The Impact of Demand Side Management on the Wholesale Prices of the British Electricity Market

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1 Introduction

The current power system in Great Britain (GB) was built after the First World War, when the National Grid was established with the intention of connecting power stations with centres of demand. During that time there were few places of generation so it was not difficult to adapt to customers' needs by putting the very first pylons on the horizon. When designed, the grid that ended up growing across the island was well equipped to respond to advances in technology without any risk of grid performance complications. However, as time went by the additions to the grid grew more and more elaborate and nowadays it seems the grid is no longer suited to keep up with what current power systems technology demands from it. There has been a significant push for the development of the so-called smart or integrated grid. A smart grid is a modernised version of the current grid, equipped to better cater to growing demand and features intricate technologies developed to decrease the likelihood of faults, blackouts, or attacks on the grid. The smart grid brings many novelties and the most discussed ones are renewable energy technologies, energy storage, electric vehicles, and demand side management (DSM). This paper aims to demonstrate the effect of integrating demand side management technology into the grid and the resulting impact that would have on wholesale prices in the British electricity market. There are many benefits to including the demand side in the electricity market as it makes the markets more efficient and competitive. Furthermore, there is a relatively low utilisation of generation and networks (of about 50%) meaning there is a significant scope for DSM to contribute to increasing the efficiency of the system investment, [1]. DSM could also aid with the integration of other smart grid technologies such as intermittent renewable generation.

2 Demand Side Management

There are three types of DSM, which are: energy efficiency, dynamic demand, and demand response. The latter's main goal is demand reduction in addition to helping with the integration of renewable energy; it is the main focus of this paper. Energy efficiency aims to use less energy required but still provide regular energy products and services. This method aims for permanent reduction of demand by using more effective load-intensive appliances. The most common example of successful implementation of energy efficiency is the switch made from using traditional incandescent light bulbs to using LED lights, fluorescent lights, or maximizing the use of natural light. Energy efficiency tends to increase with the advances in certain technologies or finding an improved way to carry through a production process, allowing for the same tasks to be performed by using less power. Energy efficiency can be achieved in simpler ways as well. For instance, instead of increasing heating in the house, the residents can also choose to wear another layer of clothing and thus avoid paying higher electricity bills. Reducing energy use is also seen as a pathway towards reducing greenhouse gas emissions. According to the International Energy Agency, improved energy efficiency in buildings, industrial processes, and transportation could reduce the world's energy needs in 2050 by one third, and help control global emissions of greenhouse gases, [2]. Dynamic demand is used to speed up or delay operating cycles of appliances by a few second to increase the diversity factor of the set of loads. The original idea that has now been abandoned was pitched in the early 80s by Fred Schweppe, [3]. The concept of monitoring the power factor of the power grid, as well as their own control parameters, individual, intermittent loads, would switch on or off at optimal moments to balance the overall system load with generation, reducing critical power mismatches. As this switching would only advance or delay the appliance operating cycle by a few seconds, it would be unnoticeable to the end user and is the foundation of dynamic demand control, [4]. There are similarities between dynamic demand and demand response when managing electricity consumption based on supply conditions for domestic and industrial users. In the case of the former, electricity use is reduced to mitigate the problems occurring with the grid and in an effort to avoid paying higher electricity prices in the latter case.

