Q, the wind factor. This system introduces the opportunity for high levels of flexibility for the consumer, with the goal that this type of tariff could be used alongside an app such as IFTTT.

3.3 Tool Creation

This tool was created using excel, due to its quick and powerful data visualisation capabilities.

Below the home page of the tool is shown:

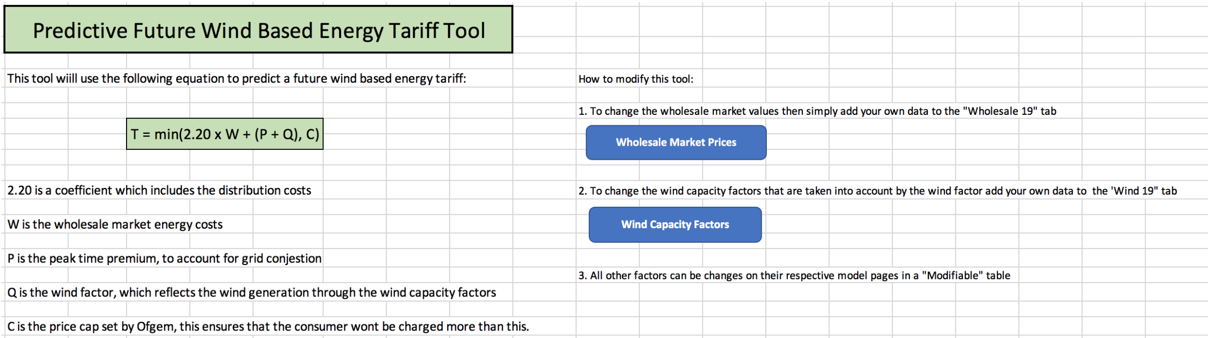

Figure 3.1: The home page of the predictive tariff tool

To change the input data such as the wholesale market prices or the wind capacity factors, the user can simply click the respective buttons on the home page. Once the desired paged has been reached the user can change out the data for their own.

Once these have been updated, the user can then test this data by changing the parameter values in a table like the one seen below in figure 3.2.

Modifiable		
Price Cap, C	35	p/kWh
Peak Premium, P	12	p/kWh
Wind Factor, Q	10	p/kWh
Wind Factor, Q	-10	p/kWh

Figure 3.2: An example of the table in which the user can change the input parameters

A table such as this is present for each scenario that was modelled.

4 Results

4.1 The Baseline

To begin it was important to analyse the data available to determine the appropriate tests that needed to be carried out. Through initial investigations it was found that given the current variation of the energy generation mix, there was no visible impact of the wind generation on the wholesale market price. This can be seen in figure 4.1 below.

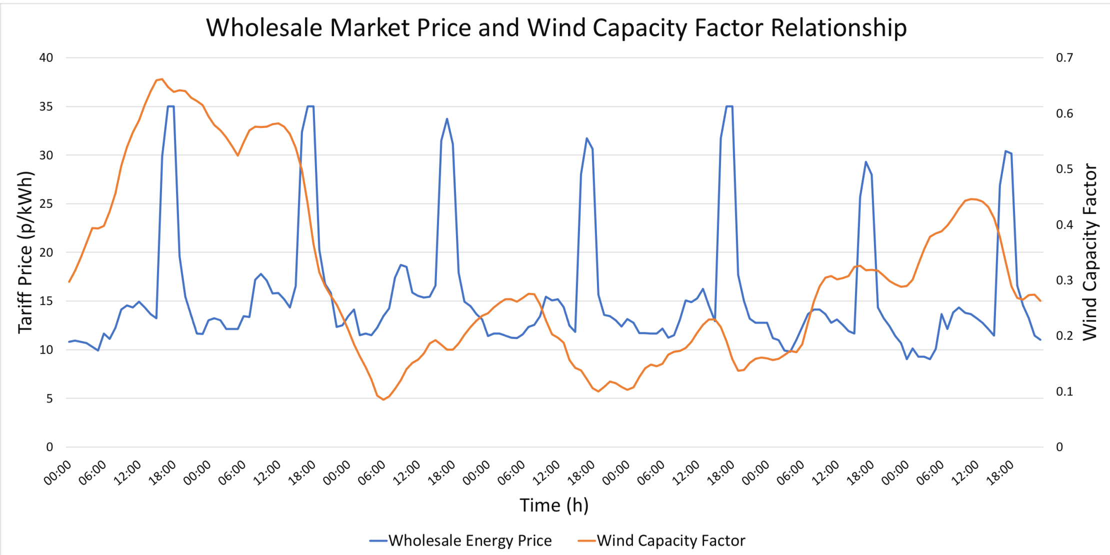

Figure 4.1: The relationship between the wholesale energy market price and the wind capacity factors for the same one week period.

As previously mentioned there was no obvious correlation between the wholesale market costs and the wind capacity factor, therefore, wind generation. However, the wholesale costs appeared to increase at peak times suggesting that it is influenced by the levels of demand.

