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DEMAND RESPONSE UNDER A SMART GRID CONTEXT

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ABSTRACT

This work focuses on the impact of Demand Response, under a Smart Grid context, in the Portuguese Electricity Market. The use of real-time pricing and incentive based DR programs in order to achieve Load Shifting, Peak Shaving and Energy Efficiency is explored and its economic benefits analyzed. The result of this changes in EDP Distribuição, the Portuguese Distribution System Operator is explored and recommendations are proposed.

Keywords: Demand Response, Smart Grid, Distribution System Operator, EDP Distribuição

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1. CONTEXT

This chapter will provide context on the work that is presented in chapter 2 and which was developed during the Business Project performed for EDP Distribuição. Firstly, the company for which the work was performed and the market in which it operates will be briefly presented. Following that, the company's current situation and the challenge at hand will be described.

1.1 Client

EDP Distribuição (part of the EDP Group) is the Distribution System Operator (DSO) in continental Portugal. As virtually the sole distributor it has more than 6 million clients. Its activity is regulated by the Entidade Reguladora dos Serviços Energéticos (ERSE). It operates the High Voltage (HV), Medium Voltage (MV) and Low Voltage (LV) networks. As the DSO its tasks include (EDP 2009):

1) Ensuring grid capacity and reliability - Connecting both clients and producers and planning, developing, operating and maintaining the grid

2) Ensuring the distribution of electricity - Supplying the final clients while maintaining quality and security of supply

3) Providing services to retailers - Such as retailer switching, disconnecting consumers, meter readings and others

1.2 Market Overview

The electricity market has 4 major areas of activity. Production, Transmission, Distribution and Retail, ranked by the order in the supply chain. EDPD acts in the distribution part where it is effectively a monopoly. It is the sole player in the High Voltage and Medium Voltage networks and has over 99% of the market in the Low Voltage network (EDP 2009). The concession to operate HV and MV networks is granted by the government for a period of 25 years to a single operator, while the LV network is granted by 278 municipalities. As was previously mentioned EDPD operates in a regulated market (electricity distribution) and its revenue earning model is set by the regulator.

1.3 Current Client Situation

Until recently the electricity market followed a very traditional business model that had changed very little since its inception. Utilities were vertically integrated monopolies, often state-owned, and distribution was not separated since the whole market was heavily regulated. The unbundling of distribution, the deregulation of the energy market with the elimination of state subsidies and the increase in the use of renewable energy fueled by concern about carbon emissions changed this situation. Currently EDPD is faced with several challenges that affect players in the electricity market and distribution in particular. The International Energy Agency identified five main challenges (Heinen, Steve 2011): An increase in energy demand, an increase in the penetration of electric vehicles and plug-in hybrid vehicles, the deployment of variable renewable energy sources both in traditional production and in micro-production, which increases volatility and makes it more difficult to manage the grid, an increase in peak demand and an ageing infrastructure.

Technological developments led to the emergence of what are generally called smart grids. They are defined by the European Technology Platform (2006) as: "A smart grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both in order to efficiently deliver sustainable, economic and secure electricity supplies.". Smart grids would allow the electricity market, through the distributor, to deal with the challenges that were outlined above. By providing flexibility and information about the grid it becomes easier to manage more complex systems. The European Union has incentivized the development of smart grids through regulations and has established the aim of having 80% of electricity meters replaced by smart meters which record consumption in real-time and are able to transmit that information back to the utility.

Following these guidelines, and in accordance with regulatory authorities EDPD has developed the InovGrid project in the city of Évora, Portugal. This is a smart grid pilot project that has a broad focus in that it is not solely about smart meters but touches on several vectors. The project's focus is described as including: 1) Active Demand Response - which gives information on energy consumption to consumers and tools to react to price signals, 2) Integration with Smart Homes - by providing consumers with smart appliances that stimulate energy efficiency, 3) Smart Metering Infrastructure - by replacing traditional meters with smart ones, 4) Smart Metering Data Processing -

gathering data provided by smart meters, 5) Integration of Electric Vehicles - by actively managing the charging of electrical vehicles' batteries, 6) Monitoring and Control of LV Networks - Technology that provides up to date information on the grid, 7) Automation and Control of MV Networks - remotely controlling MV devices which reduces the need for field teams and ensures rapid fix of failures. (Grid Innovation Online, 2014)

The results so far are promising with gains in operational efficiency, reduction of energy losses and energy efficiency gains.

1.4 The Business Project challenge

Taking into account the changes that have happened in the electricity market there were several challenges to be tackled:

1) Anticipating future developments by proposing changes in the scope of the DSO Role that consider the Smart Grid context with massive renewable energy sources integration, that reinforce the position of the DSO as market facilitator and to suggest alternative solutions to improve business model.

2) Evaluating the feasibility of Demand Side Management as an instrument for DSO through the deferral or investment and the offer of new services to market players

3) Evaluating the benefit of online data for the Portuguese electricity market by looking at its applications, namely, through the reduction of forecasting errors, the reduction in losses and outages, the improvement of operational efficiency and of commercial operations.