2.1 Demand Response

Demand response (DR) is a technique used in smart grids to shape customer load during peak hours when the generation capacity is in danger of being exceeded. Automated DR offers utilities more control and a higher degree of confidence in the outcome, [5]. Initially, the focus of DR was on reducing peaks in order to put off the high costs associated with building new generation capacity. Nowadays, however, DR is also used to help with smoother integration of intermittent renewable energy, as it aids with changing the net load shape. Further, DR can also be defined as the incentive payments designed to induce lower electricity use at time of high wholesale market prices or when system reliability is jeopardised, [6]. DR heavily relies on user participation and end users' willingness to change their habitual patterns of energy use during peak periods or high prices in the electricity system. With these behavioural changes, DR aims to achieve modifications in the timing, level of instantaneous demand, and the overall electricity consumption, [7]. Since this would mean users would have to actively change their established patterns of energy use to adapt to the electricity markets and systems, doubt has been expressed about the implementation of DR in smaller households. The impact on the customer's comfort means this technique is better suited for industrial and commercial settings than for residential homes, [5]. Issues have been raised on the platform of consumer privacy due to the two-way flow of information, which could be considered intrusive, accuracy due to the small scale of each individual participating project, customer satisfaction, and more importantly their inclination to even participate in such projects. Besides the obvious potential reduction in electricity bill costs and incentive payments, which might not mean a lot to higher income households, the real benefit of DR lies in its contribution to the electricity system as a whole and the potential it has to quickly mitigate complications arising in the grid. Wider implementation of DR could result in benefits related to the market such as a decrease in prices due to a better use of available infrastructure, which could lead to avoided infrastructure costs. Moreover, DR programmes can increase short-term capacity using market-based programmes, which could in turn could result in deferred capacity costs. The entire system and its participants would likely experience a massive surge in reliability as there would be a reduction in power outages to which the consumers themselves would contribute – even if unknowingly. The diversification of resources would give the operator more options leading to a decrease in forced outages. One of the key contributions of DR is improved electricity market performance. By encouraging demand responsiveness, main market actors lose their ability to exercise market power. Programme participants have more choices in the market even when retail competition is not available. Consumers are able to manage their consumption since they have the chance to influence the market, especially with the market-based programmes and dynamic pricing programmes. Lastly, DR decreases price volatility in the spot market, [7].

2.1.1 Customer Response

There are three possibilities for achieving customer response and each includes cost and steps taken by the end consumer. One option is reducing electricity use only during critical peak periods during high electricity prices; the loss of comfort is temporary. It can be achieved by changing the settings on a heating or air conditioning device and allows consumers to maintain their consumption patterns during other periods. Another approach calls for greater adjustments of consumers' habits. This measure requires consumers to respond to high electricity prices by shifting some of their peak demand operations, household activities, such as using a dishwasher, to off-peak periods. Besides the initial change in the pattern in which the household activities are performed, there is no loss for the customer and he or she will incur no cost. Rescheduling costs to make up for lost service would incur, however, if an industrial consumer had to reschedule their production activities. Lastly, customer response can be achieved by using onsite generation – customer owned distributed generation. Since these customers are able to generate their own power, very little difference in their electricity usage patterns would be experienced. Yet, from the utility's perspective, electricity use patterns would change significantly, and demand would appear to be smaller, [7].

3 Model

The model developed takes into account two different scenario building approaches – the first encompasses the whole GB energy scheme and is based on the 2016 Future Energy Scenarios (FES) developed by the National Grid, [8]. The second is based on the Element Energy, [9],

