Privatizing the Saudi Electricity Sector

by

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ABSTRACT

Electricity demand in Saudi Arabia has been growing rapidly with an average peak demand growth rate of 6% over the past decade. Currently, the structure of the electricity industry is based on a monopoly framework dominated by a government owned utility company (Saudi Electric Company (SEC)). Furthermore, electricity prices in KSA are heavily subsidized and as a result, SEC relies heavily on government support through grants and soft loans to finance expansion projects to meet growing demand. In order to alleviate the financial dependency of the electricity sector on government funding, the system regulator (ECRA) announced major reform plans intended to encourage private sector participation in the electricity industry. This research aims to evaluate regulatory reform options available to the Saudi government for achieving privatization objectives. Chapter 1 lays the foundation of electricity regulation and addresses technical, economical, and regulatory aspects of electricity trading. Chapter 2, deep dives into the liberalization of the electricity industry in Great Britain as a pioneer case study with main take away being the importance of ownership unbundling in structural reforms. Chapter 3 provides a description of the current status of the sector in the KSA. It also discusses the regulatory options available to the government. Chapter 4 applies a mathematical model based on the concept of "Supply Function Equilibrium" to evaluate the government proposal of splitting the generation assets of SEC between four-generation companies. The model analyzes the level of market competition as a result of the proposed plan. The analysis shows that the establishment of four-generation companies will result in imperfect competition and that additional measures are needed to mitigate market power. Chapter 5 provides a summary of the proposed recommendations and suggests future work.

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Chapter 1

REVIEW OF ELECTRICITY MARKET REFORMS

Nowadays, electricity is an essential commodity that is regarded by many as a human right. It is a main driver for economic growth and future prosperity. However, the physical characteristics of electrical systems make it difficult for electricity to be traded similar to any other commodity. The fact that until now there is limited cost effective energy storage solutions mean that power must be generated and consumed almost instantaneously. Existing energy storage solutions in the form of hydropower (pump storage or run of river) require a certain topography that is not readily available in many countries. On the other hand, grid scale Chemical battery storage as a technology is still under development and is yet to be proven as cost effective solution. In other words, a perfect balance between supply and demand must be maintained at all times. These physical limitations prevent electricity from being traded as any other commodity and increase the level of complexity associated with its trade. Since the development of the first electrical network, the evolution of the system went through many stages. For a long time, the electricity industry has been perceived as naturally monopolistic with clear advantages of economies of scale. This view led to the rise of vertically integrated companies that produced, transmitted and sold electricity to customers in most countries around the world, in other cases, generation assets were owned by private entities so as transmission and distribution such as in some places in the United States. While economies of scale remain to be significant for certain segments of the industry, namely transmission and distribution, the industry had a major paradigm shift in the early 1980's led by a group of Chilean economists who proposed major changes to the way the electrical system is regulated. The proposal entailed the introduction of a regulatory framework were generation is opened up for competition. This proposal was supported by technology advancements in power generation; especially with the introduction of more modular generation units such as the Combined Cycle Gas Turbines (CCGT) that are very efficient even at a small scale enabled such a change of views. In addition, the size and maturity of electrical networks in many places diluted the effect of economies of scale typically associated with thermal generation units.

Since Chile began a radical restructuring and privatization program, more than 70 countries have introduced electricity reforms (Bacon and Besant-Jones 2001). Especially in the last couple of decades, structural and organizational reforms can only be described as a global phenomenon. Accordingly, our understanding of market reforms has increased significantly since it all started more than 30 years ago. Generally, we understand now that market reform is a "process" rather than an "action". A process that is subject to continuous evaluation and modification. Although, many countries went through reforms, very few achieved the highest levels of liberalizations and truly harvest the benefits of those reforms. Recent issues aroused as a result of reforms, such as the price spikes in California or system blackouts in Europe, pushed countries considering reforms to reconsider their plans. The complexity of reforms comes from the fact that every system is unique in one way or another (technological, geographical, legal etc.…), most countries that went through electricity market reforms did it differently. Having said that, there are high-level steps that were common to all. To explore these commonalities and difference, one needs to understand the common features of power systems, which are described below:

1. **Physical Structure:**

The physical structure of power systems consists of three main layers: Generation, Transmission and Distribution. Each of these segments has its own physical characteristics that impose certain physical constraints on the flow of energy from the instant it is produced to when it is consumed. Indeed, these constraints are what make the trade of electricity unique from any other commodity.

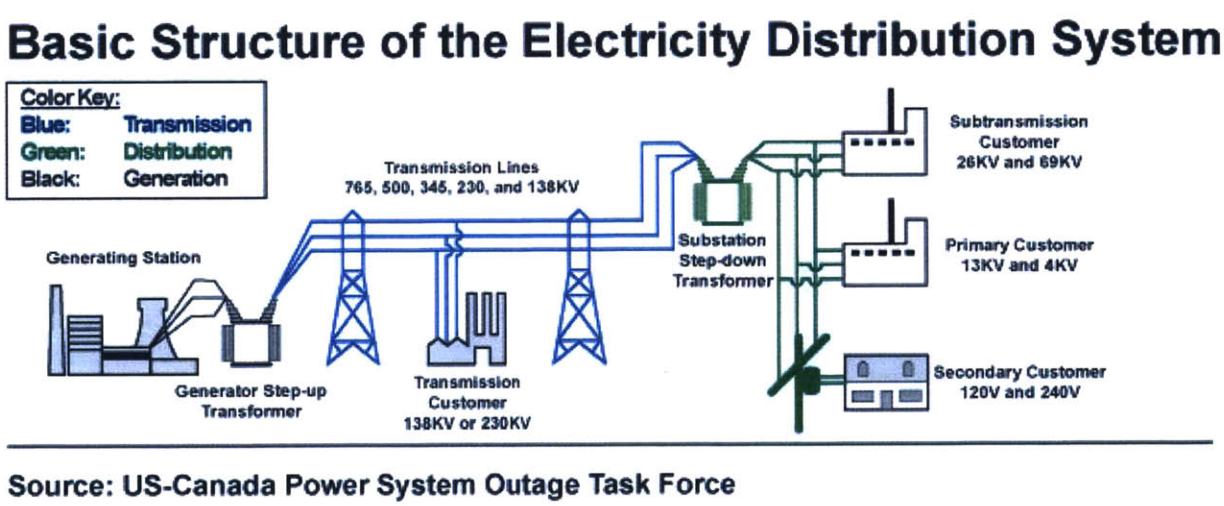

Figure 1: Power System Structure

1.1. Generation:

Typically, to meet electricity demand, power is generated centrally at power plants or stations. In such facilities, a source of primary energy (hydrocarbons, nuclear material, photons, wind, water potential energy etc....) is converted into electric power. Each technology has its own characteristics and use that defines its role and contribution to the operation of the power system. There are many power generation technologies used. Conventional power systems can be classified into three main categories: 1) hydroelectric where the primary source of energy is water and its associated potential energy due to gravity (expressed in energy terms). Under this category, water is used to generate hydroelectric energy, which is converted by hydraulic turbines into mechanical energy, which is then converted to electric energy through a mechanical shaft that is connected to an electrical generator. Since the primary source of energy for this technology is water, hydroelectric stations produce less pollution than other conventional generation technologies. In addition, given the low cost of the primary source of energy (Water) and the high level of flexibility for connection, disconnection and output modification, hydroelectric stations are conceived to be a suitable choice for system operators to regulate power output and meet demand fluctuations. However, one of the downsides of hydropower is that they require large reservoirs and often cause the displacement of human settlements or have hydrological impacts on their associated river basins 2) Steam-turbines are either fossil fueled or nuclear. Under this technology, chemical or nuclear energy is converted to thermal to mechanical and then to electrical energy. The thermal efficiency of this class of technology depends primarily on the caloric value of the fuel used and does not typically exceed 45%. This technology is known for being less flexible to changes in output, as it typically requires a certain level of heat inertia in the boiler before producing power (typically up to 7 hours), however, when such inertia is available the technology can be used to regulate power as long as it is within its output capabilities. 3) Combustion turbines that primarily use natural gas (Diesel among other types of fuel could also be used) as a fuel. Two categories of technologies are known under this category and are: i) Combustion gas turbine plants (single cycle turbines). In this case gas combustion under high pressure feeds a turbine that coverts energy generated to mechanical energy, and then an AC generator converts mechanical energy to electrical energy. ii) Type two is combined cycle gas turbines, where similar to the single cycle turbine, energy generated by the combustion is converted to mechanical energy then to electrical energy, however, under this technology the exhausted gas which is expelled at high temperature is captured and used to heat a water steam circuit to run an attached classical steam turbine. The latter technology is increasingly becoming a popular choice for system operators because of its high thermal efficiency, that can reach up to 60%; additionally the technology is a lot more flexible compared to steam power plants, more modular and produces significantly less polluting emissions, when fueled by gas.

Figure 2 shows the trend world's electricity generation by fuel type until 2040. It can be seen from the figure that the share of electricity generation from Renewable sources is expected to increase in future years. Given that the current costs of renewable energy technologies still requires a level of subsidy to be economically feasible, governments need to develop the appropriate support mechanism to guide the penetration of renewable energy.

Figure 5-3. World net electricity generation by fuel, 2012–40
trillion kilowatthours

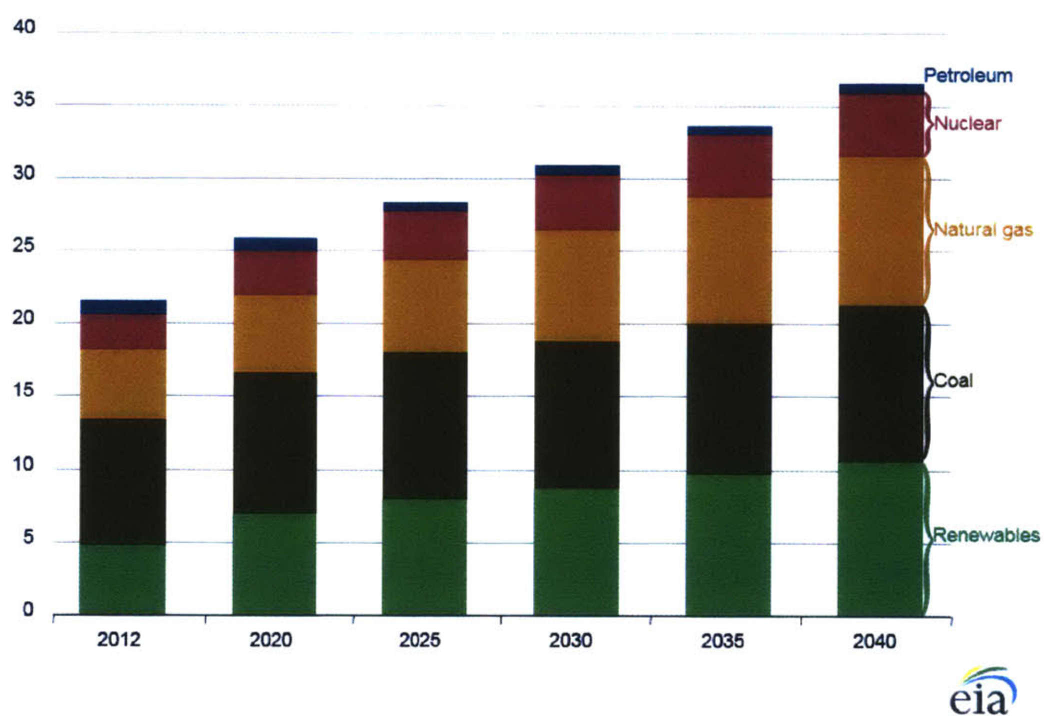

Figure 2 Electricity generation outlook by fuel type Source: EIA 2016 Energy Outlook Report

1.2. Transmission:

Transmission lines have a very important role in power systems. They transmit power produced at generation facilities to demand hubs. Long transmission lines operate at very high voltages to reduce current flow, hence reduce ohmic losses, voltage drops and cable size (insulation requirements). While there are many factors that contribute to the value of ohmic losses, a simple formulation that represents heat losses generated from transmission line resistance (ohmic losses) is as follows (Khandelwal and Pachori, 2013):

$$P_{loss} = R * I^2 \qquad 1\text{-}1$$

Where "I" is the amount of current flowing in the circuit and "R" is the line resistance. It can be seen from the equation that ohmic losses are proportional to the square of current flow. Transmission lines play a vital role in balancing the dynamics between generation and demand. Transmission remains as one of the major components of the power systems were economies of scale are evident, hence, is considered a natural monopoly. Even under wholesale markets, the transmission activity typically remains regulated.

1.3. Distribution:

These are lower voltage networks that even vary in structure compared to transmission lines. Such networks branch off transmission networks and are directly connected to costumers. Structurally, distribution networks tend to be radial. However, in highly dense areas the network is typically meshed to provide a higher level of reliability compared to rural areas.

2. Economics in Power Systems:

The economics of power systems is the discipline that studies resource allocation required to produce power to provide a range of electricity services. To understand resource allocation, the system architecture can be broken down into three main elements: The need, which is in this case the characteristics of demand, the costs of supply to meet demand and finally the allocation objectives and mechanisms (Carlos Batlle and Ocana 2013).

2.1. Demand:

Electricity is a commodity, however, the unique attributes of electricity, namely the non-convexity of Electricity market clearing prices as a result of the Electrical system's non-convex cost function discussed earlier, makes it different from typical uniform commodities that follow the general equilibrium theory. As described by (Samuelson, Paul Anthony, 1948) "General equilibrium" theory explains how agents behavior in a given market is based on the interaction of supply and demand (Classic supply-demand equilibrium), where each agent represent contribute to either the supply or demand or both. The market price is determined at the point when supply meets demand. Electricity market failure to follow this theory is attributed to a number of factors including the system's technical characteristics that could limit power production from more optimum resources (due to network or unit maximum power constraints) or as a result of structural deficiencies that yield market power.

To begin with, demand and hence supply is time dependent. Secondly, energy storage is still difficult and expensive to implement and therefore, supply and demand need to be matched at all times. In addition, the utility function of electricity not only varies with time but also with the quality of supply, type of user/use that shapes demand characteristics. Demand price elasticity, thus, electricity services needed varies by type of use or user. All these factors give rise to a variety of electricity services that distinguishes electricity from any other commodity. The bundle of services provided illustrates the non-uniform nature of electricity.

2.2. Costs of producing electricity:

The cost of supplying electricity is made up of the basic inputs required to generate electrical energy. These inputs can be classified into three main categories as follows: i) Natural resources or raw material. ii) Labor. iii) Capital, consisting of manufacturing goods, e.g. in the form of power plants.

Given the aforementioned, the cost of producing a quantity "Q" of electricity (e.g. expressed in units of Megawatthours [MWh]) is expressed as the sum of the cost of raw material, labor and capital[1]. Given a production function f, which relates costs of raw material, labor and capital, the cost of producing a quantity Q of power at any given time is as follows:

$$Q = f(L, K, T) \qquad 1\text{-}2$$

$$Total\ cost(Q) = w.L + r.K + e.T \qquad 1\text{-}3$$

Where:

w is the unit cost of labor [$/hr]

---

[1] Cost of capital includes rate of return on investment.

[2] Typically the determination of the adequate return on investment is the most difficult part of such regulations.

L is the amount of labor [man-hours]

r is the unit capital of cost [$/MW]

K is the amount of capital [MW]

e is the unit cost of natural resources [$/ton]

T is the amount of natural resources [ton/MWh]

It is worth highlighting that the total cost of power production can be classified into two main components, fixed and variable cost. The cost of power production as described above is driven by the cost of the associated inputs, a portion of which does not vary within short time periods by the level of power production, such as labor; such costs are termed "fixed costs". On the other hand, fuel costs are directly correlated with power production and as such referred to as "variable costs". This classification is true for a short-term time span ranging from seconds up to a year. However, for longer time spans (of several years), all costs of production may change with the demand level, including the capital cost since it depreciates with time, as the assets get older and closer to being retired. Power plants that are still operational and already completely depreciated ("written off") are essentially operated at zero capital costs, even though their operational costs due to maintenance and repair as well as variable fuels costs may be higher due to lower efficiencies at or after the end of life. The use of such a classification comes in handy to inform short and long term operational and investment decisions, respectively.

2.2.1. **Average and Marginal costs:**

The average cost of operating a power system is equivalent to the total cost over the amount of power produced over a time period.

$$Average\ cost = \frac{Total\ Cost}{Q} \tag{1-4}$$

On the other hand, the Marginal cost of producing electricity is equal to the change in total cost when power output changes by one unit.

$$Marginal\ cost = \frac{d(Total\ Cost)}{d(Q)} \tag{1-5}$$

Since as mentioned the total cost of electricity in the short run can be classified to a fixed and variable component, the marginal cost is equivalent to the derivative of the variable cost of generation with respect to the quantity of power generated. Additionally, since fuel costs are the main variable cost in thermal power plants, the marginal cost is found as the derivative of the fuel cost with respect to power produced. Typically, the marginal cost of power production in a given power system is determined by the variable cost of the marginal generating unit. Table 1, below provides an estimated cost comparison between various power generation technologies entering service in year 2022 in the United States.