2. REFLECTION ON THE WORK DONE

This chapter will focus on the work developed as part of the Business Project with a particular emphasis on the feasibility of Demand Response by looking at its economic benefits. It starts with an overview of the current status of the electricity market, grounded on microeconomic theory, and its implications for economic efficiency. Based on this an hypothesis is put forward which is tested by building a model on the energy market in Portugal and through benchmarking. Finally, recommendations for EDP Distribuição are made and concerns on implementation are duly outlined.

2.1 Problem Definition

The current setup of the electricity market means that prices in the retail market, which are fixed, do not reflect prices in the wholesale market which are a reflection of marginal costs. This situation leads to inefficiencies in the electricity market that are detrimental to societal welfare.

The inability to store electricity means that demand must equal supply at all times. Given that both demand and supply vary greatly depending on the time of day and of the year and that there there are major variations in the marginal cost of producing energy electricity prices will be extremely volatile. Electricity prices in the wholesale market reflect this situation with prices varying by hour and by date. Pricing in this market reflects the marginal cost of energy production, that is, price will correspond to the marginal cost of production of the last supplier to the market.

However, prices in the retail market do not match actual prices. Consumers pay a fixed price that corresponds to the average cost of electricity throughout a certain period of time. Therefore demand will not respond to price signals given their absence.

A fixed price will lead to a bad market equilibrium in which the price during off-peak periods is higher than it should be and therefore the quantity consumed will be lower than it would have been under a real-time pricing system. The opposite will happen during peak periods. This will lead to deadweight loss that diminishes total welfare as seen in figure 1 (Newell & Faruqui 2009).

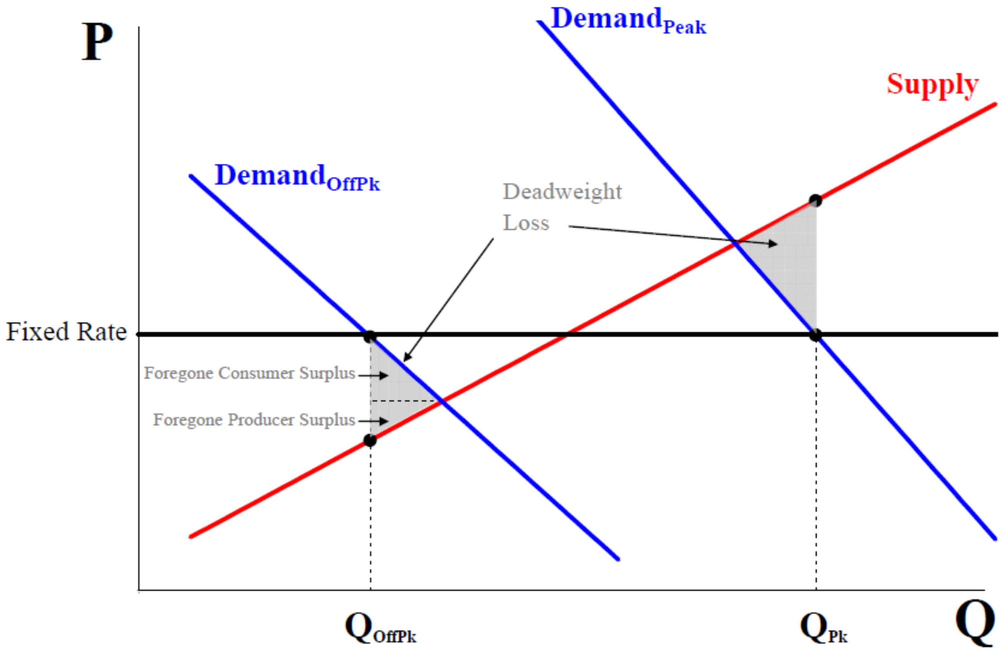

Fig. 1 Economic Inefficiencies Caused by Fixed Retail Rates

A similar reasoning can be applied to capacity supply and demand. As consumers do not pay the actual price of an extra unit of capacity in the system (both grid capacity and production capacity) they will demand more than they would in the presence of market prices. This will result in over-investment on capacity that is barely used.

Demand Response (DR) which is defined as "Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to give incentive payments designed to induce lower electricity use at times of high market prices or when grid reliability is jeopardized." (U.S. Department of Energy 2006) can be a way to address this problem. Demand response creates value primarily by enabling demand reduction through energy efficiency and by reducing the cost of energy and allowing investment optimization through peak shaving. Figure 2 summarizes these points by showing some effects of having an elastic demand. (Cooke, Douglas 2011)