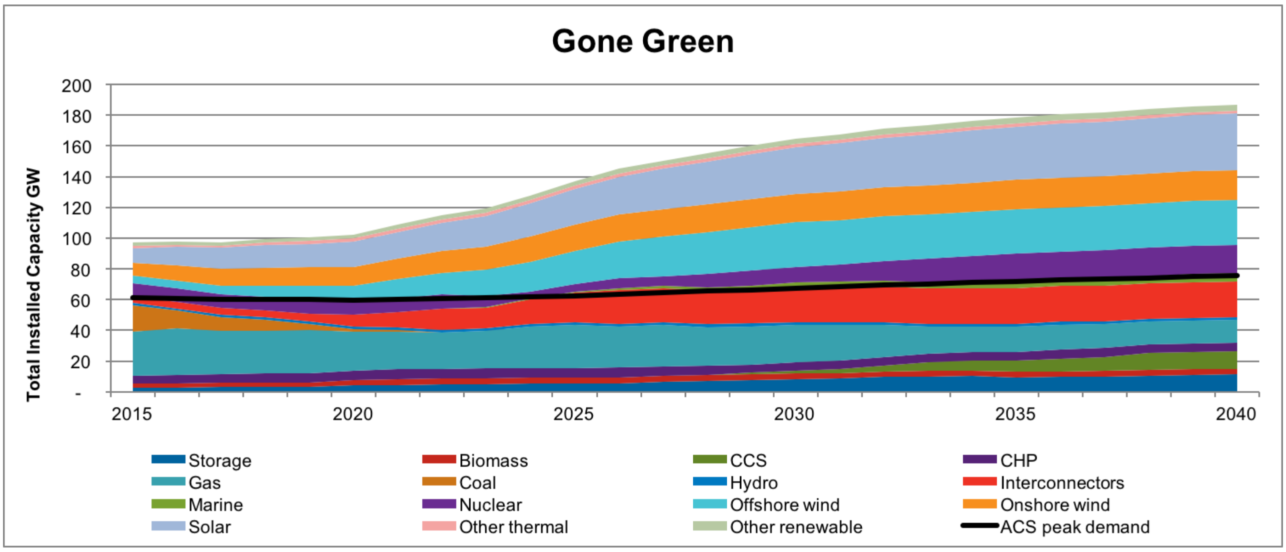

Figure 1: Predictions for the installed capacity in the Gone Green scenario

scenarios, which present different degrees of demand side management peak shaving. In a report done by Element Energy three scenarios for peak shaving are presented: conservative, moderate, and stretch. This paper takes their estimations for the future of DR into consideration as a guideline, however, adapts the scenarios to fit demand throughout the year as theirs only mimic winter day demand. We take the demand approximation for 2025 estimated by the NG and apply the peak cuts approximated in the Element Energy report. Accounting for both approaches, a cost minimisation model was developed to help simulate future British electricity prices. The model used, [10], was created to simulate time series of electricity prices under different generating capacity and fuel price assumptions. Market prices were modelled by calculating the dispatchable power delivered by thermal generators. To model market prices, the dispatchable power, which must be delivered by thermal generators in the system was calculated. For each half hour period, renewable power output was deducted from electricity demand to produce a net demand curve. The generator supply function was formed by stacking thermal plant in merit order of increasing marginal cost. The price of electricity for each time period was determined by the market clearing price. Plant capacity was assumed to be fixed throughout the year with a constant availability applied to each class of generator reducing its total capacity. The predictions for Great Britain's future renewable capacity, demonstrated in Figure 1, were included in the model, given that renewable generation is part of the integrated smart grid just like DR and was assumed to be no longer a novelty in the generation process but rather one of the core suppliers. By applying this approach towards the future of the British generating capacity we assume green generation is now the norm in energy generation and there is less risk of side-lining it for conventional thermal generation. Figure 1 demonstrates the development of capacity installation according to the Gone Green scenario, which is the only scenario that reaches the emission reduction targets.

When the electricity prices were calculated, we chose four days to study; one for each astronomical season of the year. These days were March 21, June 21, September 21, and December 21, all set in 2025, the year in which all coal-fired power plants should cease operation. Element Energy proposed three different reductions in peak demand based on a winter day, however, we applied them to days in every astronomical season. They proposed 1.2 GW, 2.8 GW, and 4.4 GW of peak shaving. We took the demand for each half hour of every one of these four days and subtracted the percent proportional to each number of peak shaving proposed from the demand of that hour and re-calculated those prices. We applied the percentual reduction of the yearly peak demand for 2025 to every half hourly demand of each of these days in 2025. For instance – the National Grid estimates the peak demand for the year 2025 will be 62 GW. 4.4 GW is 7.1% of that so a 7.1% reduction was applied to every half hourly interval in order to calculate the new electricity price resulting from this reduction. Similarly, 1.2 GW corresponded to roughly 2% and 2.8 GW to roughly 4% and these reductions were applied to each half hourly demand period as well to obtain the new electricity price. Then, the differences in wholesale electricity prices between those electricity prices occurring under regular demand and the prices that result from demand reduction applied to regular demand were calculated. We are aware that programmes aiming for peak electricity price reduction are only applicable during the hours when the demand for electricity is the highest but to illustrate a sense of continuation and to highlight just how much influence these programmes have on wholesale electricity prices and what kind of a difference they can make, we calculated it for each hour of the day.