U.S. Capacity-Weighted[1] Average LCOE (2015 $/MWh) for Plants Entering Service in 2022

Plant Type	Capacity Factor (%)	Levelized Capital Cost	Fixed O&M	Variable O&M (including fuel)	Transmission Investment	Total System LCOE	Levelized Tax Credit	Total LCOE including Tax Credit[2]
Dispatchable Technologies								
Advanced Coal with CCS[3]	N/B							
Natural Gas-fired								
Conventional Combined Cycle	87	12.8	1.4	41.2	1.0	56.4	N/A	56.4
Advanced Combined Cycle	87	15.4	1.3	38.1	1.1	55.8	N/A	55.8
Advanced CC with CCS	N/B							
Conventional Combustion Turbine	30	37.1	6.5	58.9	2.9	105.4	N/A	105.4
Advanced Combustion Turbine	30	25.9	2.5	61.9	3.3	93.6	N/A	93.6
Advanced Nuclear	90	75.0	12.4	11.3	1.0	99.7	N/A	99.7
Geothermal	91	27.8	13.1	0.0	1.4	42.3	-2.8	39.5
Biomass	N/B							
Non-Dispatchable Technologies								
Wind	42	43.3	12.5	0.0	2.7	58.5	-7.6	50.9
Wind – Offshore	N/B							
Solar PV[4]	26	61.2	9.5	0.0	3.5	74.2	-15.9	58.2
Solar Thermal	N/B							
Hydroelectric[5]	60	54.1	3.1	5.0	1.5	63.7	N/A	63.7

Table 1 Estimated LCOE for new generation, plants entering service in 2022 in the US. Source: EIA annual energy outlook 2016

Another important differentiating factor between technologies is the ramping time, which basically determines how much time does it take a generation unit to reach its maximum power output. The ramping time depends on the condition of the generation unit at the time of consideration, in other words it would take a thermal unit less time to reach its maximum power output if it is already in operation. Another important factor is the minimum run time, which is the minimum time a unit must run once turned on before being able to be switched off. Table 2 below shows a comparison between various generation technologies based on ramp and minimum run times.

Technology	Ramp Time	Min. Run Time
Simple-cycle combustion turbine	minutes to hours	Minutes
Combined-cycle combustion turbine	hours	hours to days
Nuclear	days	weeks to months
Wind Turbine (includes offshore wind)	minutes	None
Hydroelectric (includes pumped storage)	minutes	None

Table 2 Technology comparison based on ramp and minimum run time
Source: E-Education.PSU.EDU

2.2.2. Generation Costs:

The generation cost can be broken-down into three main components:

a) **Investment costs**: It includes the construction cost made up of raw material, labor and manufactured equipment. The construction time could vary between a few months to years depending on the power technology being installed. The aggregation of investment costs in a single year is referred to as the "overnight costs".

b) **Operation and maintenance (O&M):** O&M costs refer to the cost of operating and maintaining a power plant, not including fuel costs. This includes the cost of labor and repair and maintenance. The labor component of the O&M costs is typically thought of as fixed costs that does not vary much within a given year, as such is typically represented as monetary value per kW installed. On the other hand, the cost of repair/preventive maintenance depends primarily on the power produced and as such is a variable cost that is typically accounted for in monetary value per kWh [$/kWh].

c) **Fuel costs:** The costs of fuel are more important for fossil fuel fired power plants and less important for nuclear and are zero for hydropower, wind and solar plants. The cost of power produced in fossil fuel power plants is directly correlated with the cost of fuel. An important factor in this regard is the degree to which the input fuel for power generation is subsidized by the local state or national government in whose jurisdiction the generating asset resides. More importantly, the thermal efficiency (the efficiency at which the energy within the raw fuel material is converted into electricity) of the technology in use is a determinant to the quantity of fuel needed and hence the associated cost. An important consideration to highlight here is that the thermal efficiency of any technology varies with the unit's power output. Most thermal generation units can only operate at a predefined minimum power output referred to as the "technical minimum", operating below this level is both technically and economically challenging. Moreover, to reach the previously mentioned technical minimum output, a generation unit's chamber must reach a certain temperature and pressure, therefore requiring a quantity of fuel to be burnt before electricity is supplied into the system. The cost associated with this action is termed "startup cost" and varies with temperature and pressure level of the unit at startup. The total cost of startup is exponentially related to the number of hours a unit has been shut down and is typically modeled as a binary decision variable in electricity market models. it is simply formulated as follows (Šumbera, Jiří, 2012):

$$SC = ColdStart\,(1 - \exp\,(\frac{h}{H})) \qquad 1\text{-}6$$

Where:

SC: is the total startup cost [$]

ColdStart: is the maximum cost incurred at start up [$]

h: is the number of hours since the last shutdown [h]

H: is the heat input [BTU]

To sum up, it is understood that the cost of fuel is nonlinear with a number of factors contributing to the incurred cost as mentioned earlier. Such considerations are extremely important when determining the optimum operation of a power system during a given time period.

Generation costs typically make up the bulk of the cost of producing electricity. The proportional breakdown of generation cost varies among generation technologies and fuel type. Some technologies require large upfront capital and others don't. Similarly, some technologies incur large fuel costs; others don't necessarily use fuel (Solar, Hydro and Wind). Such features are essential when planning the capacity expansion of any power system.

2.2.3. Transmission and Distribution costs:

The costs of transmission and distribution are mainly made up of the investment costs that are required to build the grid itself and subsequently the cost of maintaining and operating the system. These costs include, the cost of building transmission and distribution lines, substations, switchgears as well as the associated voltage and current sensors, monitoring facilities and vehicles required for maintenance and inspection of the grid. The operation and maintenance cost is typically proportional to the volume of facilities (equipment) and as such directly correlated to the amount of investment made. Typically, the annual cost of operation and maintenance of an overhead transmission line represents 1.5-2.0% of the investment cost (Khandelwal and Pachori, 2013).

2.3. Market Fundamentals

2.3.1. Law of supply and demand

The law of supply and demand governs the trade of any goods and services. It provides the answer to how much should be sold or bought in a given time period and at what price. On the one hand, a customer's rationale for buying goods or services is based on their perceived utility value of the product he or she is buying. As long as the utility value of the product is higher than the price paid for it the rational behavior of customers is to buy more, up to an upper limit at which no additional utility can be gained (saturation). In other words, as long as the marginal utility, described as a unit increase in utility as a result of purchasing one more unit, is higher than the price paid for it, the customer's rational behavior is to buy one more unit. On the contrary, whenever the price for the additional unit is higher than the marginal utility of the good or service, then the rational behavior of the customer is not to buy more. Therefore, a customer's demand for a good or service increases until the value of marginal utility equals the price paid for it. At this point, each customer's total utility is maximized. This point represents the optimum quantity for a customer to buy.

Similarly, in the trade of electricity services, it is each customer that decides on his or her own utility value of the service provided. More specifically, how much he or she is willing pay to receive the service. As the utility function of electricity varies by customer, use and hence quantity, the aggregate demand for electricity typically has a negative slope and is made of the sum of each customer's quantity demand given a certain price. Customers are willing to pay a higher price for electricity services that provide them enough to power their essential needs, as an example they would be willing to pay more to keep the lights on at night and probably less to be able to turn on a stereo system. Similarly, manufacturing companies may have a high marginal utility for operating their factory equipment up to a maximum demand point.

On the other hand, a supply curve is subject to the producer's rational behavior, which is governed by two main factors, the cost of producing and the selling price. Each producing company seeks to maximize its own profit by determining the optimum quantity supplied. The optimum quantity is determined by the marginal production cost compared to the selling price. As long as the marginal revenue is higher than the marginal cost of producing an additional unit, the rational behavior of the producer is to supply more. As such, the optimum quantity to be supplied is reached when the marginal revenue equals the marginal cost of production.

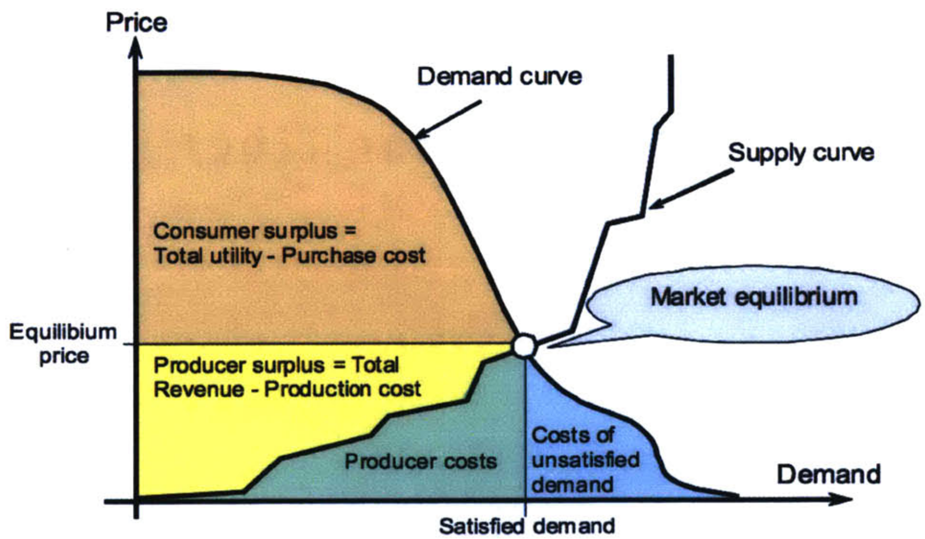

Figure 3 Supply and Demand Equilibrium Source: (Pérez-Arriaga 2013)

Market equilibrium is reached when both the supply and demand curves intersect. The price at market equilibrium is the optimum point at which demand and hence supply quantity is determined. As described in Figure 3 Supply and Demand Equilibrium, the customer's surplus equals to the total utility minus the purchase cost. On the other hand, the producer's surplus equals the total revenue minus the production cost. The area highlighted in blue is the cost of unsatisfied demand, at which the equilibrium price is higher than the utility value of any additional quantity supplied. Similarly, the blue area represents a quantity at which the equilibrium price is lower than the supply curve as such the rational for behavior for producers not to supply the needed additional quantity.

The mechanism of how the law of supply and demand comes to play changes with the industry structure. For the sake of illustration, assuming a centralized decision making mechanism where a given entity has control over all of the system's operation decisions in the short run and investment decisions in the long run, the objective function of such an entity will be to maximize total social welfare represented as the sum of the consumer's surplus plus the producer's surplus. Adding the two terms translates to the following formula:

$$social\ welfare = Total\ consumer's\ utility - total\ production\ cost \qquad 1\text{-}7$$

Assuming demand follows the same path shown in Figure 3, it is inelastic until it reaches the point of equilibrium at which the equilibrium price is higher than the marginal utility. At such a threshold, a quantity of demand is not served and is referred to as the "non-served energy". The per-unit cost of this quantity of unsatisfied demand is known as the "value of lost load" (VOLL). Then the operation of the entire system can be framed as an optimization problem that seeks to maximize social welfare as follows:

$$\max(social\ welfare) = \min\ (production\ cost + non\ served\ energy\ cost) \quad 1\text{-}8$$

The main takeaway here is that under a centralized model where social welfare is maximized, specifically, short term operation and long-term investment decisions are optimized; all cost of producing and operating a power system is covered, including return on investment. As such the long-term average profit (beyond the included return on investment) is zero.

2.3.2. Monopolies

For many years the electricity industry has been regarded as a natural monopoly as a result of a cultural expectation in many countries that commodities such as water and access to electricity are a universal right and a strong presence of economies of scale. In other words, the system's average cost of producing power declines with an increase in power output, which can be achieved by either large-scale plants or through better coordination or both. This is still true for electrical networks as the average cost of transmitting energy declines with the increase in energy flow. It is also true for the generation sector in systems that have a small installed capacity where economies of scale have yet to be exhausted. Typical economies of scale can be represented by the power law Y=aX^b, whereby X is the flow quantity, Y is the cost per unit of flow, a is a fixed scaling coefficient and the exponent b can be significantly less than unity, often on the order of 0.7-0.9 in magnitude for fossil fuel plants and 0.4-0.6 for nuclear plants (Phung, D.L, 1987). Under such a case, the company that enjoys the benefit of economies of scale has the market power to influence the price and quantity of electricity services. Consequently, the company that enjoys economies of scale has the ability to drive other competitors, if any, out of business.

As the aforementioned, the rational behavior of a producer is to seek the maximization of its own profit. As such, if unregulated, in the short run a monopolist can increase the price of electricity resulting in a drop of satisfied demand until profit is maximized. Additionally, in the long run, it is likely that the unregulated monopolist will underinvest in capacity expansion to reduce total costs, increase prices and hence increase profit.

As such, the main objective of regulation is to force the regulated monopoly to operate following the central planning approach. This entails operation under the so-called cost of service regulation, which factors in a target return on investment. In which, the regulated monopoly is required to prove to the regulator the efficiency of short and long term decisions in accordance with the objective function of maximizing social welfare. More importantly, a well-regulated monopoly will have a system's short-term marginal cost that is equal to its own long-term marginal cost. In other words, the regulated monopoly will be able to recover exactly total costs including a return on investment and nothing more or less. However, this requires the regulator (and the monopoly itself) to be perfectly informed of all the associated costs.

2.3.3. Perfect Competition

When economies of scale of the generation assets are exhausted, which is the case when a unit increase in power output does not result in a drop of the system's average cost, the regulator has the option of liberalizing the generation sector. The organization of the liberalized generation sector evolves around wholesale markets; the reason for this is to further increase system efficiency utilizing coordinated operation of the generation fleet.

When the generation sector is deregulated and an adequate number of competing firms exist, the rational behavior for each of these competing companies is to maximize their own profit subject to the following formula, whereby P_{market} is the non-regulated market price of electricity (in this case the market price is assumed to be set by the marginal unit, all other infra-marginal units that are producing receive that same price):

$$Profit_A = P_{market} \times Q_A - Total\ cost_A \quad \forall\ A\!: each\ firm \tag{1-9}$$

Therefore, finding the derivative of profit with respect to the quantity supplied and setting it to zero determine the optimum solution to this equation:

$$\frac{dProfit_A}{dQ_A} = P_{market} - \frac{dTotal\ cost_A}{dQ_A} = 0 \quad \forall\ A\!: each\ fir \tag{1-10}$$

$$\frac{dProfit_A}{dQ_A} = P_{market} - MC_A = 0 \quad \forall\ A\!: each\ firm \tag{1-11}$$

As discussed earlier, the main components that drive the shape of a supply curve is the total production cost and price. Based on the differential equation shown above, any given firm will only produce power from units whose marginal cost is lower or equal to the market price and other units that have a marginal cost higher than the market price will not be dispatched, as they will yield financial losses.

Price however, depends on the market structure, more specifically, whether perfect competition exists in both the short and long term. If this is the case, then the price will be set at a point where each of the competing firms recovers all the total costs including return on investments exactly in the same way as in the centrally controlled regime. However, achieving perfect competition is not an easy task to achieve. In the short run the number and size of the competing firms needs to be such that not a single company dominates the market. Additionally, free access to the market needs to be guaranteed to optimize long-term investment decisions.

Price signals are an important element in the functionality of a wholesale market. Whenever the market price is higher than the long-term average cost of the system, meaning that existing firms are making more profit than the minimum, this sends a signal indicating room for additional investments, hence the importance of guaranteeing free access to the market to optimize capacity investment decisions. On the other hand, whenever the market price is lower than the long-term average cost, competing firms run into the issue of being out of business. So optimally, the long-term average cost should equal to the short-term market price.

3. Electricity Regulations:

In principle the main objective of regulations is to achieve general welfare. This entails the protection of customers from higher electricity prices imposed by market power as a result of either an unregulated monopoly or imperfect competition. Additionally, it includes protecting the interest of involved firms in terms of the recovery of investments. As discussed above this is achieved by maximizing both the consumer and producer's surplus. As such, the role of regulations is to develop guidelines that steer the behavior of the industry's involved parties toward the optimum condition. As such, regulations have a vital role in governing the dynamics of the industry. The functions expected from a regulator can be distilled down to three: 1) Design and develop guidelines. 2) Supervise and monitor behavior. 3) Intervene whenever needed to correct actions. Nevertheless, it is very important for agents involved in the industry to have clarity on how and when the regulator is expected to act on any of these functions. "Regulatory uncertainty" that is the result of lack of clarity or unpredictability of the regulator's actions has negative consequences on the performance of the electricity industry. An example of "Regulatory uncertainty" is government's intervention by setting price caps at times of system stress, suppressing price signals by preventing prices from increasing significantly. Given the nature of intensive capital requirements when investing in the electricity industry and relative immobility of assets, regulatory uncertainty can hinder the participation of the private sector in the industry.