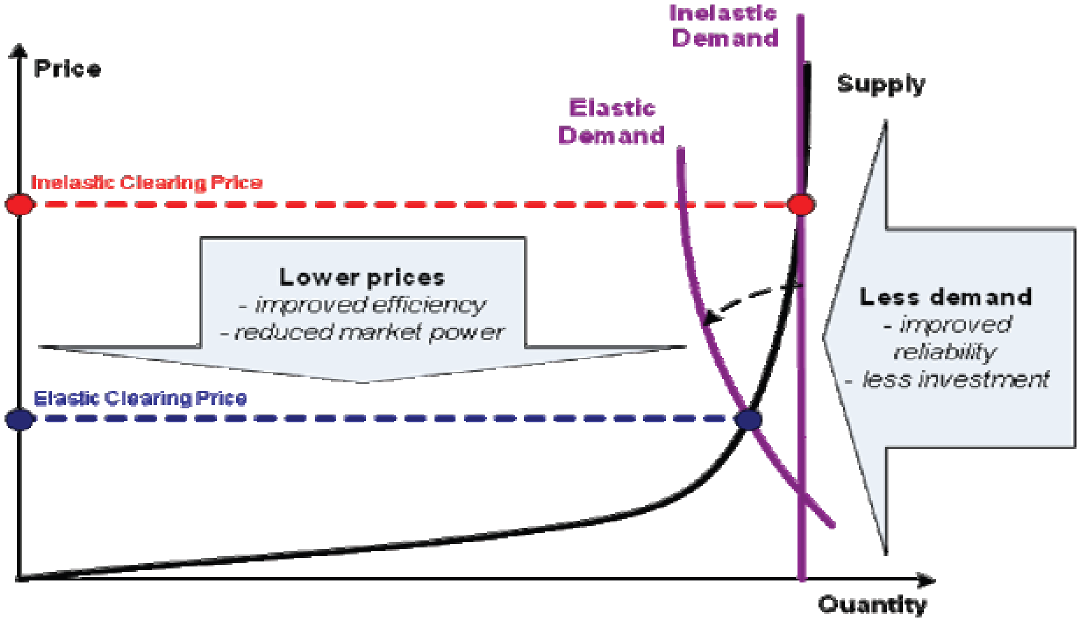

Fig. 2 Demand response potential to improve market efficiency

Load Shifting, which consists in balancing the demand and supply of electricity by reducing consumption at the peak and increasing consumption during off-peak periods, can be achieved by incentive-based or price-based demand response. With real-time pricing consumers start responding to changes in hourly prices by shifting their consumption to off-peak periods.

Peak shaving or peak clipping corresponds to the permanent reduction of peak consumption. The main benefit of achieving a permanent reduction of peak consumption versus reducing the volume of energy that is consumed at the peak has to do with investment both in grid capacity and production capacity. While load shifting will be able to assure the former it cannot guarantee the latter. As long as there is an hour in the whole year where, for various reasons (e.g. weather), consumption reaches a peak there will be a need to invest in capacity in order to accommodate this peak demand. That is the reason why price-based demand response is generally not enough to achieve peak shaving and why incentive-based programs, which are more controllable, are used in order to achieve it.

Energy Efficiency is also included in demand response. Currently, in Portugal, information on consumption is collected four times a year for domestic consumers and small business. Billing is done using forecasts on consumption profiles and does not correspond to actual consumption. Since consumers are not billed their actual consumption they will not feel the impact of energy conservation measures, such as buying more efficient appliances or turning off equipments on stand-by, on their final electricity bill. This will reduce the incentive to take actions that conserve energy. Billing on actual consumption, such as real-time pricing, can be a way to address this problem by increasing the returns on energy conservation measures taken by consumers.

Smart Grids are an electrical grid system that uses analog or digital information and communication technology to act accordingly and on-time on consumer and supplier behavior.(U.S Department of Energy 2012) They also encompass smart meters which provide real-time information on consumption. They are currently being rolled out across Europe with investments of more than 3bn €, since 2002, for 450 European smart grid projects. By 2020 80% of households in the EU are expected to have a smart meter. This is also the target in Portugal. (Oosterkamp, Paul van den & et. al 2014)

The implementation of smart grids paves the way for demand response to be used both through real-time pricing, by providing real-time data on consumption which can be effectively communicated to consumers and through incentive-based programs which can guarantee consumption reductions. According to Balijepalli & Pradhan (2011) "The recent advent of smart grid technologies advanced the integration of DR by providing the needed information and communication infrastructure to the existing grid."

Studies show that (Hougan, William 2014) forms of pricing which fall short of real-time pricing, such as time-of-use rates, miss most of the efficiency gains. According to Hougan (2014): "Where real-time prices are available, it seems worth the effort to remove obstacles from going all the way to RTP.". Therefore it became necessary to understand how this form of pricing could affect the Portuguese electricity market and what could be the gains in efficiency of a demand response system under a smart grid context. Finally, the way in which all of this impacted EDP Distribuição, how it could benefit from a change in pricing and the use of real-time data in the future was explored in order to allow for the proposal of recommendations on how to adapt to these changes.