4 Results

The results illustrate the electricity prices resulting from regular demand and the electricity prices that arise as a result of reducing peak demand over a 24 hour period. The demand follows an expected curve and the biggest peaks appear during times of highest yearly demand in December, where the highest electricity price can reach 150£/MWh, as seen in Figure 5. The price differences for March, June, and September 21st are all represented in Figure 6, due to the small differences between them themselves. Each month is represented by the first letter of the month (M, J, and S). Figure 7 depicts only the differences between prices resulting from regular demand and price resulting from peak shaving for December 21st.

5 Discussion

The figures above illustrate 24-hour electricity price fluctuations for the four days. The term "Regular Demand" refers to the electricity prices arising when no demand side management approach is applied to them. RD -1.2 GW refers to the prices resulting from a 1.2 GW peak shaving. The same naming approach was applied to the prices resulting from a 2.8 GW and 4.4 GW peak reduction. In the figures demonstrating price differences, Diff RD-1.2 GW refers to the difference in electricity price between a regular demand premise and a premise that had a various amount of peak shaving applied to it. A very important benefit of demand response when it comes to market improvement is the reduction of price volatility in the spot market. Demand responsiveness reduces the ability of main market players to exercise power in the market. This phenomenon is due to the fact that generation cost increases exponentially near maximum generation capacity. A small reduction in demand will result in a big reduction in generation cost and, in turn, a reduction in electricity price, [6]. This occurrence was observed in our results as well. When only a small percent reduction resulting from a peak shaving of