It would be difficult to reduce peak time energy costs with the driving force of the tariff prices being the wholesale costs, which make up an estimated 55% of energy bills [32].

It was important to see how the wholesale market price was influenced by the wind capacity factor as this investigation has shown that the consumer would see no benefit of using their energy at periods of high wind, due to the fact that there is no strong infrastructure for this.

By averaging the wind capacity factors for each month of 2019, it was found that the windiest month of the year was March, with an average WCF of 0.435, and the least windy month was May, with an average WCF of 0.189. A comparison of these can be seen on figure 4.2. When calculating the future wind-based tariff the weeks 10/03 – 16/03 and 10/05 – 16/05 were used, as these were the extremes within each of their months respectively.

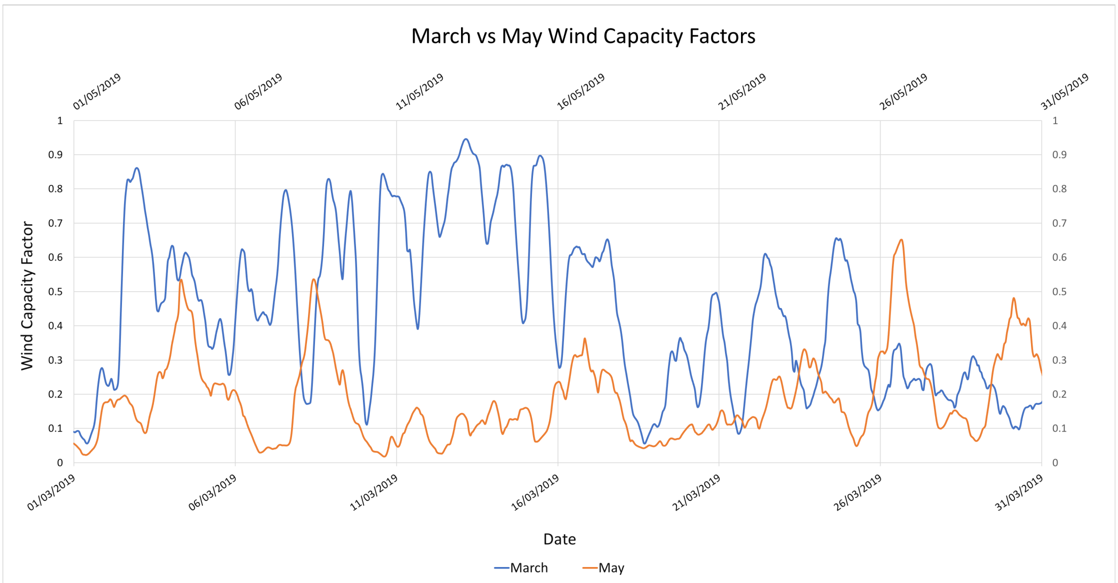

Figure 4.2: The wind capacity factors for March and May in 2019.

The graph shows a distinct contrast between high and low wind months, suggesting that going forward these periods will show the most change from scenario to scenario.

4.2 Initial Wind Based Tariff Predictions

By substituting the values in 4.1 below in to equation 3.2 in the tool, it was possible to begin modelling to predict a future wind tariff.

Parameter	Value	Units
Peak Premium, P	12	p/kWh
Price Cap, C	35	p/kWh
Wind Factor, Q	$\pm$ 10	p/kWh

Table 4.1: The input parameters used for the tool to attain an initial prediction of the future wind tariff.

Figure 4.3 below shows the wind tariff for a high wind week in March which was shown to be the windiest month on average in 2019, in comparison to the baseline tariff using the Octopus Energy equation 3.1. It can be seen that the proposed wind tariff, in this case, was almost always cheaper.