2.2 Methodology

2.2.1 Hypothesis

The hypothesis under study was "A demand response system using real-time pricing would lead to load-shifting which would eliminate the current deadweight loss existent in the electricity market and create a net welfare gain for society. It would also translate into savings from deferred capacity investments through peak shaving and savings from a total reduction of consumption as a result of energy conservation measures". To test this hypothesis it was necessary to build a simple model of the electricity market in Portugal and calculate the new market equilibrium under real-time pricing as well as look into planned investments in capacity and benchmark peak shaving and energy efficiency measures in order to obtain values of savings.

2.2.2 Data & Model

The data used were the results of the "Mercado Ibérico de Electricidade" (MIEBEL), which is the wholesale spot market for electricity in the Iberian Peninsula, on the price paid and energy bought by market agents for every hour of every day of the year 2014. This data was taken from "Sistema de Informação de Mercados de Energia" and corresponds virtually to the energy consumed throughout the year, with the exception of reserve energy (which is activated when needed). In addition, data on the price elasticity of demand for electricity was taken from a meta-analysis of 36 studies on electricity demand (Espey, James & Espey, Molly 2004). The average electricity price elasticity in the short-run, which was found to be -0.28, was used. Even though the price elasticity in the long-run might be much higher as consumers adapt their behaviors, a conservative estimate was thought to be more appropriate for this case.

The model that was built was relatively simple as the goal was to get an approximation of what would be the gains in efficiency and not perform a theoretical analysis on the new market equilibrium. The two building blocks of the model are demand and supply. By modeling the behavior of consumers when faced with real-prices and the suppliers' reaction to changes in demand the results of real-time pricing on the electricity market are obtained.

For the demand side, initially, the weighted daily average price of electricity is calculated, using hourly consumption as the weight. The weighted daily average price is used for several reasons. Firstly, because it is assumed that consumers will shift their consumption within the same day. This is plausible as consumption cannot be postponed indefinitely. It is also assumed that overall daily consumption will stay constant and hourly consumption will tend to be closer to the average daily consumption. The limitations of these assumptions are that consumers would be likely to also shift their consumption across days and that the introduction of real-time pricing might change overall consumption. In this case, however, the goal is only to obtain the daily load shift and the correspondent efficiency gains, therefore the model aims at keeping overall consumption constant. Hourly consumption is used as a weight in order to get a better approximation of the actual average price as the zero prices that are present in off-peak hours "artificially" reduce the average price when the arithmetic average is calculated.

If the hourly price is higher than the weighted daily average price then consumption in that hour will go down by 0.28% of the percentage change in price, in accordance with the price elasticity of demand used. If the hourly price is lower, consumption will go up also by 0.28% of the percentage change in price. This assumption is simplistic in that it assumes that the "correct" or equilibrium price for the day would be the daily weighted average price. This is not exactly true and obviously consumers responses are likely to vary by hour. Despite these limitations the application of the elasticity of demand to the difference between flat rates and hourly prices has been used in other (Newell, Samuel & Faruqui, Ahmad. 2009) of dynamic pricing and it will give us a fair approximation of the change in loads throughout the day, which is where the majority of the savings come from. The final assumption is that demand shifts are limited in its dimension. This means that the new hourly consumption cannot be higher than the highest hourly consumption or lower than the lowest hourly consumption in that day. This is necessary to limit excessive shifts that would be unlikely to happen.

On the supply side, a weekly semi-elasticity of supply is calculated using the data on price and consumption. This is done because the semi-elasticity of supply is unlikely to vary significantly within a week as the prices and availability of inputs (whether from renewable sources or others) are likely to be constant. Also given that, at the moment, demand does not vary with price it is possible to calculate directly the semi-elasticity of supply as prices are a function of producers' marginal costs. For the purpose of calculating the semi-elasticity of supply zero prices are excluded. The supply curve is modeled as having a part where the price will be zero and another part where prices rise according to marginal costs. The point at which prices are no longer zero and start to increase is calculated based on the maximum weekly consumption at zero price. That is, for every week of the year it is assumed that the maximum hourly consumption in which the hourly price was zero corresponds to that week's point at which an extra unit of electricity has a positive marginal cost. Therefore all consumption below this point has a market price of zero. Consumption which is above this point will have a positive market price and prices will change in accordance with the calculated semi-elasticity of supply.

Having modelled both demand and supply dynamics are introduced in the model by having repeated iterations in which hourly consumption responds to hourly prices and hourly prices respond to hourly consumption. The savings are then calculated by subtracting the new market value (new consumption x new price) to the value of the current market equilibrium.

Peak Shaving, or more specifically, the savings obtained by avoiding investment in increased capacity in distribution were obtained by analysing the "Plano de Desenvolvimento e Investimento na Rede de Distribuição" (PDIRD) and looking at benchmarks on peak reduction using demand response.

Energy Efficiency savings are calculated using the information from the InovGrid experiment in Évora, Portugal. InovGrid is the first fully smart grid and smart city in Portugal with over 30 thousand smart meters having been instaled. (Grid Innovation Online, 2014) By extrapolating the results of InovGrid it is possible to obtain a figure for energy efficiency savings.