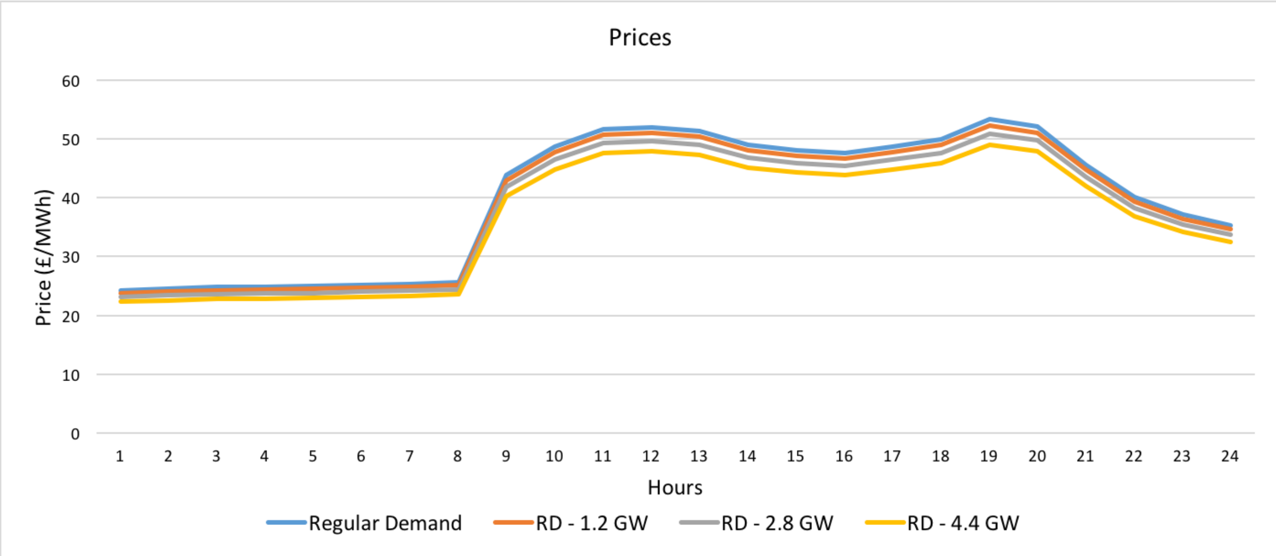

Figure 2: Wholesale electricity prices on March 21st, 2025

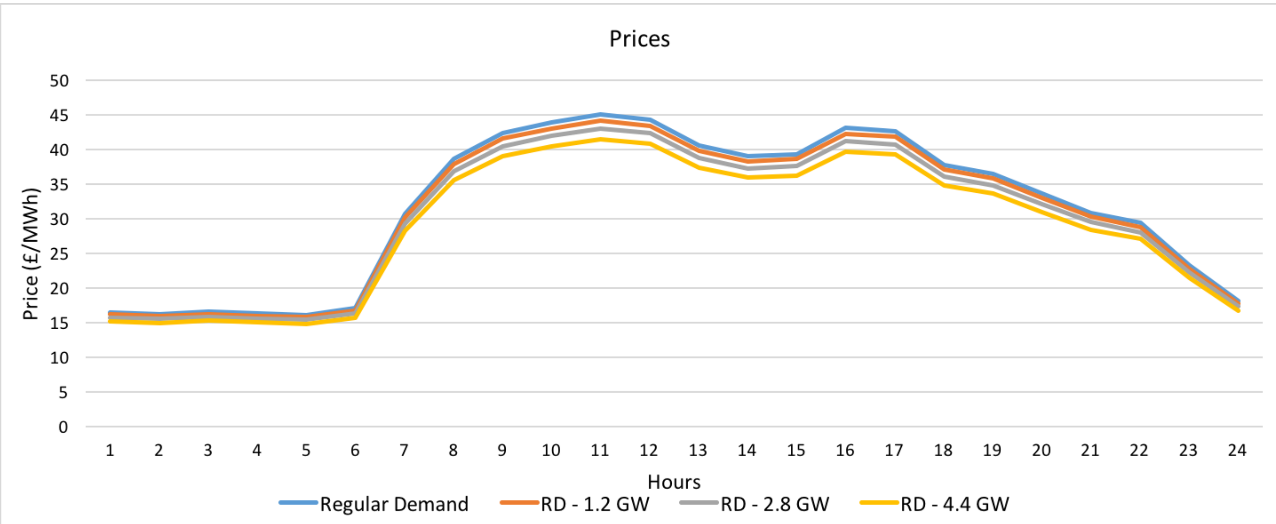

Figure 3: Wholesale electricity prices on June 21st, 2025

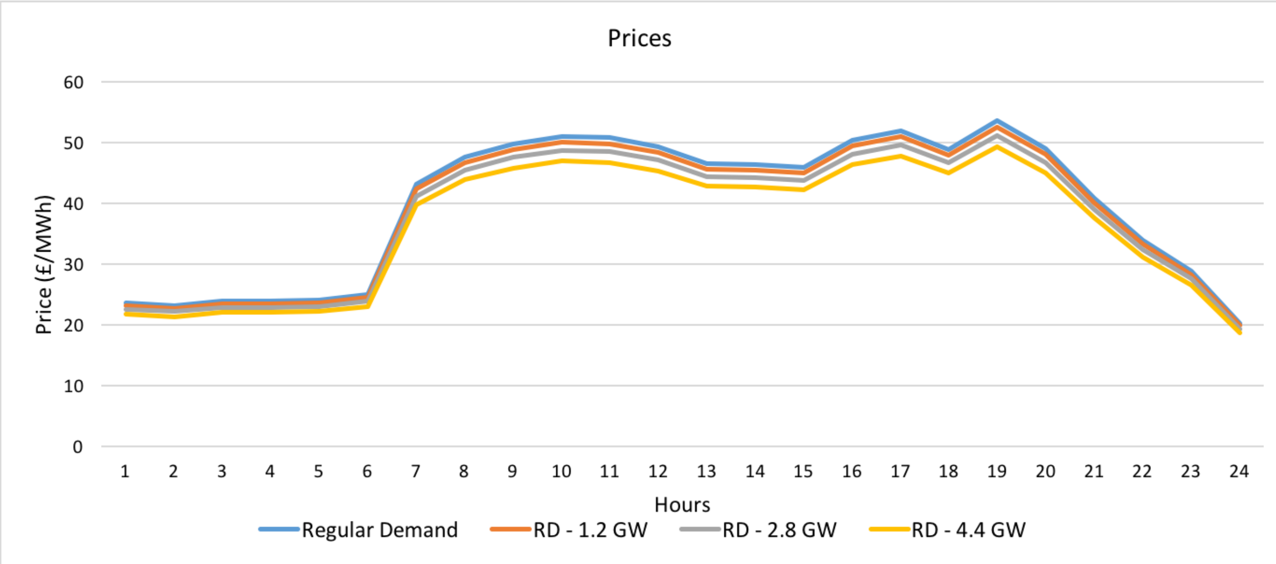