3.1. Regulatory models:

From a structure and organization point of view there are two main extreme models, as shown in Figure 4. 1) Regulated monopoly, where a given single company enjoys a vertically integrated monopoly of all activities for a given region that could span the whole country. 2) Full liberalization, in which, both the generation and retail activities are opened for competition. At the same time, transmission and distribution activities remain as regulated monopolies, although multiple owners could co-exist. In essence, the classification of a regulatory framework or model is linked to the level of competition introduced (if any).

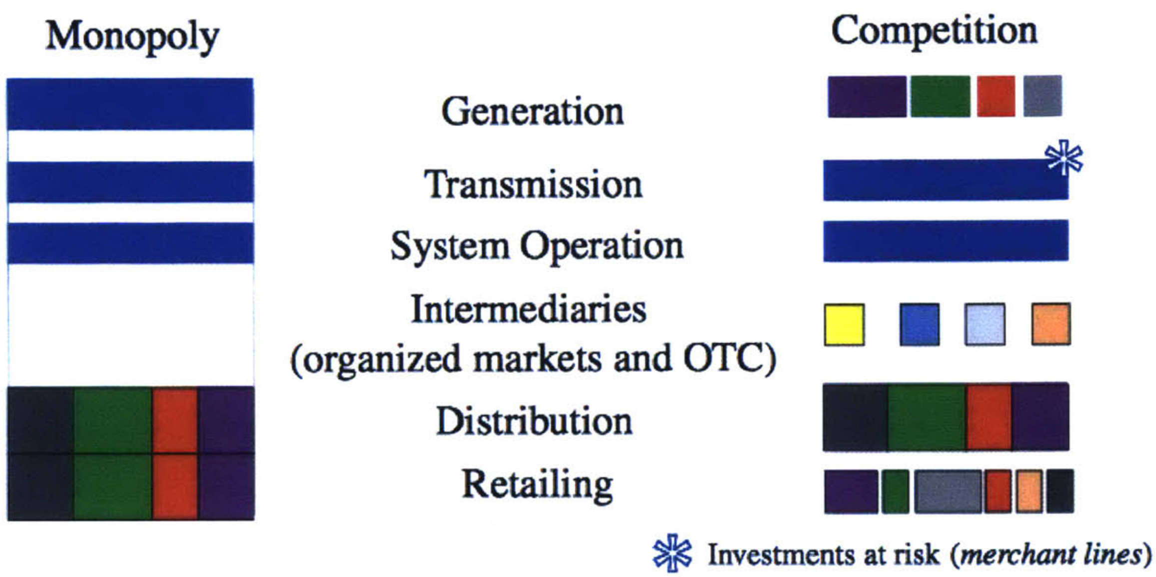

Figure 4 (Structure view of Monopoly Vs. Full liberalization. Colors indicate different legal entities in the system Source: (Pérez-Arriaga 2013))

3.1.1. Monopoly:

In the extreme case of monopoly regulations, a company is given a vertically integrated monopoly over a certain region (see Figure 4 left). This company could be state owned, in which the government makes operations and investment decisions. The cost of service is then passed on to consumers. Alternatively, the company could be owned by the private sector however is subject to oversight by a regulatory body.

In less extreme cases, segments of the electricity services activities remain regulated such as transmission, distribution and retailing. In both cases, instruments available to a regulator can be grouped into two main categories (Carlos Batlle and Ocana 2013):

3.1.1.1. Cost of service regulations:

Cost of service regulations entail two major steps: 1) Decide on the allowed company remuneration. 2) Design a tariff structure that allows the regulated monopoly to recover the allowed remuneration. The sequence of events under this scheme involves the regulated monopoly presenting full details in regards to total cost incurred and investment requirements. It is worth highlighting that under such regulations, additional measures that include minimum quality of service and security of supply are imposed on the regulated monopoly. Once the regulator approves all cost items, specifically investment and planned operation costs, the next stage involves the negotiation around the allowed rate of return. The most common method to identify the rate of return is by using the weighted average cost of capital (WACC)[2].

The final step involves the design of the tariff structure that allows the regulated monopoly to recover costs including the agreed upon return on investment. This process is typically done annually[3] and is known as the "Rate case" or "Tariff review".

The main advantage of this model of regulation is that if done well, electricity services will be priced fairly. This entails customers not overpaying for the service and also the regulated monopoly recovering total costs. Additionally, it provides governments the tool to implement social programs such as energy incentives and utilization of local energy resources. As explained earlier, the tariff structure is a major component of any electricity market design. At one hand, the tariff needs to be designed in a way that assures the cost recovery of the provided electricity services. On the hand, it also should not suppress price signals to demand. Traditionally, the Electricity industry used a regulated tariff that did not differentiate between consumers; as a result, demand has been viewed as inelastic. This has changed in the past decades with the present of more advanced metering technologies and the increasing awareness of the importance of price signals. While there are several tariff design schemes, the major three can be categorized as follow (reference):

1) Classifies customers based on their type of use and periodic consumption level and places them accordingly to a bracket price rate.

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[2] Typically the determination of the adequate return on investment is the most difficult part of such regulations.

[3] The review process can also be initiated out of cycle if presumed necessary by either the regulator or the regulated company.

2) Time of use tariff, which typically requires the installation of meters with a time log. Under this scheme, customers are informed in advance about electricity price rates of certain time blocks.

3) Dynamic (real time) pricing, which requires smart meters that has the capability of communicating electricity prices real time (used in liberated markets).

On the other hand, examples of disadvantages of this scheme of regulations include: economic inefficiency as a result of social programs, an example is the mandate of using local fuel resources that might not result in the most economic efficient option. Another disadvantage is that cost of service regulation require the regulator to be perfectly informed of all cost items, which in reality is very difficult to implement given the typical large volume of assets involved. Moreover, the determined return on investment has a great impact on the sector. If it is set higher than what is required, the regulated monopoly will tend to overinvest. On the other hand, if the return on investment is set lower than what it should be, then the regulated monopoly is likely to underinvest and as such negatively impact the system's quality of service and security of supply. Finally, the regulated monopoly does not have the incentive to optimize investments as all the costs and risks associated with the investment are transferred to consumers.

3.1.1.2. Incentive based regulations:

The overwhelming concerns associated with cost of service regulations pushed regulators to search for an alternative model of regulation. Incentive based regulations provided that alternative. The objective of this scheme of regulation is to essentially incentivize regulated monopolies to reduce cost, while at the same time not allowing them to exercise market power.

The regulator sets a price or revenue cap for a period of time, typically referred to as the price control period, typically in the range of 5 to 8 years. During the control price period, the regulated monopoly is allowed to retain some or all cost savings achieved (the difference between the price or revenue cap and the actual cost), as such providing the regulated monopoly to achieve cost savings. After the price control period ends, price or revenue caps are updated for the new price control period, as shown in Figure 5. Although in the short term the benefit to customers might be minimal, in the long run the price is expected to fall.

The best-known method applying this concept is known as the "RPI-X", which is used in Great Britain to regulate transmission and distribution activities and is explained in further details in the next chapter.

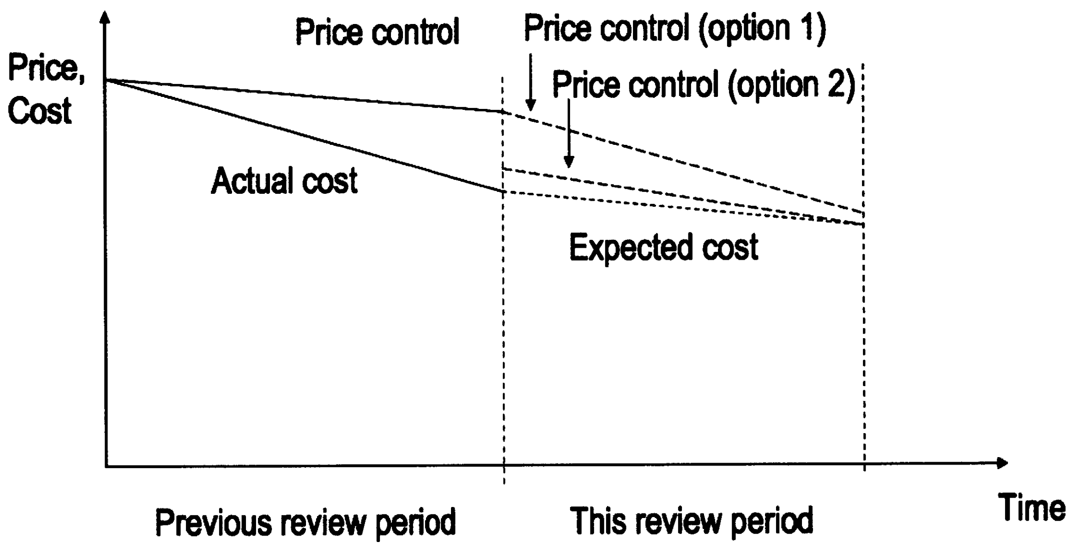


Figure 5 Projected costs and prices: smoothed revenue pattern (source: Green and Rodriguez-Pardina (1999))

A third model for monopoly regulation that is not often used is the "yardstick competition". Under this scheme, the regulated tariff for a group of regulated monopolies (typically used to regulate distribution activities) is set using statistical analysis of the remuneration data of each member of the group and determining the cost of average efficiency. Thus companies performing under such a scheme have the incentive of improving cost efficiency and reaping additional profits.

The main disadvantage of this approach is that it is not easily implementable. The regulator must obtain accurate and detailed data for a number of similar companies. The other issue is that companies are rarely similar in term of the size, mix and volume of assets under their control.

3.1.2. **Full liberalization:**

Structurally, as shown in Figure 4, full liberalization of the electricity sector involves the vertical and horizontal unbundling of the generation and retail activities. Essentially, both the generation and retail activities are carried out competitively. Simultaneously, the transmission and distribution activities remain as regulated monopolies, although they could be owned by several entities.

Full liberalization involves the establishment of wholesale and retail markets. The wholesale market provides an intermediary layer that allows central trading of power. As discussed previously, economies of scale in the generation sector prevail in two forms: 1) As a result of using large-scale plants in a system of small installed capacity. 2) An outcome of achieving highest level of dispatch coordination. Therefore, wholesale markets through coordinated power trading enable achieving higher system efficiency. The establishment of a wholesale market gives rise to two new functions. 1) System operation: It entails the physical operation of the network including the balance of supply and demand. 2) Market operation: It involves the commercial operation of the market, mainly the matching of supply and demand bids. Both functions need to be carried out by entities independent from other activities, to avoid a financial conflict of interest. Typically, both functions are assigned to the same entity. The owner (or one of the owners) of the transmission network can be designated as the system and market operator. In some cases, a single or multiple entities are established to carry on one or both functions.

The actual operation of wholesale markets is organized mainly around day ahead markets. Under day-ahead markets, generators and retailers submit their bids for supply and demand respectively. The market operator then aggregates supply and demand curves. Additionally, the market operator calculates the market-clearing price for each of the settlement periods and declares the dispatch schedule for generation units for the following day.

The formatting of the submitted bids varies on the basis of the required details. Systems that do not consider network constraints when deciding on the dispatch schedule typically require a simple format that is made up of pairs of price and quantity[4]. A more complex bid format require generators to submit details involving the ramping rates of each of the generating units and startup cost[5]. The decision to address network constraints in market operation is directly linked to the wholesale market price format. The regulator can opt to have a single price for the whole system. Alternatively, the regulator can choose to have a zonal or nodal pricing that reflects network constraints in the system.

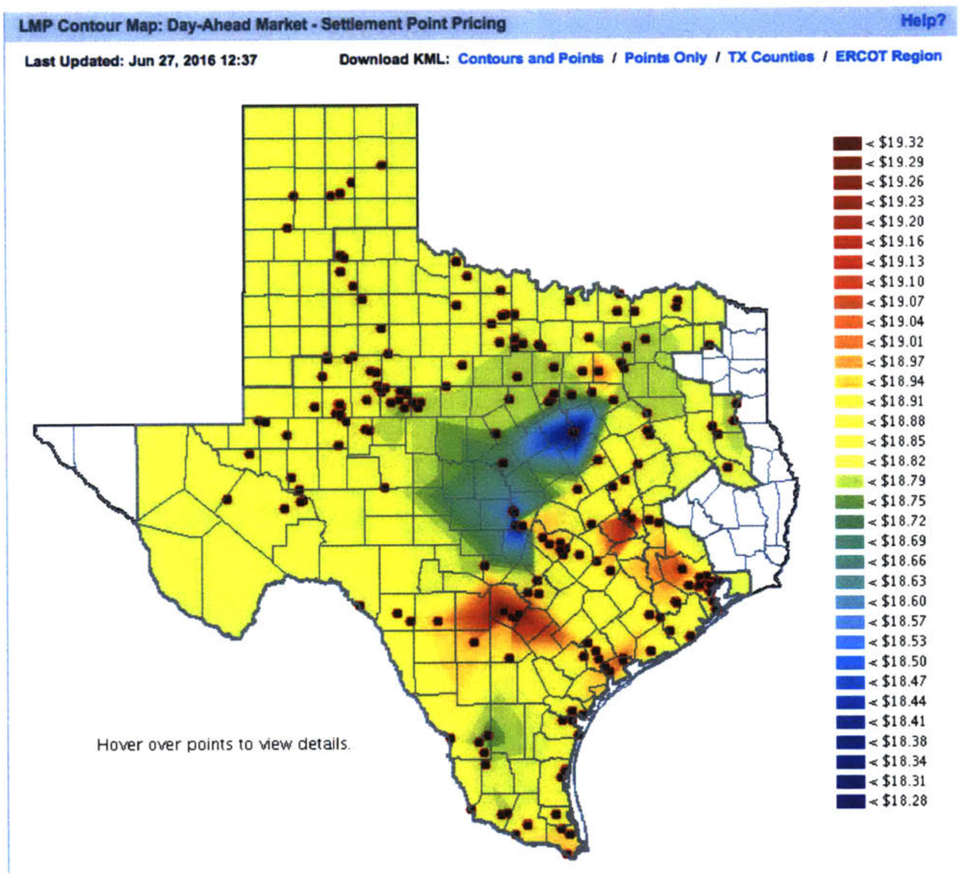


Figure 6 Nodal pricing, Texas. Source: Ercot

Additionally, regulators might choose to have intraday markets that allow both generators and retailers to modify their bids after the day-ahead market ends and until "gate closure". At gate closure, the system operator takes responsibility of operating and balancing the power grid. To balance the

[4] An example of such systems includes most of the European countries.

[5] An example of such systems is the PJM market.

system, the system operator taps into the ancillary service market. Finally, a submarket for trading long-term contracts can also be established, in which power delivery can be contracted for periods varying from few months to years.

On the hand, transmission and distribution activities remain as regulated monopolies. As discussed before, the regulation can either be based on a cost of service or incentive based scheme.

Full liberalization involves the deregulation of the retail activity. Retailers compete on the basis of pricing and services provided to customers. In principle, retailers set the electricity tariff, although in some countries such as the United Kingdom the tariff structure is standardized to allow customers to easily compare prices.

In summary, electricity market privatization is a process that many countries have opted to undertake with the objectives of increasing system's efficiency, transparency and private sector participation. The complexity of electricity services trade present in its physical characteristics imposes constraints that must be adhered to when designing electricity markets.

The two major frameworks for regulating electricity services are monopoly regulations and liberalization. In both, governments thrive to achieve the objective of maximizing social welfare. While in systems with a small installed generation capacity base (economies of scale are still present) the only regulatory option available is monopoly regulations, systems that have a large base of installed power generation capacity have a choice. Ultimately both frameworks have their advantages and disadvantages and in theory if done well should reach the same optimum solution. As such, the decision to which framework to implement is case specific and depend heavily on how well the regulatory framework is developed.

Chapter 2

CASE STUDY: GREAT BRITAIN

1. Market Evolution:

Until 1947, the electricity sector in England and Wales was similar to that of many countries in that it was entirely owned by the state. Generation and transmission expansion were done on the basis of least cost and financed by low cost loans. A "Central Electricity Generating Board (CEGB)" owned and operated generation and transmission, selling power to twelve area boards that distributed and supplied (retail) electricity to end consumers. In Scotland the situation was not vastly different with the North of Scotland Hydro-Electric Board (NSHEB) and the South of Scotland Electricity Board (SSHEB) each enjoying a regionally based vertically integrated monopoly. Professor David Newbery of the University of Cambridge highlights that the adopted framework was criticized for having poor, slow and costly investment planning and delivery processes. Additionally, few incentives were put in place to incentivize delivering cost efficiency.