2.2.3 Results & Analysis

The results from the model show a significant amount of load-shifting happens when real-time pricing is introduced. Figure 3 shows the load curves for the year 2014 both the present ones and what would have happened in the presence of real-time pricing.

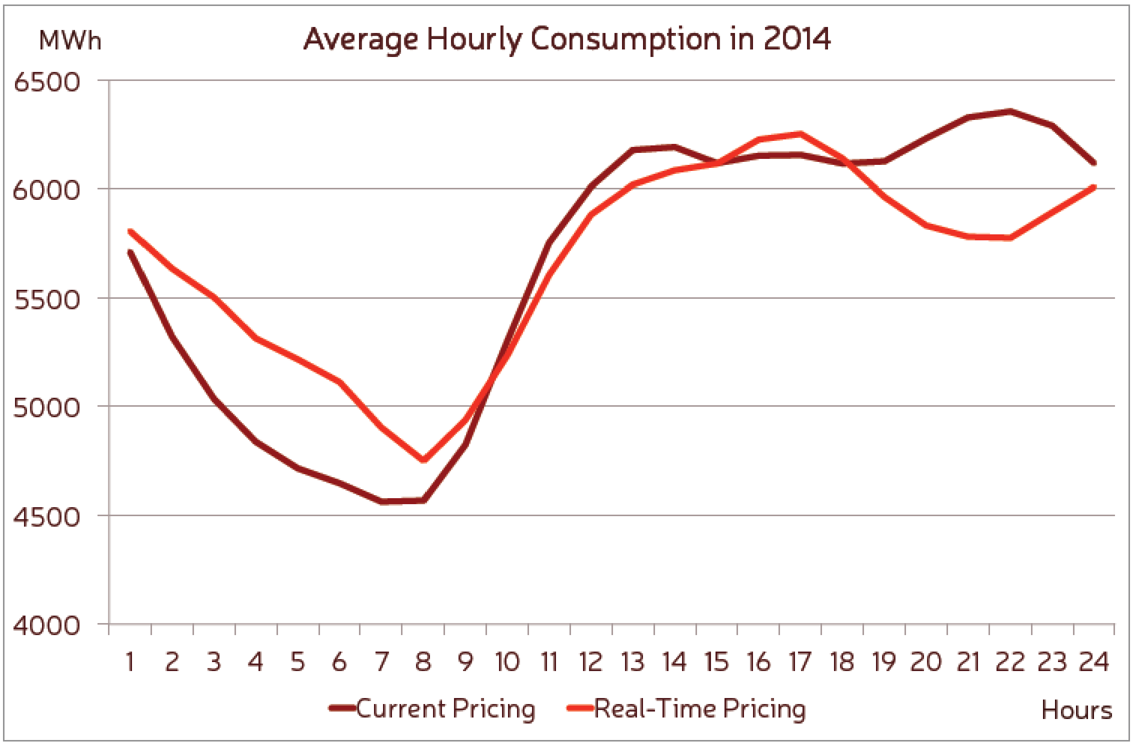

Fig. 3 Load Curves for Portugal in 2014 under different Pricing Systems

We can see from the graph that consumption would be markedly higher during the off-peak period (from 1am to 8am) and lower during the peak period (from 8pm to 11pm). During business hours and until the peak is reached (from 9am to 8pm) consumption stays more or less constant. The overall consumption will stay constant at around 49 million MWh for 2014. The average price will also stay constant 41.9€ per MWh.

What happens is that the average yearly consumption per hour of the day becomes closer to the overall average hourly consumption. Throughout the year 2014 consumers used on average 5650 MWh of electricity, this is the overall average hourly consumption. The standard deviation of the average consumption per hour is 452,8 MWh with real-time pricing versus a standard deviation of 647,2 MWh with the current pricing. This means with real-time pricing consumption per hour would be closer to the daily average consumption. The same thing would happen to price.

As consumption becomes more evenly spread out throughout the day so would hourly prices. The standard deviation of average prices per hour with real-time pricing is 4,76€ p/MWh versus a standard deviation of 7,85€p/MWh with current pricing. These results are consistent with what we would expect from the model as overall yearly consumption stays the same and it will be more evenly spread out throughout the day. This is what originates the gains in efficiency as consumption would increase when the price is lower and decrease when the price is higher. This load shift would have led to savings of 26.680 million Euros for the year 2014.

Demand Response will also lead to gains due to peak shaving and increases in energy efficiency. The possibility of curtailing peak consumption through incentive based programs means a reduction both in grid investment and in capacity investment to deal with peak demand. In 2014, in Portugal, the top 6% of consumption (in percentage of total peak capacity) was only used 1,3% of the year. From PDIRD about 20 % of Spending on Grid Development is directed to peak investment, which is a structuring investment that comes as a response to an increase in peak demand. This translates into a investment for the DSO of about 12.8 million Euros in the reinforcement of peak capacity from 2015 to 2019. Using the case of Denmark as a benchmark, the rollout of smart meters as so far brought a reduction in peak demand of 2.5%. This would be enough to defer all investment in peak capacity from 2015 to 2019. This does not include spending by the TSO or future capacity investment by energy producers in order to meet peak demand.