Figure 4: Wholesale electricity prices on September 21st, 2025

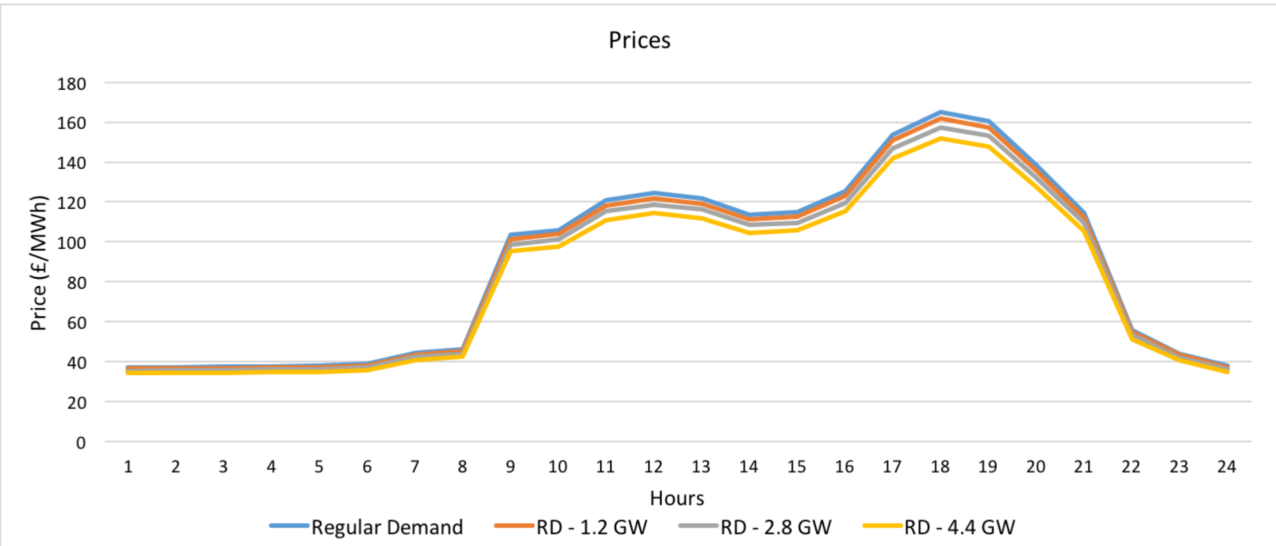

Figure 5: Wholesale electricity prices on December 21st, 2025

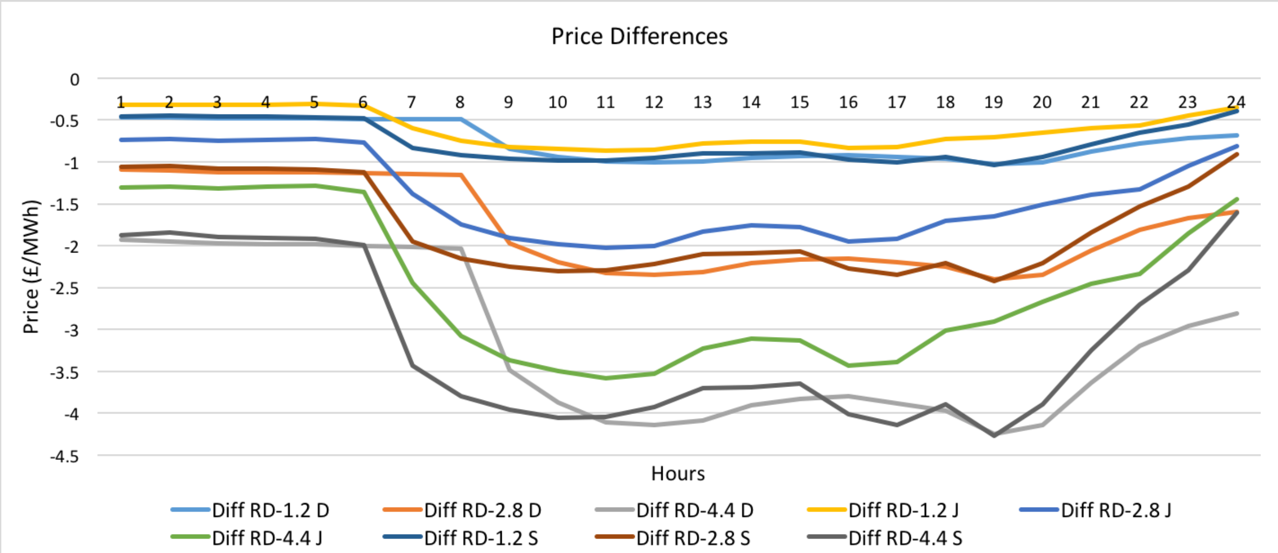