The government decided to launch major reforms to its electricity sector with the main objective of privatizing the sector to create competition and improve capital efficiency. This endeavor was part of major economic reforms aimed at actively involving the private sector in service type sectors. This movement resulted in privatizing the telecommunication and gas sectors prior to the electricity sector. In addition, there were major concerns from the public that the sector provided an instrument leveraged by politicians to influence government policies. An example of that was the use of the more expensive British coal by the state owned CEGB, which resulted in higher prices for end consumers. Another important motivation for the industry decentralization was investment risk allocation. Under a regulated monopoly framework, investment risk is solely borne by end consumers as the system's cost is typically passed to them by the regulated monopoly.

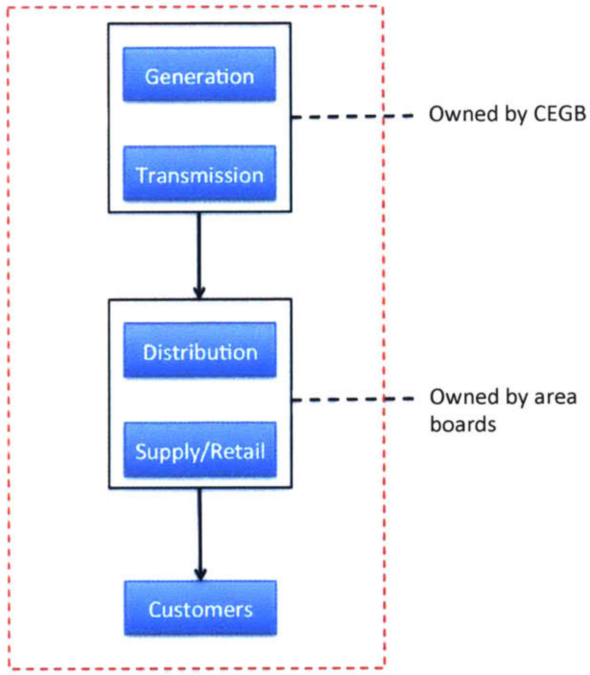


Figure 7 System architecture prior to privatization in the UK

Market reforms began in 1989 with the passing of the 1989 Electricity Act. The historically owned and operated power plants and transmission network in England and Wales was split into a transmission (National Grid) and a number of generation companies. The essence of the reforms was to guarantee "free entry" to the power generation sector and stimulate competition. The creation of competition in the generation sector entailed the establishment of a wholesale market, which was done after long debates. The next step that was long debated as well was how many generation companies to create? The answer to this question hinged on how to privatize nuclear power (which is often viewed as base-power since it is difficult to ramp up and down nuclear power on short notice). An idea that was discussed at the time was to lump all the 12 nuclear power stations into one large company (8 GW) in the hopes that the size of the new company would reduce the typical commercial risk associated with nuclear assets and make it financially viable. The government later realized through its financial advisors that the nuclear assets were not sellable at a positive price, and therefore decided to establish and transfer the assets to a publically owned Nuclear Electric company. The remainder of the assets (74 power plants) owned by CEGB was divided between three companies. 30 GW of conventional generation capacity was placed in National Power, 20 GW placed in PowerGen and 2GW of pumped storage was placed in the National Grid. The four companies were created as public limited liability companies on March 31, 1990. On the other hand, the twelve-area boards distributing and supplying electricity were also corporatized into 12 distribution companies known as the Regional Electricity Company (REC). In December 1990, both the National Grid Company and the 12 REC's were sold to the public. Subsequently, 60% of Power Gen and National Power were also sold to the public in March 1991, with the remainder of shares sold in March 1995. The pumped storage capacity placed in National Grid was separated and sold to "Edison Mission Energy" at the end of 1995. Finally, competition in power generation was introduced and all generated electricity was mandated to be sold through the wholesale market known as the "Electricity Pool". "The Office of Electricity Regulations" which is an independent entity that was established through the 1989 Electricity Act regulated the market.

In Scotland, the NSHEB went through similar yet slightly different restructuring that resulted in non-nuclear generation capacity placed in a newly created public company "Scottish Power" and the nuclear power plants remained in NSHEB, which was renamed Scottish Hydro-Electric. Despite the privatization in Scotland, the two utility companies remained vertically integrated. Nevertheless, they were allowed to trade power in the England and Wales Pool market and vice versa. The argument made by the Scottish government was that the interconnection between Scotland and England was weak and the Scottish system was small making it inadequate to establish a wholesale market on its own.

Creating a retail market required more time. During the first few years of privatization, only costumers with a power demand of at least 1MW were allowed to freely contract with any supplier. Any other consumer was forced to buy power from their local REC's. In 1994, the limit was lowered to 100kW and as a result an additional 45,000 customers were allowed to freely contract with any power supplier. In late 1998, the remaining customers had that same right and by mid-1999 the regional monopolies of the REC's ended. In the year 2000, retail businesses were required to be legally unbundled from generation and distribution. An illustration of the market structure post privatization is shown below.

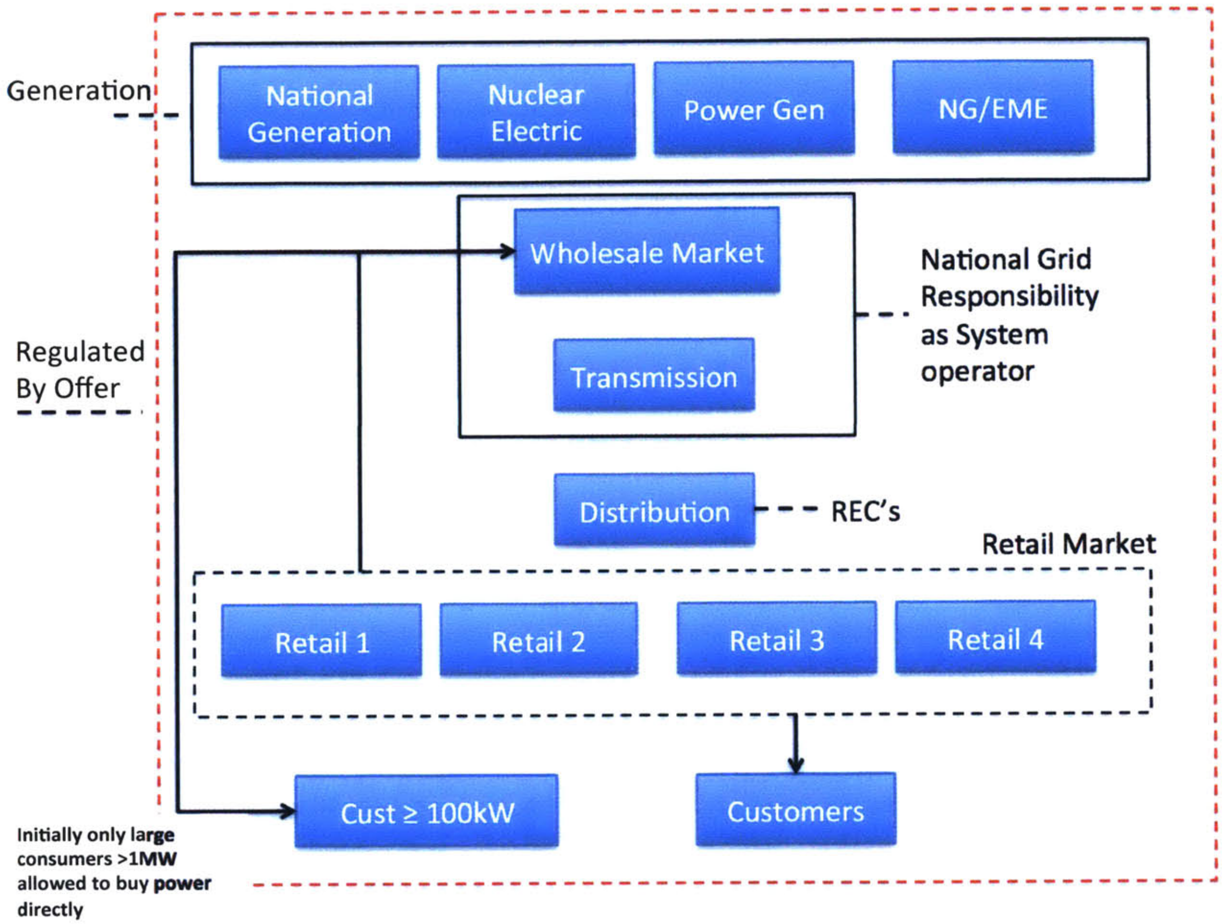


Figure 8 Market structure post privatization in the UK

Until 1995, REC's were heavily regulated under a cost of service regime and were protected against take over by Golden shares[6]. When the protection period lapsed, REC's were targeted by many investors especially those involved in the generation business in the UK. From the perspective of generators, investing in the retail business provided an opportunity to reduce their risk positions by securing a guaranteed access to end consumers. This is made possible as retail businesses are only required to be legally unbundled from other activities except when it comes to transmission (investment in transmission requires ownership unbundling from all other activities within the power system). As a result of this movement, six of the REC's were successfully acquired (two by other UK regulated utilities, one by a Scottish electric utility, one by Scottish Power, and two by US utilities). Additionally, both National Power and PowerGen made bids to acquire two RECS'. However, their

[6] Golden shares are shares typically owned by the government that are able to outvote all other shares under certain circumstances. This is typically done in government owned companies undergoing the process of privatization.

offers were blocked by the Secretary of State based on a recommendation from the Monopolies and Mergers Commission on the grounds of potential significant market power as a result of vertical integration (between Generation and Retail). The increasing regulatory uncertainty was exacerbated by findings of the Pool Review at the time and discussions of introducing major market reforms (introduction of NETA) encouraged both generation companies to find solutions that would allow them acquire a retail business. The obvious solution for both companies was to divest generation. In 1998, PowerGen engaged in discussions with the Secretary of State to sell 4GW of plants in return for acquiring East Midlands Electricity distribution and retail businesses. Similarly, National Power agreed to sell 4GW of its generation assets in order to buy the retail business of Midlands Electric. In the following years the market structure continued to evolve increasing vertical integration between generation and retail. The market attracted foreign investments made by investors from the US, Germany and France to highlight a few.

2. Major Regulatory Bodies:

2.1. Department of Energy & Climate Change (DECC):

The mission of this government entity is to ensure that the country has secure, clean and affordable energy supply and to promote international action to mitigate climate change. DECC sets the policy direction of the utility sector at a country level.

2.2. Gas and Electricity Markets Authority (GEMA):

GEMA is a government authority, the role of the authority is to set strategic direction for the regulator of electricity and gas sectors (acts as the executive board to the regulator). The authority oversees Ofgem (see below).

2.3. Ofgem:

The system regulator Ofegm charter is to achieve fair and acceptable competition in the UK electricity wholesale and retail markets. Additionally, Ofgem regulates distribution and transmission activities.

2.4. Competition and Markets Authority (CMA):

CMA advocates for competition for the benefit of customers both within and outside the UK.

3. Wholesale market:

3.1. Early wholesale market model: The "Electricity Pool":

A year after the 1989 Electricity Act, a wholesale market was established based on the electricity "pool", a central dispatch model. The established market was a compulsory day ahead market. The clearing mechanism used was the same unit commitment optimization algorithm used for central dispatching prior to the privatization of the sector known as "GOAL". The Transmission System Operator (National Grid) had the responsibility of running the model. Market participants would bid supply (generation) (by 10:00 a.m. the day before) and demand is forecasted establishing a supply and demand curve for half hour intervals for the following day. The algorithm would then optimize cost (including startup and ramping costs) and provide a dispatch schedule for the generating units on the bases of their merit order (by 5:00 p.m.). The algorithm would also calculate the system marginal prices (SMP) for each of the time intervals, which is equal to the cost of the most expensive generating unit dispatched in the system in that time interval. All participating generators were paid the same price (SMP) for every hour that is computed ex-ante. In addition, plants declared available and not dispatched received capacity payments in proportion to the loss of load probability factor (explained in the following section). Inputs to the model primarily were technical constraints of generation units including technical minima and ramp rates. As the model did not factor in network constraints, these were treated at a later stage through a simple re-dispatching scheme.

3.1.1. Final market clearing price calculation:

As highlighted by Prof. Perez-Arriaga, the unit commitment model that was in use is a deterministic model, an additional term was needed to calculate final market prices that reflect the possibility of supply or demand deviation resulting in the system's inability to meet demand at a given time period. Such capacity payments were made available to compensate units declared available providing the needed ancillary services and were not dispatched (when dispatched they receive the

SMP). Therefore, market-clearing prices were calculated using the following formula("Wiley: Power System Economics: Designing Markets for Electricity - Steven Stoft" 2016):

$$Market\ price = System\ marginal\ price \times (1 - LOLP) + VOLL \times LOLP \qquad 2\text{-}1$$

Where:

System marginal price: was calculated using the unit commitment model. Once the unit commitment schedule has been determined for the following day, each generators marginal price was computed for every half an a hour of the day in a way that allows the generator to recover total operating costs including startup and no load costs. Then the system marginal price (market clearing price) was set equal to the highest generator's marginal price.

"LOLP": stands for loss of load probability and is calculated using a separate model.

"VOLL": is the value of lost load, which is a determined by the regulator as the marginal price of non-served load.

Moreover, consumers had to pay additional charges that were due to re-dispatching requirements as a result of network constraints. Generators occasionally manipulated the system by declaring unavailable units at critical times causing the value of LOLP to go up and as a result obtaining higher remuneration that did not reflect the actual status of the system.

3.2. Current wholesale market model: The "Power Exchange":

3.2.1. The New Electricity Trading Arrangement (NETA):

In 1997, the government required the regulator (Offer at the time, currently renamed to Ofgem) to review the electricity trading arrangements and report results by mid-1998. The Pool Review (Offer,1998) was done on the basis to investigate change options that would improve market conditions such as prices, quality of service, security of supply and promoting market competition. In the review, Offer argued that generators benefited from the complexities of market price calculations and that a market structured like a classic commodity market would limit price manipulation practices. On the other hand, many area experts criticized the approach and recommendations pinpointed by the Pool Review. Newbery (1998) highlights that "The present review appears to have relied mainly upon unsubstantiated claims, inappropriate analogies, un-quantified criticisms, and a remarkably uncritical assessment by the participants of the debate, without commissioning the kind of detailed analysis one might have expected from a regulatory agency claiming industry expertise." Also, Shuttleworth (1999) states, "it is difficult to find any rigorous analysis to underpin the reform proposals". Nevertheless, the Government decided to introduce major changes to the utility sector regulations. The New Electricity Trading Arrangement was enforced starting on March 27, 2001. NETA replaced the pool and the wholesale electricity market became based on a power exchange scheme rather than centrally dispatched. One of the main differences between the two schemes is that under the Pool market, units are dispatched centrally, while under NETA, units are self-dispatched.

The adopted framework allows power to be traded in four interdependent markets over different time scales (see Figure 9):

Future markets: allow market participants to engage in standardized long-term contracts (Power Purchase Agreements) for several years.

A market for **Bilateral** contracts covering medium term periods from few months up to a year.

Spot market that allows trading from as early as 24 hours to "Gate Closure", which is set at an hour and a half before real time dispatch. The spot market also serves as a market for ancillary services that are subject to the "Balancing Mechanism". Several power exchange platforms were created and are linked to the European exchange platform (ICE, Intercontinental Exchange). An example of a platform in use is the Automated Power Exchange platform (APX). The bids are simple in that they only consist of price and quantity pairs. As a rule, prices are submitted with a precision of two decimals. In addition, power could be traded in block hours (number of hours) subject to the principle of "fill or kill".

Electricity is traded in half hour periods referred to as "settlement periods". Therefore, there are 48 settlement periods in a day. At gate closure, counterparties are not allowed further trading/modifications and the system operator (NG) takes over control of decision-making. The system operator balances the system by handling any imbalances caused by deviations from declared positions. This process is governed by "balancing and imbalance settlement rules" under BETTA, where the operational part is done by the system operator and the cost of handling such deviations is endured by counterparties causing the imbalance if any or else is socialized. Electricity can also be imported or exported through interconnectors. Currently the UK electrical grid is interconnected to France, the Netherlands and Ireland.

The **Balancing Mechanism** (BM) is also used for balancing services (ancillary market), which is governed by the "Balancing and Settlement Code". All market participants are required to announce their Final Physical Notifications (FPNs) to the System Operator before Gate Closure. National Grid (the System Operator) has the overall responsibility as 'residual balancer' of the electricity system, and takes actions to ensure that electricity supply and demand match at all times. The System Operator accepts bids for balancing services through the Balancing Mechanism and produces cash-out prices for clearing imbalances between the declared position of each trader and the actuals. The cash-out price is set to incentivize market participants to ensure demand is met, and the 'residual balancing role' of the system operator is minimized. The cash-out price is based on SO's incurred cost of balancing the system.