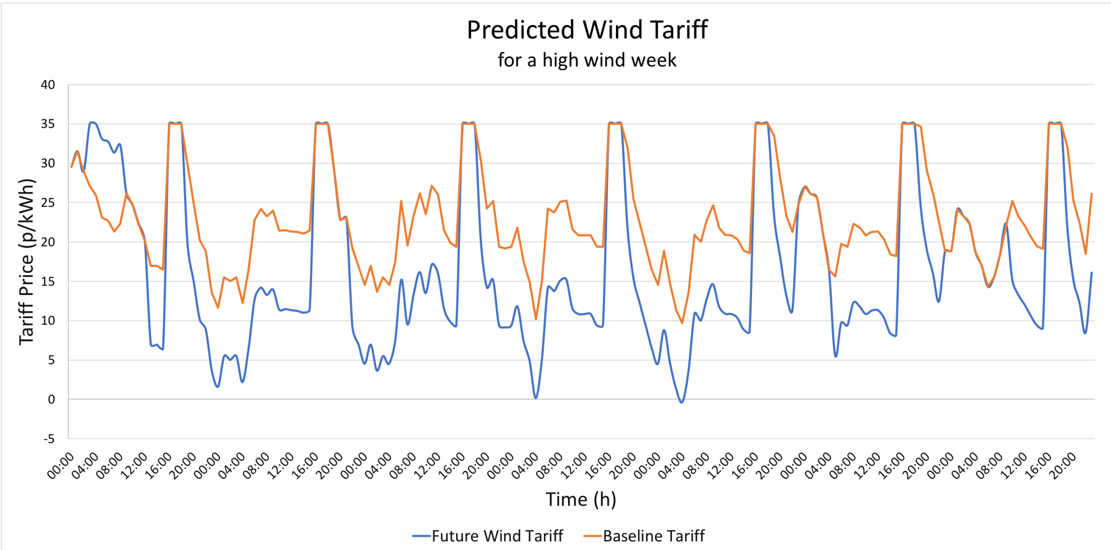

Figure 4.3: Predicted wind tariff for a high wind week in March 2019 in comparison with baseline tariff from the Octopus Energy UK equation

For this high wind week the average baseline tariff price was found to be $\underline{22.9p/kWh}$ and the future wind tariff was predicted to be $\underline{16.5p/kWh}$.

The wind tariff follows the same trend as the current tariff and is still subject to the peak periods. The wind tariff however was almost always discounted, outside of peak periods, in comparison with current tariff calculations. This gives a clear view of the impact of the wind factor on the tariff. As this was a high wind week there was a clear benefit to the customer as in theory this discount would passed on directly to them.

In comparison, future wind tariff for a low wind week was much more expensive as seen in figure 4.4 and often reaches the energy price cap (which at present is increasing every 3 months [33]). This raises questions of whether this kind of tariff provides value in the long term.

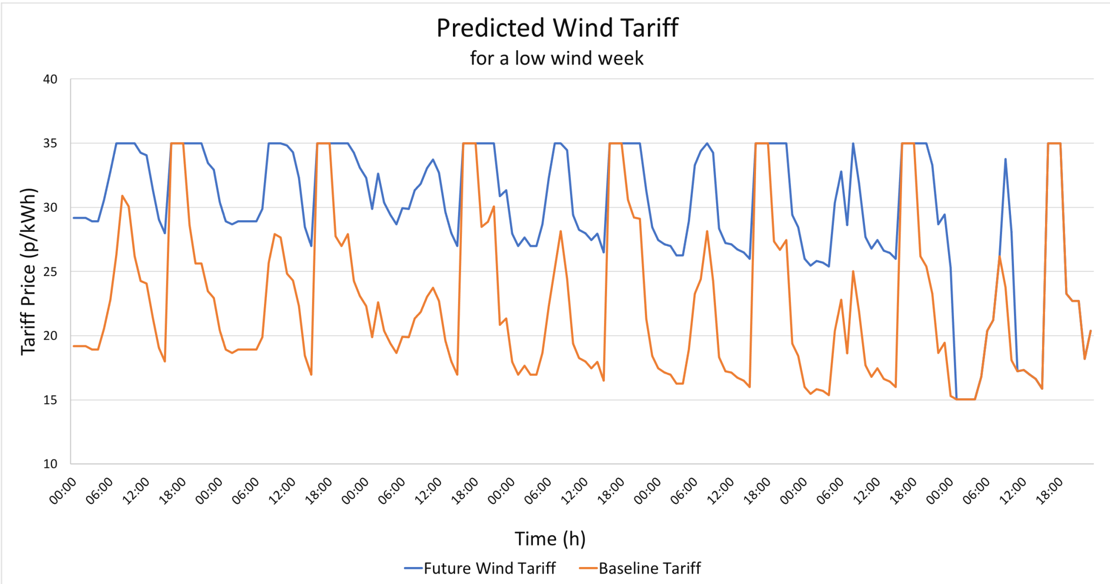

Figure 4.4: Predicted wind tariff for a low wind week in May 2019 in comparison with baseline tariff from the Octopus Energy UK equation

For this low wind week the average baseline tariff price was found to be $\underline{22.6p/kWh}$ and the average wind tariff was predicted to be $\underline{29.9p/kWh}$.

This shows a potential downside of the proposed wind tariff. When the wind generation is low, the tariff price is always more expensive. In many instances, the tariff reaches the price cap outside of the peak periods, which does not appear to happen on the baseline tariff.

Therefore, it could be said that it would appear more beneficial to remain on the current energy tariff in this case – this however comes with consequences. The move to renewables to meet climate change targets requires subsequent changes in tariff calculations.

In figure 4.5 below it can be seen the wind capacity factor has a direct impact on the tariff price as expected, only at peak periods was the effect of the wind minimal or non-existent due to the peak time premium. This would suggest that if the wind generation were to be increased, then this effect could be further exacerbated. If the wind capacity is higher, the price would be cheaper. The opposite observations were made for a low wind period. This relationship is the key to future energy tariffs as the shift to renewables continues.