Figure 6: Price differences resulting from demand reduction on March, June, and September 21st, 2025

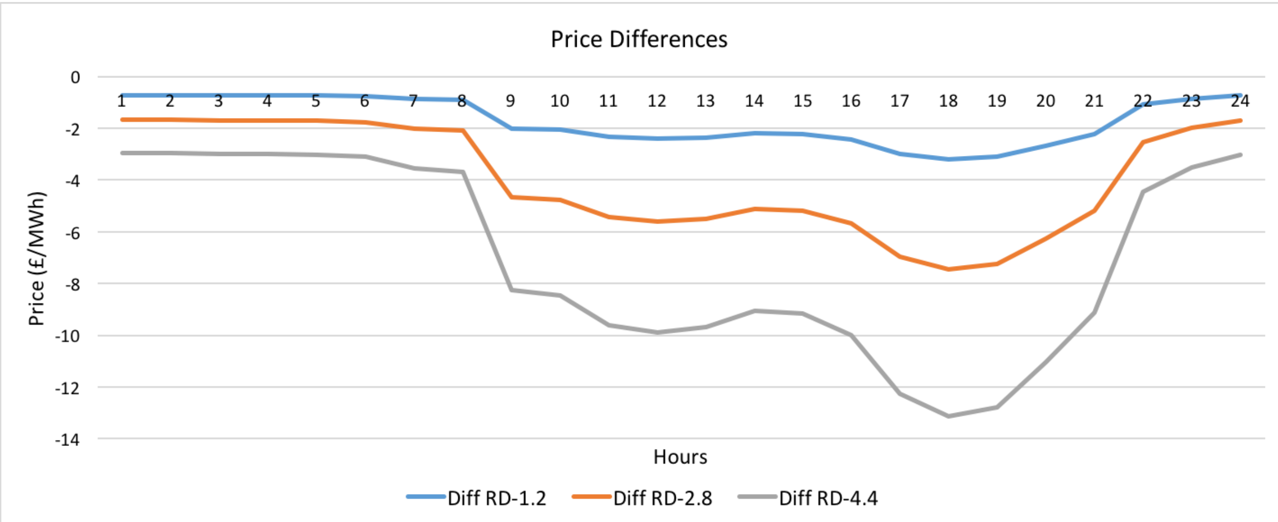

Figure 7: Price differences resulting from demand reduction on December 21st, 2025