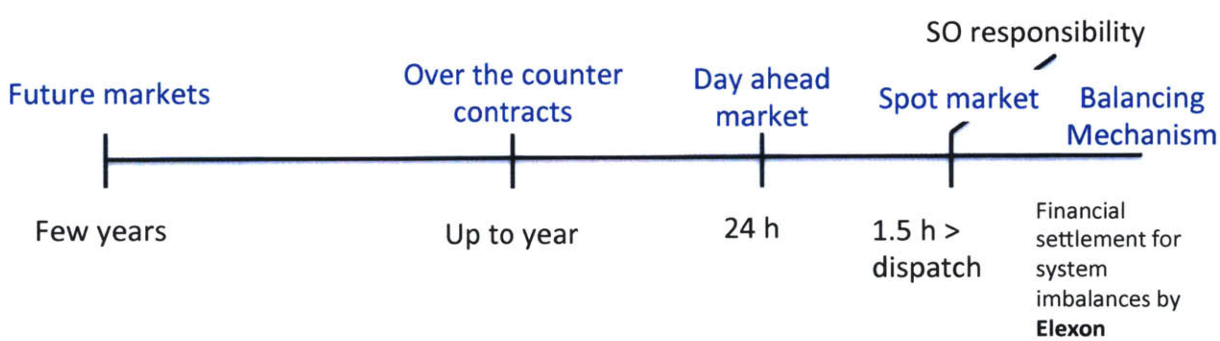


Figure 9 Market Operation Sequence under the UK NETA

The financial aspects of the "balancing and imbalances settlement" rules are handled by "ELEXON", which is a subsidiary of National Grid. NG uses the spot market to balance the system. Generators indicating their operational flexibility make offers to increase or decrease their power output. Similarly, power suppliers (retailers) could participate by offering the shedding of some of their loads.

3.2.2. British Electricity Trading and Transmission Arrangement (BETTA):

Later in 2005, NETA was extended to cover Scotland and was renamed to the "British Electricity Trading and Transmission Arrangement). The British Electricity Trading and Transmission Arrangements (BETTA) created, for the first time, a fully competitive British-wide market for the trading of electricity generation (the wholesale market).

In October 2001, the two vertically integrated utility companies in Scotland were forced into legally separating their generation, transmission and distribution businesses into separate entities.

Additionally, this endeavor entailed extending the responsibility of the National Grid as a system operator beyond England and Wales to cover Great Britain as a whole. As mentioned before, two companies owned and operated the transmission system in Scotland, after the introduction of BETTA, both companies retained ownership, however, the entire system operation responsibility was assigned to National Grid. Both systems are interconnected through high voltage overhead lines that connect Scotland to England and Wales. The undertaken reforms were meant to promote competition mainly in the Scottish system by ensuring open and fair access to the network for independent generators and retailers.

Moreover, BETTA introduced regulatory support mechanisms aimed at increasing the penetration of Renewable energy penetration such as "Renewables Obligation" and access to capital grants. Additionally, financial instruments such as a "contract for differences" were introduced to provide financial hedging for market participants.

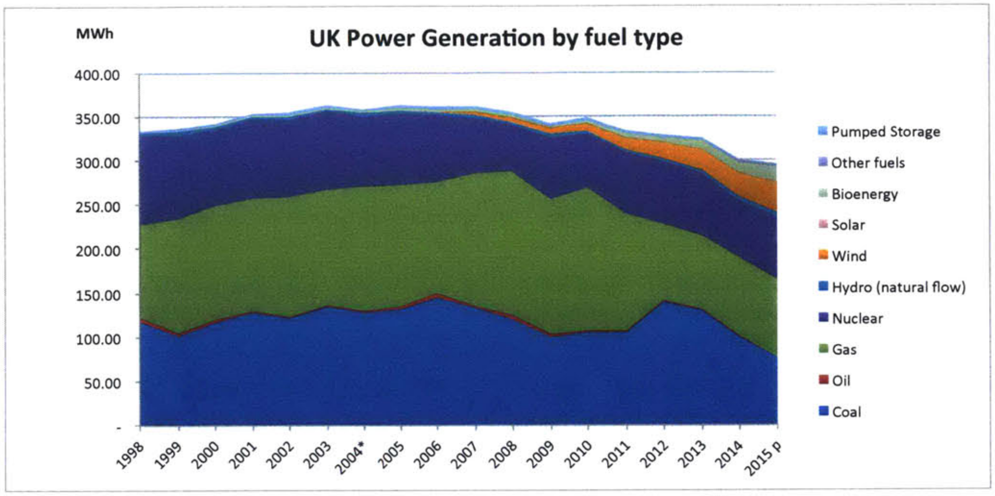


Figure 10 Annual UK Power Generation by fuel type (Data source: DECC Energy Statistics)

3.3. Electricity Market Reforms (EMR)

Recently the British government launched new major reforms of its electricity sector. The project outlined in the Energy Act 2013 aimed at paving the road to achieve the government objective of decarbonizing the energy sector. Many concerns have been raised about the ability of the UK to meet its carbon pledge of reducing carbon emissions, given the major dysfunction of its electricity markets. The UK has pledged to reduce its carbon emissions by at least 80% by the year 2050 compared to 1990. The main concerns were as follows: 1) functionality of the wholesale market and whether the wholesale prices were actually sending the right price signals to investors. According to Professor Steven Thomas of the University of Greenwich, only 1% of power was really traded through the market. He also adds that about 60-70% of power delivered did not really go through the wholesale market and was done through integrated generation/retail companies that owned the majority of power and served most consumers. The generation sector is split into six major players, all of which owned retail companies that served the largest segment of consumers. As such energy provided to those consumers was typically done between divisions of these large companies and was not exposed to market competition. The rest of supply was subjected to long-term contracts that did not go through the day ahead or spot markets. This in turn has resulted in distorting economic signals to investors. It also has led to the other concern that was highlighted by many which is short-term market liquidity. To meet the decarbonization targets, significant investments are required to upgrade the generation and network infrastructure and limited liquidity would discourage new entrants from competing in the market. Thirdly, low carbon electricity generation tends to require large upfront capital expenditures, even if it has lower variable production cost (see Chapter 1); left to the market, it is most likely that those investments would not be made given the high uncertainty and lack of proper economic signals. On the other hand, reserve margins have been tightening and are expected to go as low as 4% during the period from 2017-2019. Finally, participation of the demand side has been very limited and needs to be promoted. To counter these concerns the government put forward a plan to revamp the electricity market. The review recommended a number of measures to be implemented, which are discussed in the following sections.

3.4. Security of supply:

Until 2014, investments in capacity expansions were left to the market. Nevertheless, increasing regulatory uncertainty emerging from the government's endeavor of decarbonizing the system, in addition to distorted price signals and other issues present in the wholesale market, investors were not making the much needed investments. The Department of Energy and Climate Change estimated that the power system will be experiencing severe shortages in available capacity. As such, the regulator (Ofgem) took a number of measures to ensure the availability of firms and adequate capacity in the future. The first of which involved the relaxation of the system operator's license conditions by allowing National Grid to own and operate 4GW of "Strategic Reserves" that is only permitted to be in use under situations of scarcity. Also, the electricity market reform review recommended the implementation of a capacity mechanism (reliability call option) to ensure future new investments in the power sector. The proposed measure starts by calling for bids in the form of an auction with a defined delivery date[7]. Interested parties submit their bids and winners are awarded a capacity payment for a period of time depending on the age and condition of the generating unit. In return, during energy scarcity or when needed, the system operator calls the committed capacity and if not available then is subjected to large financial penalties. The first round of market auctions was held in 2014 to commit about 50 GW of already installed capacity. It also included an additional 3 GW to be available in 2018. Older units are provided with one-year capacity payments, unless they are going through

[7] Typically there is a lag period between the auction and actual delivery date; the lag period is meant to allow a new unit to be built. The length of the lag period influences the choice of technology.

refurbishment in which case the period is extended to 3 years. On the other hand, new units are awarded 15-year contracts.

The downside with reliability options is that they suppress price signals to a large degree, which could impact efforts of demand reduction, however, consumers don't necessarily need to be exposed to real prices to respond positively, hence, this issue could be addressed in an improved tariff design. However, the main advantage of reliability options is that they address short-term dynamics with a clear incentive for generation units to be available when needed.

3.5. Low Carbon Power Generation:

Prior to the Electricity Market Reform program, the main mechanism put in place to support renewable energy was the renewable obligation certificate. However, this scheme, which will expire by 2017, has been replaced by a number of explicit and implicit mechanisms. The existing explicit support mechanisms include:

3.5.1. Feed in tariff (FIT) with a contract for differences (CFD):

FIT with CFD is a contract made between a low carbon power generator and a public company established to be a counter party to this contact. The established company "Low Carbon Contracts Company (LCCC)" acts as a single buyer of all power produced under this contract. As illustrated in Figure 11, the way the mechanism works is by first establishing a "strike price". Participating generators are paid the difference between the strike and market price when the market price is lower than the strike price. In the event that the market price is higher than the strike price, the generator would only be entitled to the strike price. The strike price reflects the cost of investing in a particular low carbon technology and as such is set separately for each of the available low carbon technologies. The main purpose of this support scheme is to provide greater certainty and stability of revenues to power generators, and reduce risk exposure as a result of price volatility to both generators and consumers. Additionally, it helps generators secure financial loans at lower interest rates given the increased income certainty. DECC developed a CFD allocation process, where generators compete to secure CFD based on their generation cost. An auction is held for each low carbon generation technology and investors bid the strike price they require. An interesting observation regarding the FIT with CFD scheme is that unlike a typical CFD, it is not tied to a quantity, hence, generators are basically fully hedged for whatever quantity they produce. As this is the case, generators are indifferent to the time when they are producing, in other words the scheme does not encourage the production in times of scarcity. The FIT CFD scheme is available until year 2020, with no certainty if it will be continued afterwards. The assumption is that by the year 2020 many of the low carbon generation technologies would have reached grid parity and therefore will no longer require support.

3.5.2. Off taker of last resort:

This is an additional mechanism that aims at supporting the penetration of renewable energy by offering an alternative to developers who are not able to secure a Power Purchase Agreement through the market.

3.5.3. Feed in Tariff for small-scale generation:

A predetermined feed in tariff that targets the penetration of distributed generation and is periodically updated. Germany made extensive use of feed-in tariffs and encouraged significant photovoltaic small scale and distributed generation.

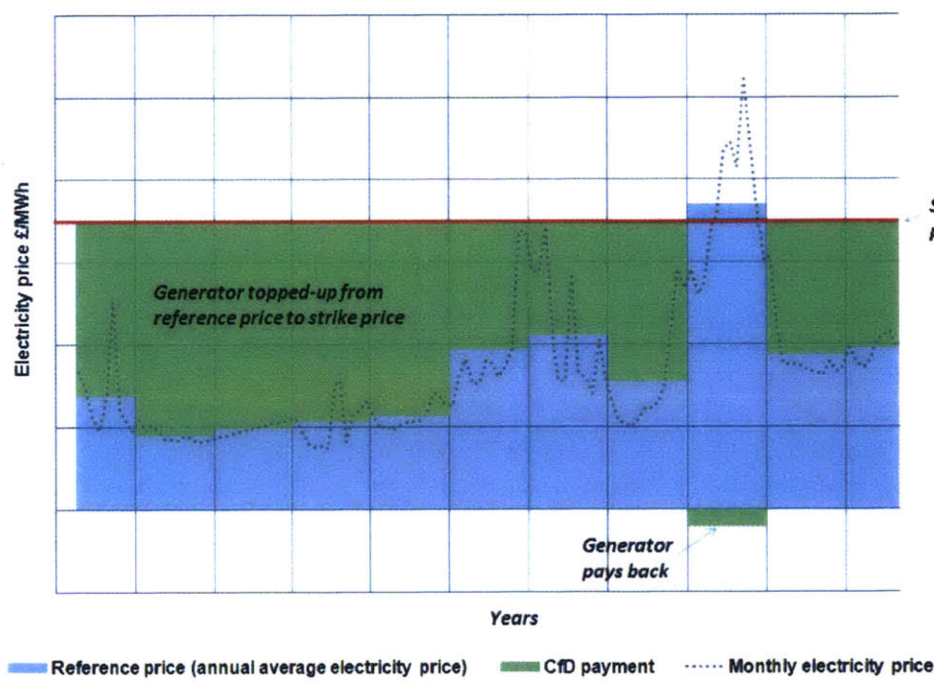


Figure 11 An illustration of the FIT with CFD mechanism, Source: DECC

In addition, there are two implicit support mechanisms:

3.5.4. Carbon price floor:

The carbon price floor is essentially a carbon tax paid by carbon emitting generators. The way this mechanism functions is by low carbon emitting generators selling carbon permits through an auction to generators production carbon emissions, the carbon price floor is a minimum price of carbon set by the regulator that becomes active when the price of carbon permits is lower than the predefined price. When this is the case, an additional tax is applied to bring the price of carbon permits to the price floor. This measure results in carbon emitting generators internalizing the carbon price and therefore increasing their variable cost, which changes their dispatch merit order, giving low carbon emitting generators a better chance of being dispatched. See Figure 12 for detail.

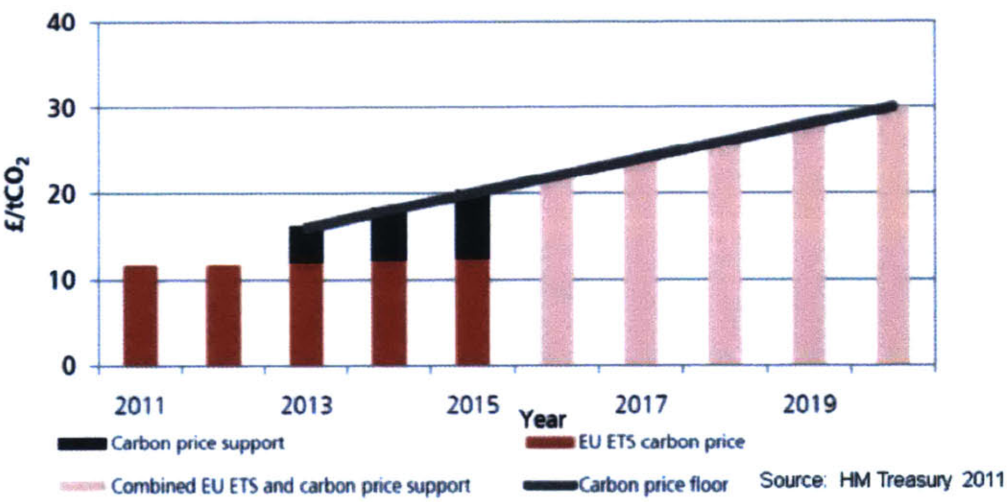


Figure 12 Carbon Price floor. Source: DECC

3.5.5. Emission Performance Standard:

The standard forbids the installation of any new coal-fired power plants without the installation of a carbon capture system.

4. Transmission Regulations:

4.1. Network:

As of 2015, there are seventeen licensed transmission companies in Great Britain. Three of those own the bulk majority of the onshore transmission network. As illustrated in Figure 13, National Grid owns most of transmission lines in England and Wales, SP Networks owns the transmission network in southern Scotland and Scottish Hydro transmission owns the network in the north of Scotland. The rest of licensed companies build and own either onshore merchant lines that are tendered by the system operator or are engaged in the development of offshore transmission lines mainly connecting offshore wind generators to the main land.

The duties of transmission network owners include guaranteeing free access to the grid, operating and maintaining the network, reducing system losses and improving quality.

Figure 13 Transmission Network Ownership, Source: National Grid

4.2. Pricing:

4.2.1. Losses

Network losses and congestion have an impact on energy prices; losses are addressed by the energy balancing mechanism and costs are charged to both generators and consumers. On the other hand, Great Britain has a congestion management service requirement (one type of system imbalance services) that is under the responsibility of the system operator. The service provides the system operator a tool to manage power flow within the network to maintain system stability or maintain a minimum level power quality. Under this service, which is based on terms typically included as part of the connection contract, a service provider agrees to cap his power output or setting output at a minimum level or profile. The constraint management service is required on an ad hoc basis depending on the system's condition (outages), forecasted demand and available generation. As such, the service is locational and the requirements from each unit are dependent on its ability to help resolve a constraint (location and size relative to the system constraint). In any of the cases above the participant in the congestion management contract is paid a fee during the settlement period. In the case of unanticipated congestion due to network failure, the resultant congestion could be either managed using the "optional" congestion management contract if there is one in place, or through the balancing mechanism.