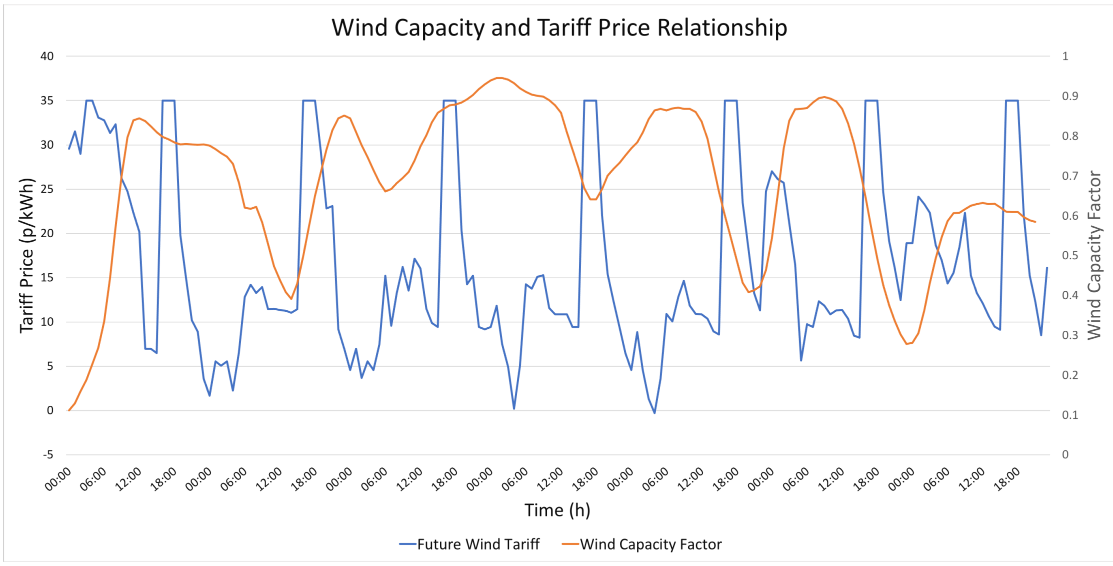

Figure 4.5: The relationship between the wind capacity factor and the predicted wind tariff for a high wind week in March 2019

The implications of this relationship are not to be understated. By taking advantage of this relationship by potentially increasing wind generation the effects of this would be directly seen the tariff price.

4.3 Future Scenarios

4.3.1 Increased Price Cap

Looking to the future in October 2022 the energy price cap is set to increase by a predicted 78% with trends suggesting further increases into 2023 [31]. Therefore, it was necessary to test the tool for such circumstances. This was modelled using the values in table 4.2 below. It was also modelled that the baseline tariff was also subject to the increased price cap here. The price cap used was calculated based on current predictions.

Parameter	Value	Units
Peak Premium, P	12	p/kWh
Price Cap, C	62	p/kWh
Wind Factor, Q	± 10	p/kWh

Table 4.2: The input parameters used for the tool to predict the effects of an increased price cap, and later the effects of increasing wind generation.

Figure 4.6 below demonstrates a similar trend to that of figure 4.3 only now the peaks are particularly expensive, and the troughs are not as cheap as they once were.

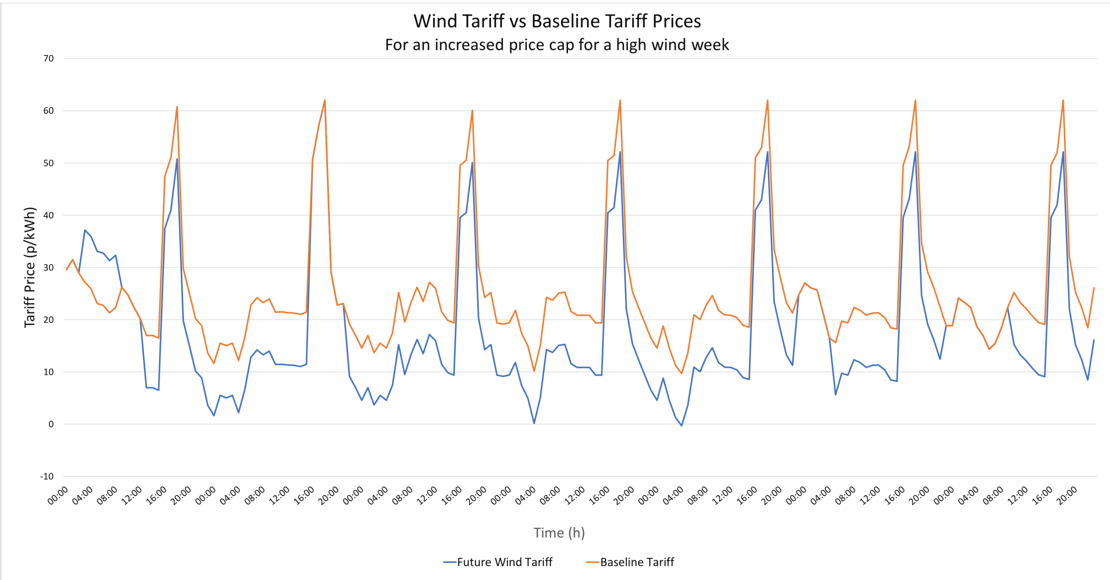

Figure 4.6: The predicted wind tariff and baseline tariff under the effects of the increased energy price cap of October 2022 for a high wind week.