There's also the question of *planning reserve margins* which are imposed externally on the market in order to maintain security of supply, given its public good characteristics (Joskow, Paul & Tirole, Jean 2007). This leads to subsidies which are borne by consumers and are an extra cost for the whole system. All of this costs could be managed leading to gains in societal welfare.

Finally, DR is also responsible for an increase in energy efficiency through an automatic feedback on energy conservation measures taken by consumers. The InovGrid project, a smart grid project which was undertaken by EDP Distribuição in the city of Évora, shows that energy efficiency can lead to a reduction in total consumption up to 4%. In the year 2014 this would have meant savings of 84 million Euros in energy costs. More conservative estimates point to savings of at least 2% of total energy costs.

In addition, there are also savings with the reduction of CO_2 emission due to a reduction in total energy consumption. (Grid Innovation Online, 2014)

2.2.4 Other benefits

There are other gains to be realized from load shifting and the use of smart grids other than in the cost of energy and deferred investment. Besides the cost of actually generating electricity, consumers also pay for the cost of transmission and distribution, respectively to the TSO and the DSO. Both of these areas would also stand to gain in terms of efficiency and quality of service.

Firstly, because the amount of energy lost in transportation and distribution is proportional to the amount of electricity flowing through the grid and the distance travelled. A load schedule that is more evenly spread throughout the day means less electricity usage at peak times and therefore a reduction in energy losses. It would also lead to less episodes of grid congestion (when energy is insufficient to meet the demand of all customers) reducing costs related to the activation of emergency reserves which are both costly and heavily polluting.

In addition, the probability of outages would be lower and the quality of supply higher, leading to positive externalities. Costs with power outages for Portuguese business range from 5000€ (less than a second) to 58.000€ (around 4 hours) per company per outage. Low quality of supply also leads to costs related to products with defects and rebooting of processes. Finally, a more even load schedule means a more even supply schedule as well, which will also have an impact on CO_2 emissions as low emission producers are the first ones to be used, since they are also the ones with the lowest marginal cost (e.g. renewable energy sources, nuclear energy) while high emission producers are generally the last ones. (Patrao, C. & et. al. 2011)

2.3 Recommendations to EDP Distribuição

EDP Distribuição as the distribution system operator has a need to adapt to the changes that result from the large scale implementation of smart grids. For this to happen it needs to change its current business model without compromising its role as a independent market operator and while continuing its core business of developing, operating and managing the electrical grid. The biggest source of disruption as well as the major opportunity for EDPD will arise from the data obtained by the use of smart meters. As mentioned before this data will allow demand response to be put in place. There are, however, many more uses to it, which would allow not only for inefficiencies in the electricity market to be corrected but for new value-adding activities and services to emerge that could benefit market agents. The DSO could leverage its current experience managing data to transform itself into a data management center. This would mean that the roles and responsibilities of EDPD regarding data management would grow and evolve in the future. The DSO would in effect turn into a data hub while maintaining its grid management function, which would allow it to provide an array of different services to different stakeholders in the marketplace.

The data itself would be valuable to the DSO as it would allow for the improvement of operations management and increase efficiency. This would happen, for example, by the use of detailed information on the quality of supply, which is one of the measures of efficiency DSO's are evaluated on, ensuing the reduction of outages, theft, fraud and other problems. Another example is the reduction of costs related to meter reading, that are currently done by EDPD employees in a manual fashion. This would no longer be necessary.

Advanced cooperation with the TSO is also important. TSOs are responsible for the overall system while the DSOs are responsible for operating the network. Cooperation will ensure an optimal constraints management, taking into account local and system-wide needs. With this, agreements (e.g. on reactive power exchange) will be facilitated providing a more cost-efficient way to manage the power system at different levels. This will be particularly important when putting in place incentive-based demand response programs that aim to achieve peak shaving while guaranteeing security of supply.

For the purposes of data use, a separation between technical data and commercial data must be made. Technical data such as information on aggregated consumption, energy flows in the network, voltage profiles and interruptions would continue to be provided to all stakeholders. On the other hand, commercial data such as individual detailed consumption data can be provided both to individual customers and to retailers in order to enable demand response and dynamic pricing strategies.

Retailers could also benefit from commercial data in another area. Presently, they incur in costs that result from forecast errors. When retailers purchase energy in the wholesale market they make assumptions on energy consumption which, if not correct, lead to penalties that can be quite high. Regulatory authorities would have a role in determining which type of data should be accessed for free and without discrimination in order to preserve the DSO's neutral role and which data can be provided as a service. In addition the DSO could develop add-ons that would combine meteorological data with forecast data as well as user-friendly commercial applications. The value of this type of information is growing as consumers also become producers and renewable energy sources become more and more relevant in the production of electricity.

2.4 Concerns regarding implementation and regulatory issues

There are several concerns both with the implementation of a real time pricing system as well as the implementation of the recommendations that were suggested.