4.2.2. Transmission Tariff:

The tariff is computed based on three components: 1) Use of system charges which is governed by the "Connection & Use of System Code". 2) Access charges governed by the Connection Charging Methodology Statement. 3) Administrative charges of the National Grid subject to the approval of either Ofgem or the CUSC modification panel. The methodology for computing tariffs includes a locational signal component but not time differentiation. The methodology used is very adequate, locational signals drive new generation assets to be suitably located within the network.

4.2.3. Access:

The transmission license states that it is the responsibility of the transmission network owners to provide access to parties wanting to connect to the grid subject to the approval of the system operator. The details of the mechanism governing the process of connecting to the system are described in under the "Connection and Use of System Code". Technically, connecting parties must establish an agreement with the system operator "standard agreement" that includes terms of operation that provides the flexibility to the system operator to manage system constraints. Additionally, in response to concerns over transmission access, Ofgem and the national grid have developed a "Connect and manage guideline" manual that has been approved by DECC. The developed guideline further clarifies the process of connecting to the grid and complements the CUSC. Technical requirements are established under the "Grid Code" and charges are calculated based on the Transmission Network Use of System Charges. Integrated Transmission Planning and Regulation is also another way the Ofgem is regulating access to the grid and it is more subjected to offshore network integration to the grid, the regulation calls for coordinated planning to ensure highest level of economic efficiency. The UK is currently interconnected with four of its neighboring countries, these interconnections are governed by EU legislations known as the "Third Energy Package", however, the issue of access is currently under review by the national grid in what they refer to as the SO to SO project. The existing interconnections are managed through a similar agreement to the ones done locally, where the interconnecting parties are required to establish an agreement subject to the approval of the UK System operator.

4.3. Investment planning

The transmission planning is done by each of the transmission owners and submitted to the system operator in this case the "National Grid Electricity Transmission plc (NGET)", the transmission owners referred to in this case are the "Scottish Power Transmission Limited" for southern Scotland and "Scottish Hydro Electric Transmission plc" for northern Scotland. The system as whole is solely operated by NGET. The responsibility of transmission network planning falls under the responsibility of NGET (highlighted under the Grid code). The plan approval however falls under the responsibility of the Ofgem or the Secretary of State. This centralized planning approach was further enforced by the conclusions of the "Integrated Transmission Planning and Regulation (ITPR) project" which gave the system operator "NGET" additional responsibilities that include "to identify the need for investment in the transmission network, and coordinate and develop investment options. This will include a new network options assessment process".

4.4. Remuneration:

Great Britain, embraces an incentive based regulation to govern the remuneration of transmission and distribution activities. Unit 2013, charges were linked to inflation through a formula known as "RPI-X". Under "RPI-X" the revenue cap method is applied over predetermined time blocks (periods) of five years. The annual revenue cap in sequence years within a period cannot be raised more than a retail price index (RPI) minus a productivity factor (X). The productivity factor (X) equates the present value of revenue to the present value of the estimated cost over the time period in subject. Additional incentives/penalties were also put in place to encourage reducing system losses and improving power quality. The model encourages investors to improve capital efficiency and seek financial savings in return for allowing them to retain the additional profit until the end of the price control period. This is done while maintaining strict quality levels to ensure that savings are not at the expense of power quality.

In light of the government objective of decarbonizing the electricity sector, there came a need for a new scheme of regulations that encourage investments in innovation. The assumption is that the demand side will be more active in the power system dynamics requiring innovation in system operation and coordination. A new model known as "RIIO" was introduced in 2013. Similar to RPI-X, a revenue cap is set for each price control period (extended to eight years instead of five) and additional incentives that aim to encourage innovation are provided. RIIO stands for Revenue= Incentive +Innovation + Output. The first price control period is due to expire in 2021.

5. Distribution Regulations:

5.1. Network:

There are 14 licensed distribution network operators (DNOs) in Great Britain and each is responsible for a designated area. Six different groups own the fourteen DNOs. In addition, there are multiple Independent Distribution Network Operators that operate in areas within the one designated to DNOs. The distribution activity is heavily regulated in Great Britain. Participation in distribution activities is only allowed through licensing/exemption permits that are obtained from the system regulator Ofgem. Only legal unbundling of distribution activity is required as indicated in the Utility Act 2000 (no ownership unbundling requirements from retail). The duties of distribution network operators as outlined in the Utility Act of 2000 includes connecting to load when requested, plan reinforcements as needed to enable connections, in addition to facility and equipment operation and maintenance.

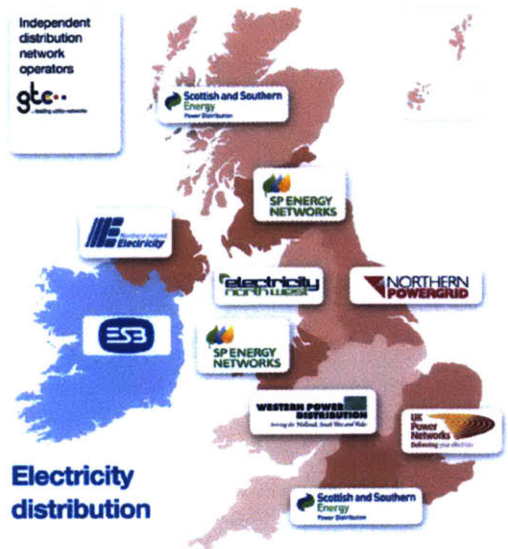


Figure 14 Distribution Network Ownership, Source: National Grid

Owner	DNO license	Type of Ownership
Electricity North West Limited	Electricity North West Limited	Private
Northern Powergrid	Northern Powergrid (Northeast) Limited	Private
	Northern Powergrid (Northeast) Limited	
Scottish and Southern Energy	Scottish Hydro Electric Power Distribution plc	Private
	Southern Electric Power Distribution plc	
ScottishPower Energy Networks	SP Distribution Ltd	Private
	SP Manweb plc	
UK Power Networks	London Power Networks plc	Private
	South Eastern Power Networks plc	
	Eastern Power Networks plc	
Western Power Distribution	Western Power Distribution (East Midlands) plc	Private
	Western Power Distribution (West Midlands) plc	
	Western Power Distribution (South West) plc	
	Western Power Distribution (South Wales) plc	

Table 3 Licensed DNO's in the UK

5.2. Licensing Requirement:

The "Electricity Act of 1989" addresses the licensing and exemption requirements of the distribution of electricity, parts of the act were later amended through the Utilities Act 2000. By law no one is allowed to participate in electricity distribution activities without obtaining permission through the electricity regulation authority (Ofgem) (section 4.bb and 5).

5.3. Access:

Regulations for connection to the distribution network and use of system rules are stated under the "Distribution and Connection Use of System Agreement (DCUSA)". On the other hand, it does not include the cost directly charged to consumers for cases of new connections, the boundary between the two charges are outlined in the "Distribution and Connection Use of System Agreement (DCUSA)". In case of a new connection, customers are required to pay for the assets of connecting them and in some cases also contribute to the cost of system reinforcements. The role of Ofgem is not to approve the charge per se but rather approve the methodology of calculating the tariff.

5.4. Remuneration:

Similar to the incentive based regulatory scheme used for regulating transmission activity remuneration, Distribution network operators are set an allowed revenue to cover their cost during a price control period. The allowed revenue includes the cost of maintaining, reinforcing and operating the network.

RIIO (Revenue=Incentives+ Innovation + Outputs) is the model currently in use. RIIO replaced the RPI-X model used earlier. The first price control period using RIIO began in 2015 and will last for eight years. The procedure is developed to provide a stronger incentive for DNOs to search and find cost effective solutions.

Prior to RIIO, the distribution network incentive based regulation was governed by RPI-X. As discussed earlier, RPI-X is a revenue cap formula that sets the maximum allowed revenue during a price control period of five years, the revenue is adjusted by rate of inflation (Price Index) minus a productivity factor "X" that is determined by the regulator. The revenue base was calculated using the building block approach, determining total capital expenditure, which was a critical component of setting the maximum revenue, is subject to approval and is assessed using benchmarking techniques. On the other hand, OPEX (operating expenditures) were established through a separate assessment process. Additional incentives (or penalties) were then added to promote improvements in capital expenditure, quality of service and reducing system losses. An example of such incentives is the information quality incentive that provided DNO with higher rate of returns for getting a lower capital allowance base. Price reduction targets were set for each distribution network operator individually for each price control period, through this scheme the regulator was able to achieve major price reduction on the distribution network charges.

Unlike RPI-X, RIIO's revenue base is based on the total expenditures rather than putting more emphasis on capital expenditures. This is important as with the increase in complexity of distribution networks it is likely that the operational expenses will grow. Additionally, incentives are put in place to encourage DNOs to connect Distributed Generators. Innovation in telecommunication systems that aim for improving coordination and operation of the network are supported through the regulation with rounds of pilot project funds available to DNOs. Also, the price control period was extended to eight years to allow DNOs to reap the benefit of investing in innovative technologies. On the other hand, quality and network losses are still being monitored and subjected to incentives and penalties.

6. Retail market:

Competition in retail was introduced in a second stage of the electrical industry privatization process. At the early stages, only large consumers of a power demand that is greater than 1MW were given the freedom to choose their own supplier. The second phase involved extending this freedom to cover customers with a demand greater than 100 kW. In 1999, the market was fully liberalized. The idea of creating competition in retail is centered on putting retailers under pressure to cut their profit margins, while competing on better customer service. This in turn also translates to retailers bidding more aggressively in the wholesale market, hence, increasing competition across the entire system.

Currently, retailers (suppliers) have the freedom to set prices using a predefined number of core tariff structures. The decision to limit the number of core tariffs offered to customers was the outcome of a lengthy study to review the retail market. The study highlighted the customers' lack of understanding and confusion as a result of large number of options available. As such in order to promote awareness and improve the customer's ability to shop for best deals, Ofgem decided to limit the number of core tariff structures to four that depend on the meter installed:

- Two rate meters/mode (for electricity only, e.g. E7 tariffs)

- Three rate meters/mode (for electricity only, e.g. E10 tariffs and variants).

- Dynamic Teleswitching (DTS): Requires a certain meter to be installed. DTS allows remote control of the customer's heating demand (electric heating, typically used by customers with no access to gas supply) by retailers to shift their demand from peak time, hence reducing cost of electricity

- Any other meter/mode for both gas and electricity (including smart meters)

Each tariff may include choices over: (a) dual fuel, (b) payment method, and (c) online account management.

Additionally, online support tools were made available to customers to help them compare deals and prices available at their location.

Prior to the liberalization of the retail business, electricity prices were heavily regulated. The regulated Regional Electric Companies (REC's) were subjected to an incentive based regulation (revenue cap model) that was linked to a retail price index. Figure 15 shows the annual average selling price of electricity to consumers prior to the sector liberalization.

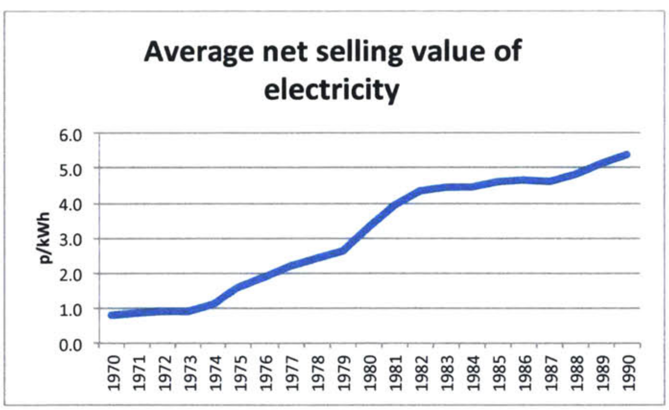
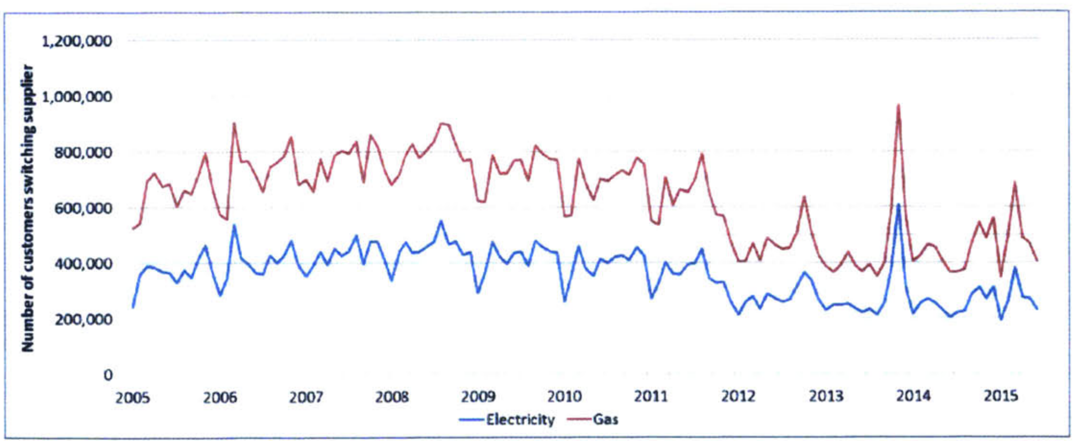


Figure 15 Average net selling value of electricity. Data Source: Department of Energy and Climate Change electrical historical data 1920-2014

Despite the arguably highly competitive retail market[8], the establishment of a retail market did not yield low electricity prices as promised. Ofgem and many involved parties in the retail business have expressed concerns regarding the malfunctioning of the retail market in GB. This has been attributed to vertical integration between generation and retail in cases and also between distribution and retail in other cases. The vertical integration between generation and retailers presents a significant barrier to entry for new entrants as all the six big generators in GB have a retail business and hedge their risk by matching their generation supply with customer demand internally, essentially bypassing competition. This in turn makes it almost impossible for new entrants to achieve significant market share given the insufficient energy trade in the wholesale market. On the other hand, the integration between distribution and retail also poses significant barriers that hinder retail competition. As an example, retailers belonging to the same group as the distributor have an advantage when it comes to access to commercial information which can be used to improve market position by offering better products. These concerns and many others have been the subject of debates around the adequacy of the retail market. To address these concerns, Ofgem launched a major retail market review and proposed several measures to be implemented aiming to improve the competition environment and actively involving customers.



Source: Ofgem analysis of data provided by DNOs, Xoserve and suppliers.

Figure 16 Customer Switching rate (Source: Ofgem).

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[8] The market has one of the highest customer switching rates in Europe of about 11% as indicated in Figure 17

Despite Ofgem's effort in reducing market power in the sector, the market remains fairly concentrated with more than 80% market share owned by only six companies, four of which has a market share of more than 10% as shown in Figure 17.

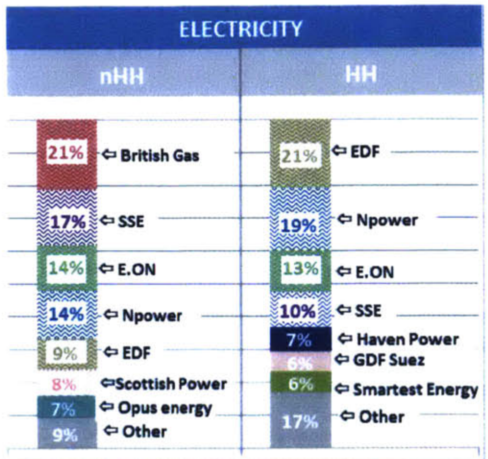

Figure 17 Market concentration (source: Ofgem)

In conclusion, the electricity market in the UK is considered one of the most developed markets in the world (DG Comp, 2007). The evolution of the market went through three major phases. First were the structural reforms that led to the establishment of four-generation companies and the vertical separation of the electricity activities namely generation, transmission and distribution. Second was the establishment of the wholesale market based on the pool model. Although at this stage the privatization brought about significant efficiency gains and net social benefits (Newbery and Pollitt, 1996), the model was criticized for poor performance as a result of major structural flaws (Newbery, 2000), as the two major utility companies owning thermal generation units had significant market power.

This has led to government intervention through enforcement of further generation assets divestment. Additionally, this has led to the second phase development of the market with the replacement of the pool model with the "New Electricity Trading Arrangement", which was a self-dispatch model where agents were allowed to freely secure bilateral agreement (pay as bid scheme). During the first years of NETA, the wholesale market achieved price reductions and the model was considered a success, however, later reviews highlighted that price reductions were a result of structural reforms that were implemented before the implementation of NETA, (Bower, 2002; Evans and Green, 2005; Newbery, 2005). Lack of wholesale market liquidity as a result of vertical integration of generation and retail has been identified as one of the major flaws of the British wholesale market. The model was further extended to include Scotland in addition to England and Wales and renamed as the British Electricity Trade and Transmission Arrangement.

Driven by concerns regarding the performance of the wholesale market, Ofgem announced the implementation of the "Electricity Market Reform" project, which sets the third phase of the British market evolution. The reform objectives are mainly to address the challenge of vertical integration, promotion of low carbon generation and improving the overall level of competition. Despite the current challenges facing the electricity market in Great Britain (GB), it remains as one of the more successful markets in the world. One the main lessons to be learned from GB experience is that a market reform is a continuous process that requires monitoring and adjustment at all times.