With the increased price cap the average wind tariff price was found to be $\underline{17.9p/kWh}$. This is overall a higher average compared to the lower price cap.

Even though the tariff is more expensive here than shown in figure 4.3, it still remains cheaper than the baseline tariff in most instances. This shows how the benefits of this tariff could be reaped as the price cap increases in October.

When the price cap is increased the wind tariff is still almost always more expensive than the baseline tariff for a low wind period, only now it even surpasses the baseline tariff price during the peak periods. This is shown in figure 4.7 below.

With the increased price cap the average wind tariff price in this case was found to be $\underline{33.3p/kWh}$.

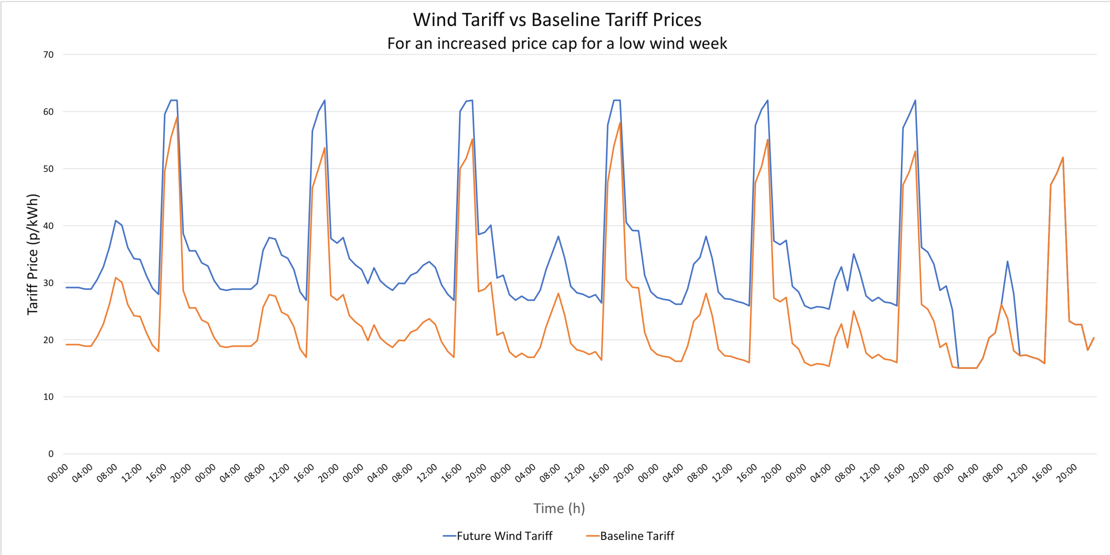

Figure 4.7: The predicted wind tariff and baseline tariff under the effects of the increased energy price cap of October 2022 for a low wind week.

4.3.2 Increased Price Cap and Increased Wind Generation

In attempts to mitigate the effects of the increased price cap, the wind tariff was modelled with a 30% generation increase in this future scenario. This is also indicative of the UK's current plans to build more wind farms [34]. Therefore, it is necessary to model this.