When it comes to real time pricing there are drawbacks that need to be considered in the implementation of such system. The volatility of electricity prices creates a risk for consumers. This is an issue that should be taken into account given the obvious importance electricity has in everyday life. On the other hand, consumers need to be exposed to price signals in order for the market to function efficiently. One way of addressing this question is through the use of financial products that can be used to hedge risk. They are currently used in the wholesale spot market and could be extended to the retail market. This would provide a market based solution for the problem of price volatility. (Cooke, Douglas. 2011)

There is also the matter of price regulation. Currently, in Portugal, a regulated market co-exists with a liberalized market. In the former the prices of energy charged to consumers are below the actual cost of energy which has had an effect on the liberalized market by keeping prices artificially low. Retailers entered this market with the expectation of future profits. For real time pricing to be implemented the regulated market has to be phased-out. This situation is supposed to be resolved by the end of 2015.

Privacy issues must also be taken into consideration. The data obtained can be extremely detailed and provide a lot of information on individuals. Therefore data management and use must be approached with care and always considering the rights of consumers. The state also has a role to play here as it has the responsibility to frame an appropriate legal structure.

On the implementation of recommendations much will depend on the regulatory authorities. As a regulated entity EDPD will need to discuss these changes with ERSE (Entidade Reguladora dos Serviços Energéticos) to understand whether it is possible to adopt the recommendations. The example of other European countries shows that this may not always be feasible. For example, in Spain a recent law requiring domestic customers to be billed on an hourly basis means DSOs are required to hand in all consumption information to retailers free-of-charge as well as informing consumers of their consumption information through specific websites. In Italy the possibility of having an independent third party managing the data is being studied. Should this go forward it would limit the possibility of having the DSO as data hub.

Regarding peak shaving and the deferral of investment it is important to point out that currently there is no incentive for EDPD to not invest as capital expenditures are remunerated according to a rate of return system. For this reason it is important to consider how can regulation be improved to avoid giving incentives for over-investment.

Regulation may reduce the possibilities EDPD has to adapt its business model to a smart grid environment, but given that costs and benefits are so dispersed throughout the whole range of electricity market agents it is an essential part of the system. EDPD should aim to work with the regulators to maximize the benefits for society.

2.5 Conclusion

In a future where the electricity market increases in complexity and where the range of technical solutions on offer are wider, Demand Response appears as a solution to increase the economic efficiency of the electricity market and achieve a welfare improving equilibrium. A combination of real-time pricing with incentive based programs would lead to savings in energy costs through load shifting and energy efficiency as well as deferred capacity investment due to peak shaving. Other benefits such as the reduction in carbon emissions and reduced capacity subsidies reinforce the case for the use of Demand Response. This would be possible through the use of smart grid technology but its implementation would require a new business model for distribution system operators and a new approach to regulation. EDP Distribuição, has an advantage in this area, having had experience in managing a pioneer project in the area of smart grids. It could stand to benefit greatly from the possibilities opened by real-time data while benefiting the system as a whole.

3. REFLECTION ON LEARNING

As indicated by the title this chapter will focus on the author's personal perspective on the work done, namely previous knowledge that was applied during the development of the Business Project as well as new insights that were gained as a result of the practical application of theoretical concepts. The final part contains a personal reflection on the whole experience and the benefits of hindsight.

3.1 Previous knowledge

3.1.1 Masters content applied

There was a whole range of content applied to the Business Project work. Starting with concepts on microeconomics such as elasticities of supply and demand, notions of market equilibrium, deadweight loss, externalities, economics of scale and scope and very importantly, the difference between economic value and value as commonly perceived by businesses. In the case of Demand Response benefits tend to be spread out while costs are concentrated on one or two agents, therefore it is generally not profitable for one market agent to invest expecting a return on capital. The course on Economic Regulation was also essential to the work done. In this course I had already done a work on electricity regulation in The Netherlands which meant that I already had previous knowledge on the different players in the electricity market and their roles, types of regulation and on legislation at a European level. Electricity distribution is a natural monopoly and therefore a regulated activity. This is because since the lowest long-run average cost is obtained when production of the socially optimum quantity is concentrated in a single agent. More specifically the cost function is sub-additive due to the presence of economies of scale, economies of scope and cost complementarities (taking peak and off-peak power supply as being two different products). EDP Distribuição is subject to constraints that other companies are not. It was important to understand the specific incentives that EDPD faces as well as the market in which it operates to be able to approach the problem correctly and make appropriate recommendations. The concepts learned on unbundling and remuneration of regulated companies allowed for a rapid understanding of the issues that were analyzed. Importantly, the theory on peak-load pricing serves as the basis for real-time pricing It was also on the basis of this knowledge that the idea of exploring load shifting and peak shaving came about. Particularly for the recommendations part, but not only, it was very important to keep in mind the regulators' mindset which, as previously mentioned, was studied in the course on Economic Regulation. This was important to understand that not all recommendations would be feasible as the regulator has specific objectives related to its task. Throughout the work this was taken into account by outlining how not only could the changes in the electricity market benefit EDPD but also the system as a whole by increasing societal welfare. Benchmarking was also important in this regard as it demonstrated that there are tried and tested uses of smart grids and online data that have were welfare enhancing.