Chapter 3

THE SAUDI ELECTRICITY SECTOR

1. Electricity Industry Evolution:

The evolution of the electricity industry in Saudi Arabia went through several stages. Since the establishment of the Kingdom in 1932 and the discovery of fossil fuel resources in 1938, the government focus shifted to the optimum utilization of available resources to achieve future prosperity. Despite the fact that the Saudi Economy faced major challenges in the early stages, the economic wheels soon started turning. However, from the beginning, it was clear that "electrification" was a major hurdle facing any attempt to grow the economy; this in turn had its implications on evolution of the electricity industry.

At the early stages, specifically before 1961, electricity services were provided only on a commercial basis. Private investments in mini grids were made targeting urban areas including major cities and villages. With no established regulations, the electricity service was provided by private investors and priced based on the cost of providing the services plus a markup that guaranteed a decent return on investment. Therefore, electricity prices were dispersed and varied significantly by provider and the served area.

In 1961, the Ministry of Commerce established the Electricity affairs administration, chartered to manage the electrical industry. The administration put in place laws and orders that govern the ownership and operation of the provided service. The Ministry required investors to obtain licenses and permits prior to engaging in any new activity pertaining to the electricity industry. On the other hand, the Ministry took the responsibility to advocate for national investment to expedite the sector development. Since then major infrastructural investments were made, the government took a leading role in this regard.

1970 marked the beginning of the second stage in the industry evolution. During that year, the Saudi government introduced major structural and organizational reforms aimed at boosting economic growth. The government decided to adopt a rigorous planning scheme that involved the development of long and short term strategic planning objectives, with rigorous accountability and screening processes that involved annual reviews and five-year business plans. The development of the industry was given a priority, as it is a major enabler to economic growth and a factor to improving social welfare and standards of living. Late in 1972, a Department of Electricity Services was established and separated from the Ministry of Commerce. In 1974, the department of electricity services was placed under a new Ministry that was named the Ministry of Industry and Electricity Services. Later in the same year, the Ministry passed a legislation enforcing a single uniform price for electricity sales. The price was heavily subsidized and below the true cost of the service. As a result, the Saudi economy witnessed a massive boom registering double-digit growth rates for the few years' after.

In 1975, the government set ambitious plans aimed at increasing the electrification level in the country. The Ministry of Industry and Electricity services was assigned the responsibility to oversight the development of sector's infrastructure. Later in 1976, an Electricity Corporation was established and assigned the responsibility of coordinating investment planning and implementation as part of the Kingdom's five years' investment plan. Between 1976 and 1981, all electricity services (mainly made up of private commercial entities) were gradually incorporated into four regional Saudi Consolidated Electricity Companies (SCECOs), located in the Central, Eastern, Southern and Western regions of Saudi. Through the establishment of the four regional companies, the government was able to achieve major progress in the electrification of urban areas, as shown below.

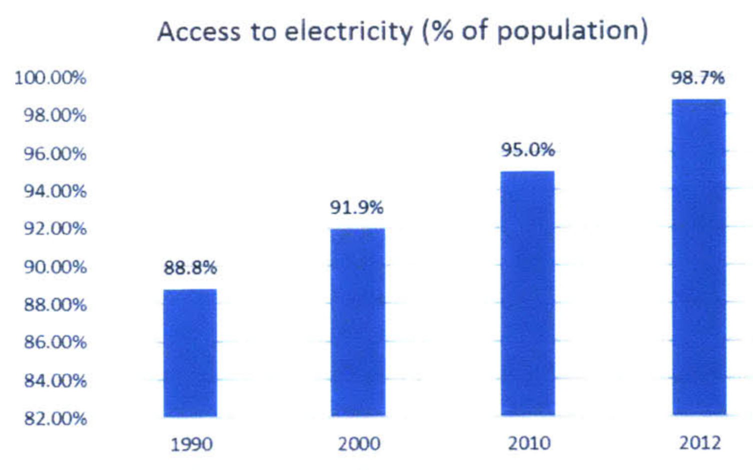

Figure 18 Electrification level, Data source: World Bank

As a result of this setup, the national grid of Saudi Arabia as a country was poorly interconnected. The four regional companies concentrated in developing the infrastructure within their assigned territories, which led to the underdevelopment of the electrical grid at the national level and hence limited the benefit from higher system efficiency gains that could have been achieved through coordinated investment and operation decisions. In 2000, the government cabinet issued a decision to consolidate the four regional companies into a single joint stock vertically integrated company under the name of the "Saudi Electricity Company" (SEC). The company enjoys a monopoly on generation, transmission, distribution and supply of electricity. It is 80% owned by the government (74% direct and 6% through Saudi Aramco).

Later in 2003, the oversight of the electricity industry was assigned to a new Ministry under the name of the Ministry of Water and Electricity (MOWE). Two years before that (2001), the Saudi government created a regulatory body under the name of "Electricity and Co-Generation Regulatory Authority" (ECRA). The charter of ECRA is to ensure the adequacy, reliability, quality and cost efficiency of the power supply. ECRA has also been assigned the responsibility of promoting and regulating the participation of the private sector in the electricity industry.

2. The Current Status:

2.1. Major Stakeholders:

2.1.1. Ministry of Water and Electricity (MOWE):

The Ministry is responsible for developing long term strategic planning and policies for the sector. Additionally, the Ministry chairs the Board of Directors of the Saudi Electricity Company (Currently Dr. Saleh Alawaji).

2.1.2. Ministry of Petroleum and Minerals Resources (MinPet)[9]:

The Ministry of Petroleum and Minerals is in charge of ensuring availability of fuel supply to the sector. The Ministry is heavily involved in the sector's generation capacity expansion planning to ensure adequate allocation of fuel supply.

2.1.3. Electricity & Co-generation Regulatory Authority (ECRA):

[9] In May,2016, The Ministry of Water and Electricity has been resolved and the responsibility of electricity affairs has been assigned to the Ministry of Petroleum and Minerals, the Ministry has been renamed to the "Ministry of Energy".

ECRA's charter is to regulate the electricity and water desalination industry to ensure adequate, high quality, reliable and reasonably priced supply of electricity. The objectives of ECRA include customer protection and encouragement of private sector participation in the industry.

2.1.4. Saudi Electricity Company:

SEC is a vertically integrated utility company (similar to the highly integrated companies in the UK before liberalization, see Chapter 2) that enjoys a nationwide monopoly of power supply. It has the responsibility of ensuring the adequacy, reliability and cost efficiency of the system. Specifically, SEC is responsible for the activities of generation, transmission, distribution and retail of electricity. This responsibility includes the operation and maintenance of existing assets, in addition to investment planning and implementation of generation capacity, transmission and distribution network expansion.

2.1.5. Saudi Aramco:

Saudi Aramco has a huge influence on the sector as the sole fuel supplier in the Kingdom. Additionally, Saudi Aramco owns 6% of SEC and is represented in SEC's Board of Directors. Moreover, Saudi Aramco owns more than 2 GW's of its own captive generation.

2.1.6. Saline Water Conversion Corporation (SWCC):

SWCC is a Saudi Government Corporation responsible for the desalination of seawater producing electric power and supplying water to various local municipalities.

2.2. Industry Structure:

A single vertically integrated company (SEC) enjoys a nationwide monopoly in Saudi. SEC is regulated by ECRA on activities pertaining to the operation of the electrical system and by the Capital Market Authority (CMA) on all financial matters. Additionally, the industry houses another vertically integrated company under the name of "MARAFIQ" that enjoys a regional monopoly covering two major industrial cities namely Yanbu and Jubail. Similar to SEC, MARAFIQ is a joint stock company that is mostly owned by the government.[10]

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[10] "Marafiq is owned by its four major shareholders - the Royal Commission for Jubail and Yanbu (RC), Saudi Basic Industries Corporation (SABIC), Saudi Arabian Oil Company (Saudi Aramco), and the Public Investment Fund (PIF). Seven private-sector investors make up the remaining shareholders." "| | MARAFIQ | | ** First Utility Company for Jubail & Yanbu in Saudi Arabia.**." 2016. Accessed June 16. http://www.marafiq.com.sa/en/aboutus/profile.aspx.

The SEC is responsible for ensuring the instantaneous balance between supply and demand at all time. Additionally, the company has the responsibility of developing the system's overall investment planning subject to government approval (approval is mainly granted by the Ministry of Water and Electricity, Ministry of Finance and the Ministry of Petroleum and Mineral Resources). The regulator (ECRA) monitors the functionality of the industry against a set of established Key Performance Indicators (KPI) and also establishes regulations that govern the sector's activities. ECRA, although financially independent is still under government control as until recently the chairman of its board was the Minister of Water and Electricity[11].

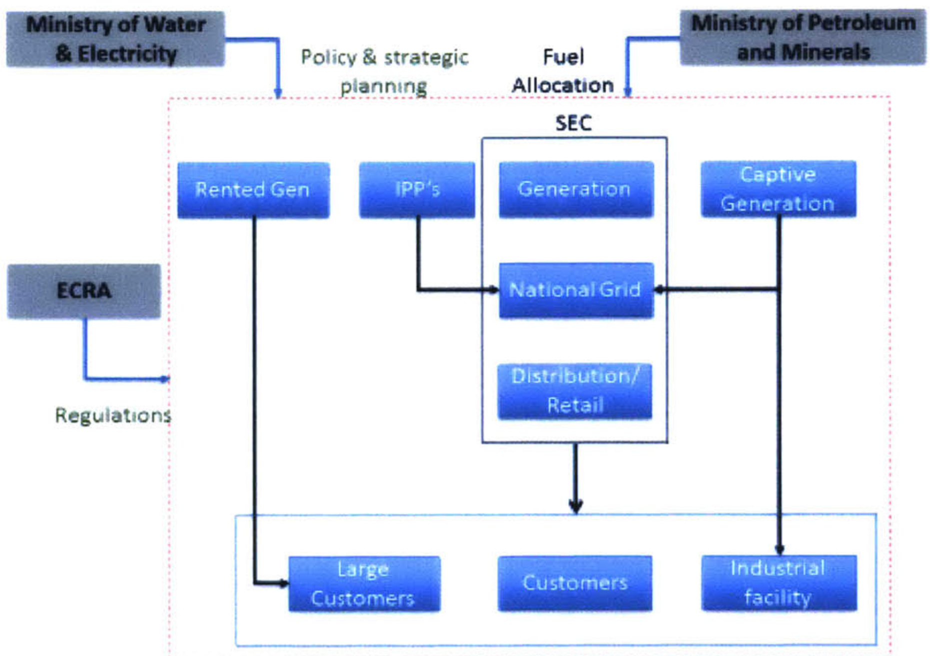

Figure 19 Saudi Electrical Sector Structure as of 2015

The participation of the private sector has been notably growing. In mid 2000's SEC launched a program to encourage the participation of Independent Power Producers (IPP's) offering long term Power Purchase Agreements (PPA). Also, SEC contracts generation rental (typically Diesel Generators) from small and medium energy service enterprises to supply power to small towns and villages that are not yet grid connected.

[11] In May 2016, H.E Dr Mohammed Al-Jasser has been appointed as the chairman of the board. Dr Al-Jasser is an advisor at the General Secretariat for the Council of Ministers.

Water desalination is a vital resource of water supply in the Kingdom. More than 50% of municipal water is supplied through desalinated water. SWCC as a government organization is responsible for the activity of water desalination and is regulated by ECRA. SWCC owns more than 60% of the installed desalination capacity in the Kingdom. On the other hand, Independent water and power producers (IWPP) own the remaining 40% of the installed capacity. SWCC jointly with SEC has established a company under the name of "Water Electricity L.L.C" as a counter party (off taker) to long-term agreements with IWPP's.

2.2.1. Generation:

The Saudi Electrical sector is the largest in the Middle East with a total grid connected capacity of 65.5 GW's in 2014 (SEC Annual Report, 2014). The total available capacity has more than doubled since the year 2000, increasing from 25.7 GW to its current level of 65.5 GW[12]. This massive growth in power production capabilities has been imposed by a brisk increase in demand. In 2014, the system registered a coincidental peak demand of 56.5 GW, as shown in Figure 20.

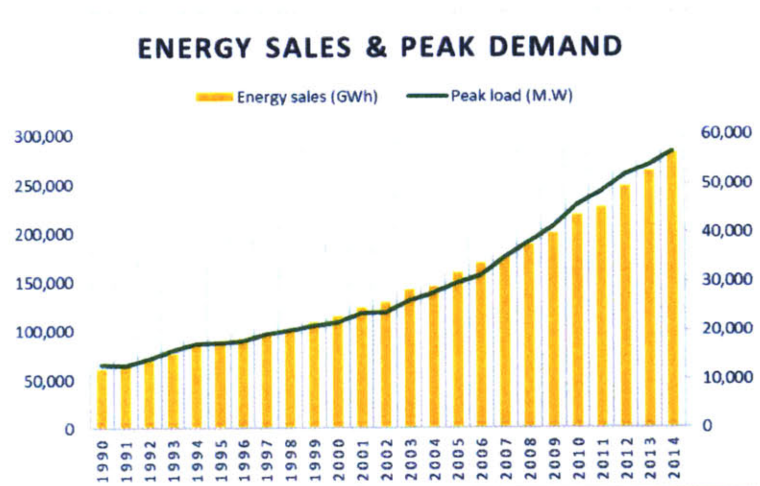

Figure 20 Growth in Energy sales and Peak demand, Data source: ECRA

The growth in demand has been fueled by significant growth in population and the economy. Another factor is the change in lifestyle, which has introduced air conditioning, and other amenities in many Saudi households. Currently about 70% of residential electricity consumption is due to air conditioning with peak loads in the summer season about twice as high as those in the winter. As a

[12] This only includes grid connected capacity, the total installed capacity is more than 77GWs.

result, the Saudi government has started to invest more heavily in energy efficiency, as mandated by the Saudi Energy Efficiency Center (SEEC). The Kingdom's economy has expanded significantly since the nineties with a focus on energy intensive industries (oil and petrochemicals). This trend continuously pressures the electrical system to add more capacity to catch up with the increase in demand. In turn, this phenomenon had its implications on the sector's technology mix. As shown in Figure 21, the technology mix is dominated by simple cycle power plants that require lower upfront cost and less time to be built. Simple cycle turbines make up about 50 % of grid-connected capacity and about 40% of total installed capacity. The remainder is split between steam turbines, combined cycle, and diesel generators. Additionally, Combined Heat and Power (CHP) plants are installed and utilized for water desalination by SWCC or Independent Water & Power Producers (IWPP). Also the use of CHP is present in the industrial sector by facilities that require heat input in its manufacturing processes (ex. Saudi Aramco).

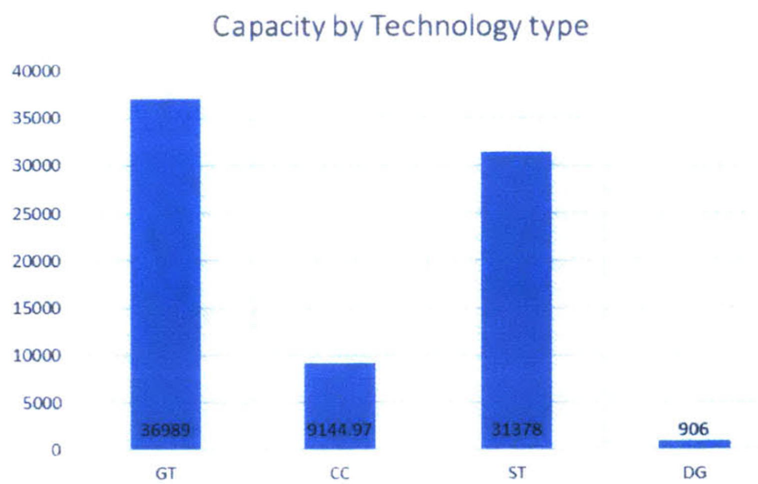

Figure 21 Installed Capacity by Technology, Data source: ECRA, 2014

The available capacity is not evenly split among the main four operating regions. The eastern region, which forms the main industrial hub in the country, houses most of the installed generation. Eastern, Central and Western operating areas make up most of the demand of electricity, hence, 93% of the total installed capacity resides within these three areas and only 7 % serves the Southern operating area.