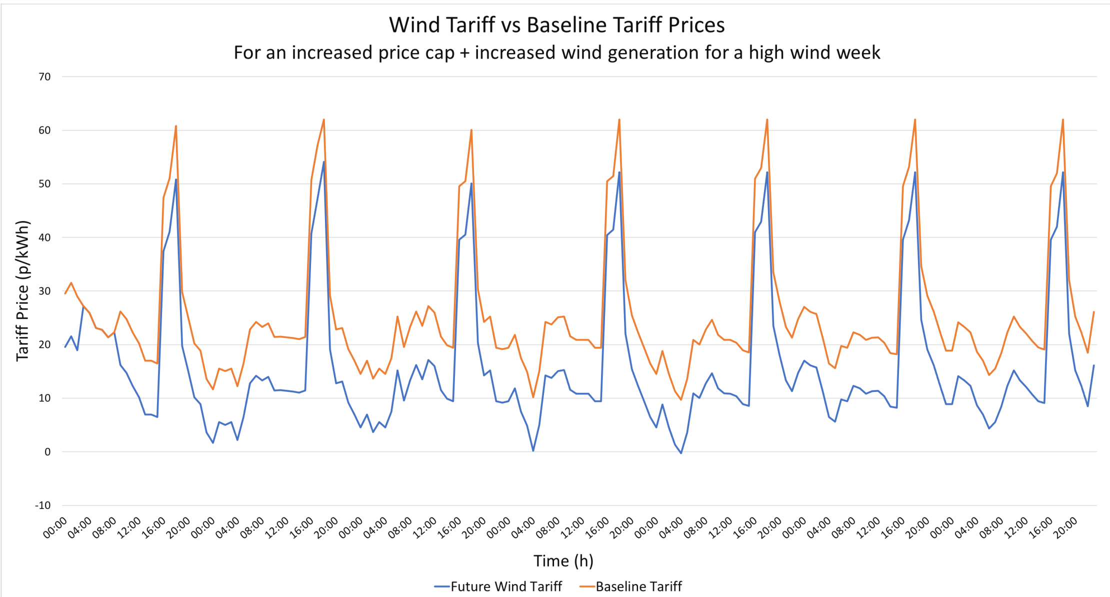

Figure 4.8: The predicted wind tariff and baseline tariff under the effects of the increased energy price cap of October 2022 with a 30% increase in wind generation for a high wind week

It can be seen that by increasing the wind generation by 30%, the wind tariff prices can be decreased in some places shown in figure 4.8, yet again making the wind tariff always cheaper than the baseline tariff, save for one occasion in which they are the same suggesting the wind tariff was no influenced by the wind factor here - it was neither a high nor low wind period. The change for a high wind week such as this was not particularly drastic. By increasing the wind generation here the average wind tariff price was found to be $\underline{15.7p/kWh}$

Contrary to a high wind week, and previous scenarios for low wind weeks, here a generation increase lowers the wind tariff price down to a similar price to that of the baseline tariff. The wind tariff is only cheaper here at the end of the week.

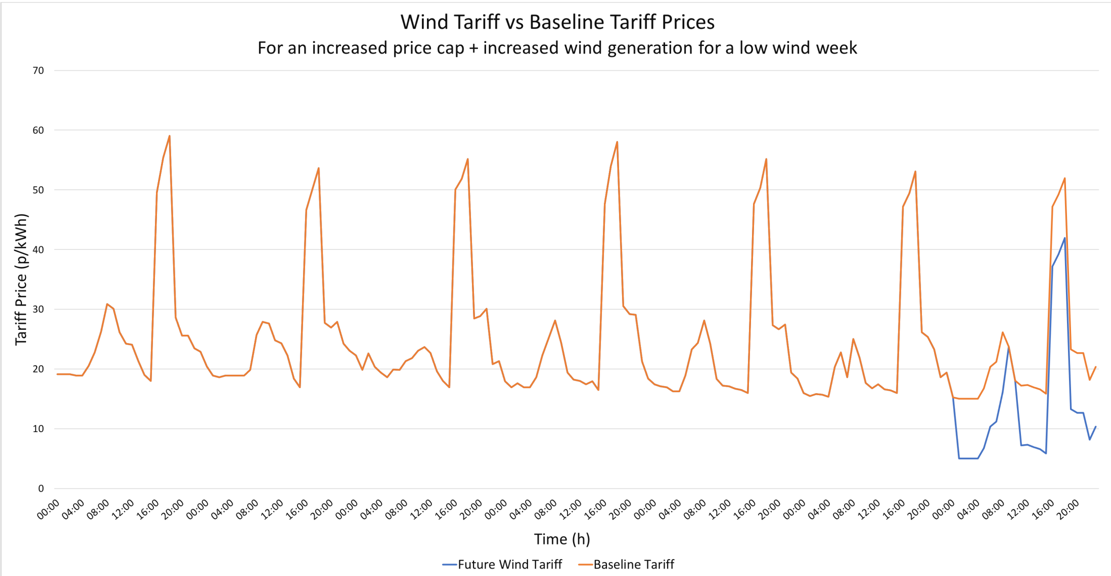

Figure 4.9: The predicted wind tariff and baseline tariff under the effects of the increased energy price cap of October 2022 with a 30% increase in wind generation for a low wind week.

For the low wind week in this case the average wind tariff price was found to be $\underline{23.3p/kWh}$, which is less than 1p/kWh more expensive than the baseline on average. It can be seen here that by introducing higher levels of generation, for the first time in modelling, the wind tariff for a low wind period can be lowered enough to be almost the same price as the baseline tariff.

4.3.3 Extreme Future Scenario

For the final future scenario the price cap was increased drastically to simulate a future in which the energy crisis continues. Therefore, to model this the values shown in table 4.3 below were used.

Parameter	Value	Units
Peak Premium, P	12	p/kWh
Price Cap, C	150	p/kWh
Wind Factor, Q	$\pm$ 50	p/kWh

Table 4.3: The input parameters used for the tool to predict the effects of a significantly increased price cap and wind factor with a larger range.