1.2 GW or 2.8 GW was applied to demand the decrease in electricity prices was not significant. However, when a decrease of 7.1%, corresponding to 4.4 GW of peak shaving, was applied we observed a considerable decrease in electricity prices especially during the daily afternoon peak around 6pm. Although this decrease was observed in every season the biggest decrease was seen for the winter scenario, on December 21st. There was as much as a £16.5 reduction in the resulting electricity price.

This means for demand response programmes to really take off it is of foremost importance that the information and updates on how they function and how they can impact the costs end consumers must pay are readily available to current and potential clients, since if participation is too low so is their impact, which could in turn lead to turning away existing clients from further participation. Even though very high electricity prices are normally only observed during the winter period there should be incentive for consumer engagement during other seasons as well. An uncharacteristically hot summer month could lead to an increase in air conditioning use, however, consumers would not be willing to give up other daily other energy use such as the use of hair dryers as they do not pay real-time prices and these spikes are insignificant to them from a cost perspective. During the summer a lot of sporting events such as the World Cup or the Olympics take place meaning locations used for social gatherings such as pubs are often consuming more energy than they would on a regular day in the summer or the winter. This is due to a likely increase in the capacity of refrigeration used to keep a large amount of beverages cool and available, more frequent and more intense use of air conditioning devices, and any sort of technology used to broadcast these events. Obviously people cannot be expected to trade their wish of drinking a cold beverage or enjoying a soccer match in a cool ambient to keep the pub owner's electricity bill low, so owners of these pubs would have to develop their own pattern to keep the demand as flat as possible throughout less busy days so that the monthly cost outcome is less discouraging for them.

Even though price reductions resulting from peak shaving might seem trivial and not cost-effective when compared to the cost of device installation and implementation and maintenance of these programmes the reduction should not be overlooked as electricity demand is on the rise. Demand increases are expected due to population growth and increased electrification of sectors such as heat and transport. A shift from fossil fuels to electricity, combined with greater uptake of renewables, has been identified as a means of improving diversity of energy supply and meeting greenhouse gas emission reduction targets, [9]. In recent years demand has been lower due to the financial crisis and the impact the crisis has had on individual households, especially those that fall in the lower income category. Although, initially the use of renewable energy resources leads to an increase in electricity prices, they are expected to fall in the future, when the renewable capacity adapts to the market. This pattern has been observed in other western and central European countries, such as Denmark and Germany, where the use of abundant renewable energy resources and inflexible generation even led to negative electricity prices. As prices continue to fall, the increase in energy consumption is expected to rise as paying electricity bills becomes a less strenuous feat for people of different economic backgrounds. However, heavy energy use and spiky demand curves will continue to pose problems for generators and utility companies so it is important to maintain the load profile as flat as possible, [7]. In order to have that in the future and avoid the pressure and restrains such high, unregulated, and uncontrolled energy use might have on the grid operation in the future and the complications that might arise from it is reasonable to try to achieve this while electricity prices are still high, normalize these patterns in individuals' energy use habits and then only maintain them in the future. There are other benefits associated with DSM and specifically DR, such as decreased use of peaking plants, which are usually thermal generators since they are available at any time period. Running these peakers even a few days a year can have a considerate effect on electricity costs and having a better idea of when they will need to be run contributes to the improved operability of the grid. Additionally, decreasing peaking plant use leads to overall less intense use of thermal generation, in turn leading to a decrease in greenhouse gas emissions.

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