3.1.2 Masters content adjusted

Given the time constraints and the broad focus of the project (which extended beyond Demand Response) it was necessary to adjust what I learned about modeling and make simplifying assumptions. Based on microeconomic theory, ad-hoc adjustments were necessary. For example, the existence of zero prices complicated the modeling of the supply curve which led to the adoption of a two part supply curve with the "maximum weekly zero" as the changing point.

Beyond the model itself it was necessary to adjust the theory learned and put it in practice. Although the notions acquired on courses like Microeconomic Policy Analysis or Economics of Regulation make for good frameworks there is a need to go beyond the clarity of theoretical knowledge to the messiness of practical application. The Business Project had EDPD has a client and therefore the goal was to recommend value creating opportunities for the company and not only analyze the economic benefits of Demand Response. In the recommendation part this meant being more business-oriented and, while understanding the specificities of a regulated business, make bold proposals that anticipate changes in the market and that can be used in the debate with the regulators to raise awareness of improvements that can be made in the regulatory framework. It also meant being more consumer-focused. While theoretically prices that change every five minutes, reflecting the conditions in the market, would be the most efficient way of signaling scarcity and sufficient by itself, this is not a feasible a way of structuring pricing and it is likely that consumers will adapt by learning and depending on the way communication is made. Which is why it is important to consider effective and user-friendly systems of communicating prices. It also meant considering issues which are beyond the scope of the electricity market but are relevant for consumers, such as the issue of privacy and the use of data.

3.2 New knowledge acquired

During this work I acquired new knowledge both out of a need for information and as a result of the work itself. The extensive research that I had to perform on electricity markets allowed me to further explore the knowledge I already had acquired. I did not know about the particularities of electricity distribution and regulation in the Portuguese market or anything about smart grids.

Firstly, when doing overview of smart grids in Europe as well as benchmarking relevant projects in this area I learned about what they are and future perspectives for the their development and use in Europe. Looking at examples also allowed me to understand what had been achieved and what are the regulatory and financial constraints to further exploration of smart grid potential. Secondly, I explored the concept of demand response as a way to balance the grid and overcome the inefficiencies that arise as a result of flat pricing. The process of electricity procurement and the question of forecasting and the imbalances that result from forecast errors was also something I did not know much about and that I have now learned.

Additionally, I developed my business process and project management skills. Having to prepare frequent meetings with the company, reporting to the academic advisor and coordinating with my group meant learning how to "behave" in a consulting project and helped acquire skills that will be useful in the future such as agenda-setting, time management and of having a clear methodology in order to breakdown a complex problem into simpler ones. The importance of presentation, by having a storyline that communicates a message clearly and, for example, the use of action titles and visually stimulating slides was something that was not carefully explored in the Masters in

Economics and that was of paramount importance while developing this Business Project.

I also improved both my Microsoft PowerPoint skills working on the final report and my Microsoft Excel skills while working on the model presented above, to which I counted with the support of my helpful academic advisor.

3.3 Personal experience

Being this project I was able to understand better what are my strengths and weaknesses. I would say that my analytical capabilities and the capacity to absorb great amounts of information and coming up with clear and simple explanations are some of my strengths. I was able to realize this since, given the complexity of the electricity market and the task at hand, I felt that I had a clear picture of what was happening and which areas could be explored. Here I obviously benefited from my academic background and work developed previously, having already analyzed a part of the electricity market. Working as a team was an area where I felt no issues and I believe that I performed well in this regard.

The weaknesses I identified as having were essentially in areas that are under explored in the Masters in Economics. As I mentioned, the capacity to transmit information to any audience in an effective manner is something that I had not worked on as much as some of my colleagues and the whole structure of a consulting project and the idea of being more business-centric, with all that it entails, were not easy tasks to deal with at first. My Microsoft Excel skills were also lacking as I had not used it much during my academic studies.

In order to improve my capacity to communicate and persuade I intend to pay more attention to the presentation side of future work as well as aesthetics and use more frequently frameworks that consultants generally use to clearly communicate a message. My Microsoft Excel skills have already improved with this Business Project and I plan to develop them further.

3.4 Benefit of hindsight

In hindsight there should have been more structure in the project from the beginning. A lot of time was wasted in meetings that were not that productive and the failure to decide on an approach early on prevented some areas from being explored further. This was further complicated by the sheer complexity of the task at hand and the misalignment between the company's initial requirements and the team. The Business Project had to disregard some of the more technical aspects of smart grids as there was no one with expertise on the subject. A better agenda-setting process with more research in the beginning would have allowed us to have a methodology and a storyline earlier on and would have allowed us more time to dive deep into the subjects that were presented in the final report. With all this in mind, focusing on Demand Response was a good idea that allowed us to add-value and explore a subject that has not been looked at carefully in the Portuguese market.

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