The larger range of the wind factor was also chosen to emulate a potential high penalty of resorting to energy generated from fossil fuels. Similarly, a higher discount would be given at periods of high wind to incentivise the use of renewable energy. The impacts of changing these parameters by larger margins can be seen in figure 4.10 below.

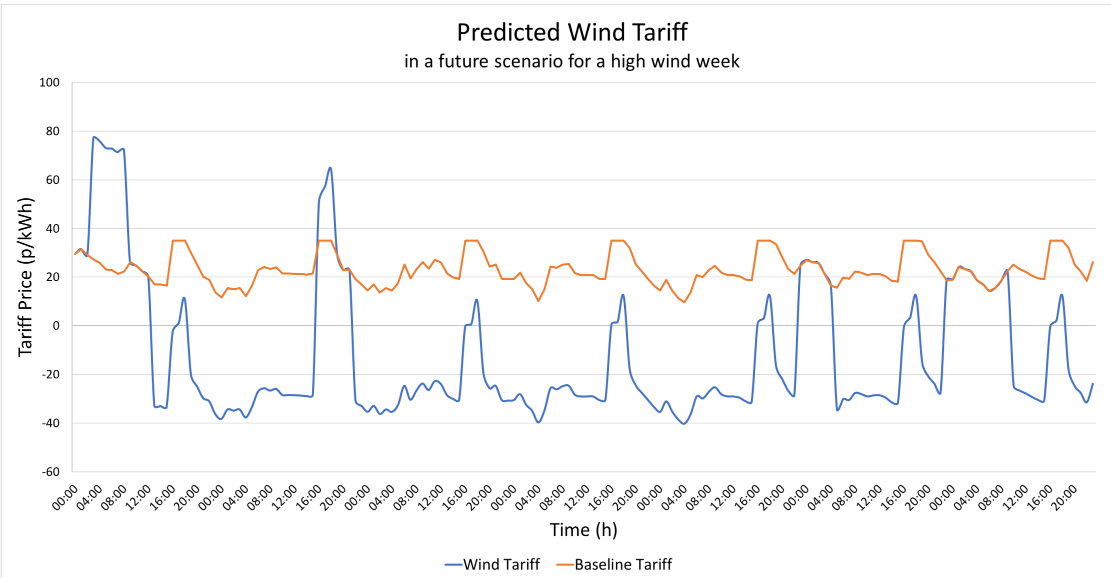

Figure 4.10: The predicted wind tariff and baseline tariff under the effects of a dramatically increased energy price cap and a wind factor with an increased range for a high wind week.

It can be see that despite a much higher price cap, the wind tariff in this case was significantly cheaper than the baseline tariff and the other scenarios for high wind periods with the average tariff price being $\underline{-12.1p/kWh}$. This means that the customer is being paid to use their energy, this again mostly occurs outside of peak periods.

In the time when the consumer is being charged for energy, the prices are exceptionally low. Only on four occasions does the wind tariff price reach above $20p/kWh$. While this benefits the consumer, energy companies would have to assess whether this would mean a loss of profit for them or whether investments in storage may be needed. This is where it is important to also look at low wind periods, a representation of which can be seen in figure 4.11 below.

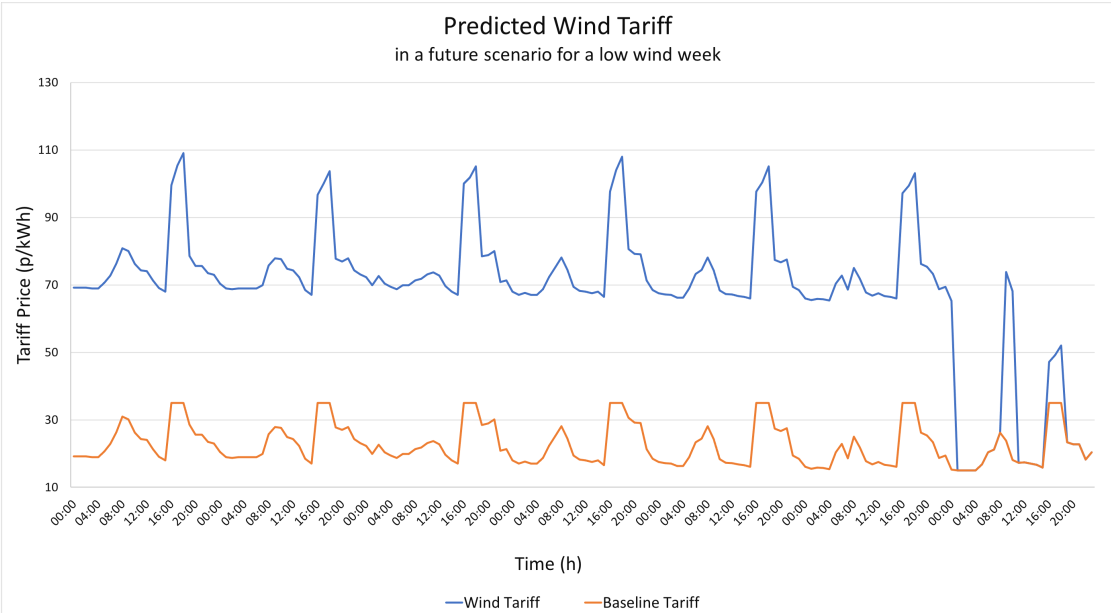

Figure 4.11: The predicted wind tariff and baseline tariff under the effects of a dramatically increased energy price cap and a wind factor with an increased range for a low wind week.

Here the effects of increasing the price cap and having a penalty when using fossil fuels when the wind generation is low can be seen working in tandem, as the price of energy on the wind tariff appears to skyrocket with the average price being $\underline{68.5p/kWh}$. This is an increase of $80p/kWh$ from the high wind week modelled in figure 4.10.

4.4 Summary of Results

In table 4.4 below is the average tariff prices for each of the modelled scenarios.

Scenario	High Wind Week (p/kWh)	Low Wind Week (p/kWh)	Whole Year (p/kWh)
Baseline	22.9	22.6	22.3
Predicted Wind	16.5	29.9	23.3
Increased Price Cap	17.9	33.3	26.0
Increased Price Cap + Increased Wind	15.7	23.3	17.8
Extreme Future Scenario	-12.1	68.5	32.0

Table 4.4: The average output tariff prices for each scenario

By comparing these values it is seen that the tariff price for high wind periods was always cheaper then the baseline tariff. However, the tariff price for low wind periods was always more expensive then the baseline tariff. Modelling suggests that on average for the full year this tariff is more expensive, save for the introduction of increased wind generation. Further demonstrating the importance of building more wind farms across the UK.

5 Discussion

5.1 Outcomes

By introducing the wind factor into equation 3.2 it was possible to see the tariff price was significantly affected, whether that be for high wind periods when it was always cheaper or in low wind periods when it was more expensive than the baseline. This is what would be expected given the nature of the Q factor, which has been designed to have an impact on the tariff price depending on the WCF.

This further emphasises the importance of increasing wind generation. As seen in table 4.4, the scenario with the wind generation increase was cheaper over the year. This suggests that the low wind penalties are outweighed by the high wind discount.

The results found implied that by having this tool in place customers at the domestic level would benefit directly if suppliers were to adopt this method. Given the climate of the UK, and plans to increase wind generation there will be a demand for a tool such as this. It was possible to observe how the wind could have an overall positive impact on the way energy tariff prices are determined and the significance of the WCF and the tariff price.

Taking the current energy crisis into account, as the UK continues to heavily depend on fossil fuels energy prices will continue to rise, as they have been in recent months. Results from the 'extreme future' scenario demonstrate potential future trends if wind generation were not increased. On average the cost of energy could go up by as much at 50% compared to the baseline tariff previously determined.

5.2 Limitations

Given the nature of Master's theses, the time frame in which to carry out this work limited the potential scope of investigation. More possible future scenarios could have been taken into account, potentially investigating the effects other methods of renewable generation may have had on the tariff prices.

Due to the fast-paced nature of this field it was a challenge to always model with the most recent data. The data used was that which was available at the time of modelling, which is a consideration for future work. The breadth of this field also made it difficult to consider every single element that goes into pricing energy tariffs which is very complex. To quote statistician George Box - ”All models are wrong, but some are useful”.

5.3 Future recommendations

This tool could be built on to include many of the other elements that go into pricing energy tariffs - VAT costs, distribution costs (DUoS) and transmission costs (TNUoS) to name a few. Given access to more detailed data, this would be a possibility.

As mentioned previously this is a very fast moving industry, therefore this tool will have to be modified to keep up with current trends, which this tool allows for given its flexibility and versatility.

6 Conclusion

A predictive tariff tool was created and was able to successfully predict a future wind based tariff for multiple future scenarios. The tool was able to take into account key variables such as wholesale market costs, peak time premium cost, the energy price cap and the wind factor. This wind factor was a new concept brought in to reflect the wind generation in the tariff price, which proved significant. The tool was modelled in such a way that it is straightforward for users to navigate and modify to test further scenarios or the existing ones within the tool. This demonstrated the flexibility that this tool aimed to provide. This tool could aid in bringing this type of wind-based energy tariff onto the market at a larger scale, following further work.

A key observation made from this work was the relationship between the wind tariff and the wind generation. While it may seem obvious, wind generation showed to have a large impact on the tariff prices. The future scenario where the generation was increased appeared to be the most positive scenario overall with cost falling across the full year. This clearly demonstrated the importance of increasing the wind generation in the UK to work in conjunction with this tool, as the consumer stands to benefit greatly from renewable energy not solely from a climate perspective, but also an economic one.

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