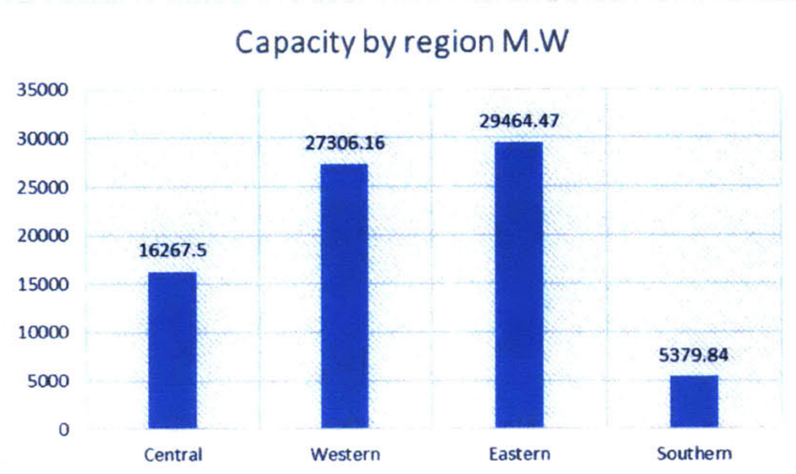

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Figure 22 Installed Capacity by Region, Data source: ECRA

As shown in Figure 23, the fuel mix is exclusively fossil fuel based. Oil and oil liquids make up 56% of the fuel mix and the rest is fueled by natural gas. It is worth highlighting that the selection of fuel type is subjected to the availability of fuel at the location of interest, which could be constrained by the fuel supply system.

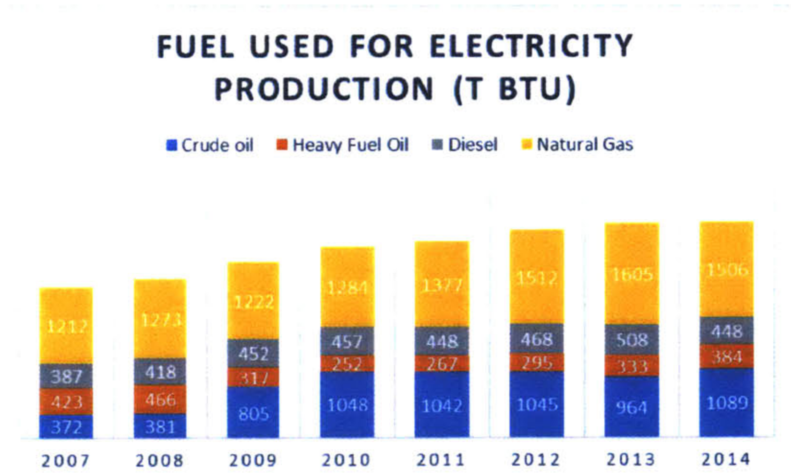

Figure 23 Fuel used for electricity production. Data source: ECRA

As of 2015, there are 17 licensed generation companies, however, the generation sector is heavily concentrated with SEC owning about 70% of total installed capacity, as indicated in Figure 24.

[13] The illustrated capacity figures include isolated capacities, which are typically supplied through rented generation units subjected to long term agreements (PPA).

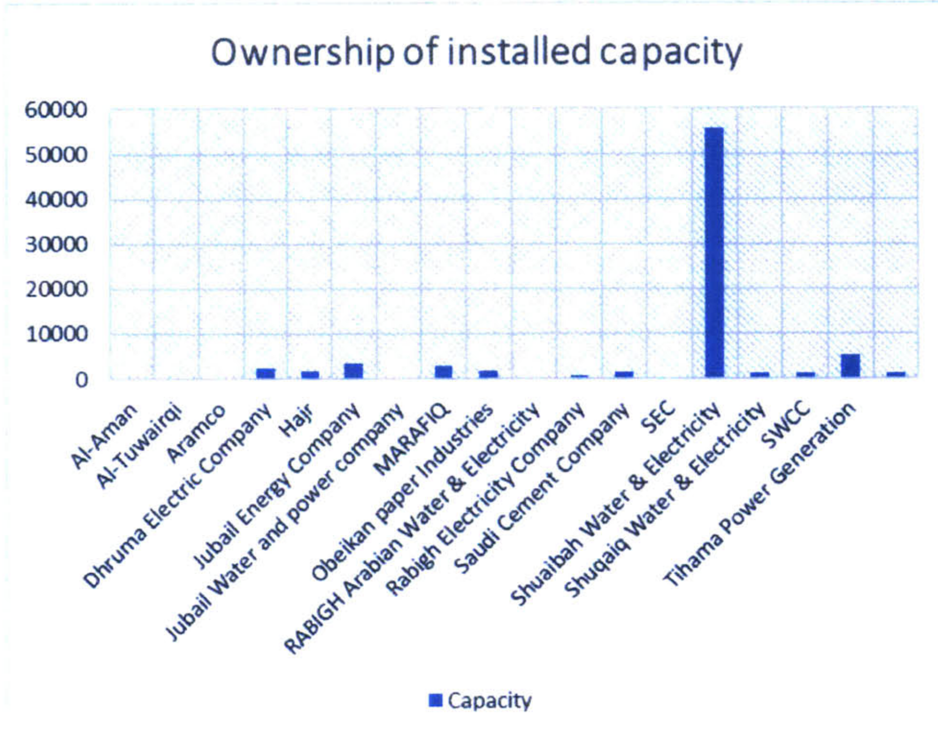

Figure 24 Total installed capacity by ownership – Saudi Electricity Generation Companies

2.2.2. Transmission and Distribution networks:

The electrical grid in Saudi Arabia is not fully interconnected yet. A number of areas remain isolated, however, SEC in coordination with MOWE has announced plans to strengthen the network interconnectivity. The proposed plan is currently in the implementation phase with a number of transmission lines currently being constructed and to be completed within the next few years. A comprehensive overview of the existing high voltage transmission line system in Saudi including the current projects that are being carried out and future ones is shown below in Figure 25. Transmission and distribution losses are at an average of 9.7% (ECRA data) indicating room for improvement. Compared to the US with an average of 6%.

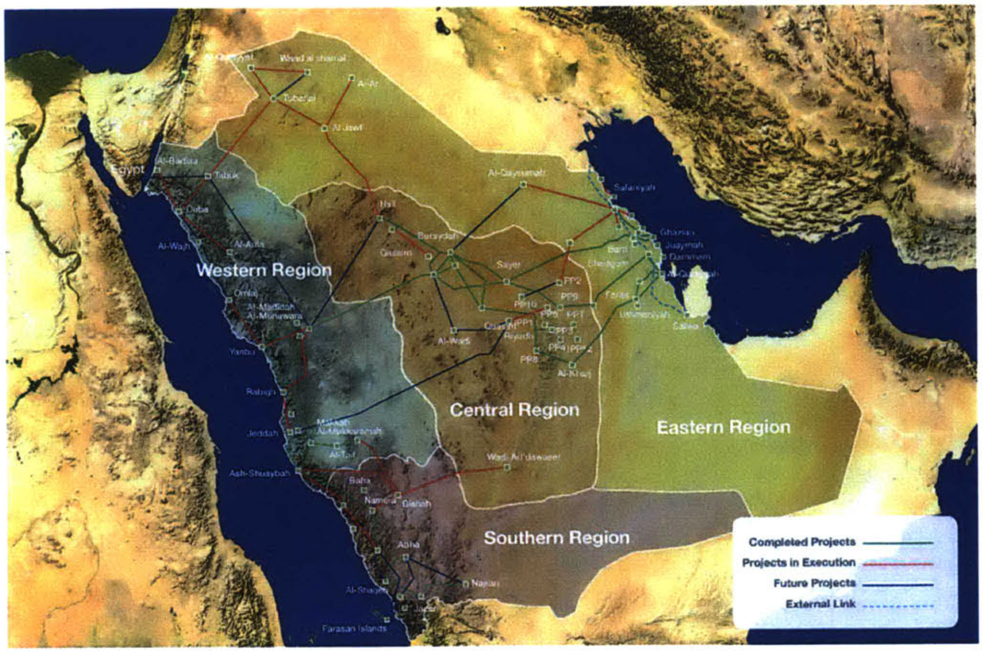

Figure 25 Transmission Grid Overview. Source: SEC Annual report 2014

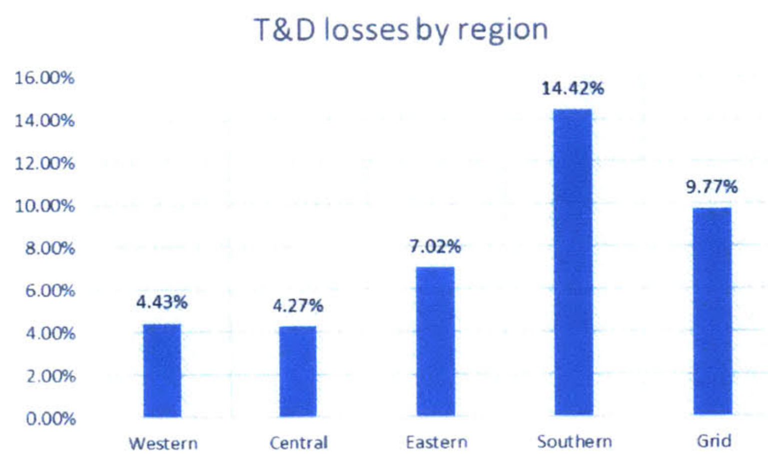

Figure 26 T&D losses by region, Data source: ECRA

2.2.3. Tariff Structure:

Electricity prices in the Kingdom are heavily subsidized as a means of wealth redistribution. The subsidy is enabled by a low priced fuel supply to all electricity generators in the sector. Nevertheless, the tariff structure is fairly developed and is based on a bracket scheme that varies by the level of consumption and type of metering technology. Table 5 shows a comparison of electricity tariff worldwide.

Residential		Commercial	
kWh/month	$/kWh	kWh/month	$/kWh
1-2,000	0.013	1-4,000	0.043
2,001-4,000	0.027	4,001-8,000	0.064
4,001-6,000	0.053	More Than 8,000	0.080
6,001-8,000	0.080		
More Than 8,000	0.080		
Government		**Industrial**	
kWh/month	$/kWh	kWh/month	$/kWh
All	0.085	All	0.048
Agriculture		**Private hospitals and schools**	
kWh/month	$/kWh	kWh/month	$/kWh
1-4,000	0.027	All	0.048
4,001-8,000	0.032		
More Than 8,000	0.043		

Table 4 Saudi Tariff structure. Source: ECRA data, 2015.

Electricity prices in selected countries 2015	
Global electricity prices by select countries in 2015 (in U.S. dollar cents per kilowatt hour)	
	Data
Italy	15.7
Germany	15.22
UK	14.16
Belgium	11.17
Portugal	11.05
Spain	11.04
Slovakia	9.9
U.S.	9.43
France	8.97
South Africa	8.46
Austria	8.38
Poland	8.33
Netherlands	8.23
Australia	8.17
Czech Republic	8.03
Canada	7.23
Finland	6.42
Sweden	5.34
Saudi Arabia	1.3-8

Table 5 Electricity price comparison source: Statista and SEC

2.3. Renewable and Nuclear energy:

In 2010, the Saudi government passed a royal decree announcing the establishment of "King Abdullah City of Atomic and Renewable Energy" (K.A.CARE). The K.A.CARE mandate calls for the diversification of the energy mix through the introduction of renewable and nuclear energy. The K.A.CARE charter emphasizes the establishment of an industry around alternative energy fostering education, research, global collaboration, local integration, commercialization and social benefit.

Since then, K.A.CARE announced a roadmap of progressive deployment of renewable and nuclear energy targeting an installed capacity of 54 GW and 17.6 GW by 2032 respectively.

According to the K.A.CARE proposed plan, detailed in a whitepaper titled "Proposed Competitive Procurement Process for the Renewable Energy Program", separate auctions will be held for each technology type for all on-grid projects. On the other hand, for off grid projects, the auction format will allow all technologies to compete. The winner of a project will be offered a long-term contract in the form of a power purchase agreement (PPA). K.A.CARE intends to establish a standalone government guaranteed entity (The Sustainable Energy Procurement Company (SEPC)), which will serve as the counterparty to the signed PPA's.

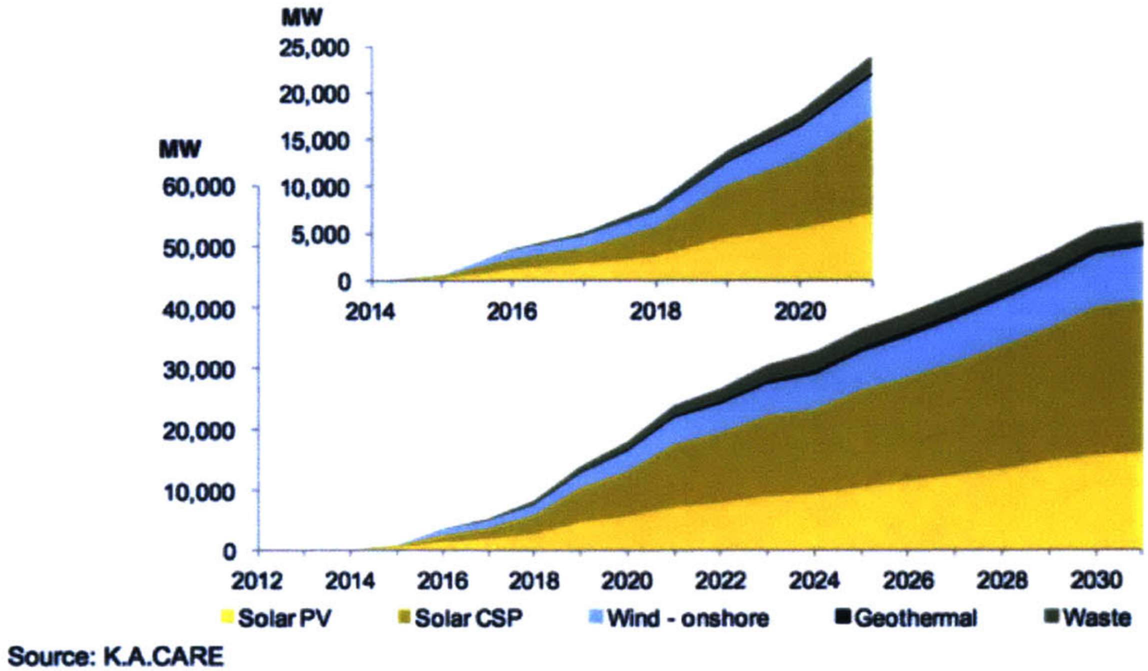

Figure 27 Long-term Renewable energy target by technology type Source K.A.CARE

2.4. Existing regulations:

2.4.1. Electricity law:

In 2005, a royal decree was issued establishing the primary legislation governing the engagement of any activity pertaining electricity services. The main highlights of the legislation titled "Electricity Law" are as follows:

a) The law calls for the transition to a competitive based arrangement of activities pertaining to electricity services with the objective of maximizing social welfare through the protection of consumers' and private investors' interest. This can be interpreted as an effort towards "privatization" of the electricity market, which is the title of this thesis.

b) It sets the participation of the private sector as an objective.

c) The law also established a licensing requirement for any party interested in carrying on an electricity service activity, subject to the approval of the regulator (ECRA).

d) It mandates structural unbundling of electricity activities including generation, transmission, distribution and retailing. It also sets the mitigation of a "dominant position" as an objective that shall be achieved by the system regulator.

e) It requires the establishment of a mechanism that guarantees free access to the network on a non-discriminatory basis.

f) It assigns the responsibility of designing and periodically reviewing a tariff structure to the system regulator subject to the approval of the Council of Ministers.

g) It provides a framework for dispute resolution.

h) The legislation assigns the responsibility of establishing an electricity market and the required secondary regulations to the system regulator.

2.4.2. The Electricity Law Implementing Regulations

In 2007, the system regulator (ECRA) issued a secondary regulation (The Electricity Law Implementing Regulations) that details the rules and policies in accordance with the provisions set by overarching "Electricity Law".

2.4.3. The Electricity Industry Restructuring Plan:

Subsequent to the development of the "Electricity Law Implementation Regulations", ECRA in 2007 announced a plan to introduce competition in the electricity industry. The plan titled "Electricity Industry Restructuring Plan" (EIRP) consisted of three phases to be completed within eight years (by 2016). The three phases are as follows (ECRA, 2008 Annual report):

Phase I Institutional development and unbundling: This stage aims for the separation of activities pertaining to electricity services. Specifically, the regulator's objective was to unbundle generation, transmission and distribution from their existing vertical integration under the umbrella of SEC. Additionally, the plan for this stage included horizontal unbundling of SEC's generation. The plan also included the establishment of an independent system operator tasked with the operation of the transmission network

Phase II Competition for services for large consumers: The second stage mainly targeted the establishment of a wholesale market and the exposure of large consumers to real time pricing.

Phase III Full liberalization: The final stage targeted the liberalization of the retailing activity and the creation of a single/principle buyer company. At this stage the expectation was that all power trading would be done through the market via spot price or bilateral agreements.

Despite the ambitious plan, the regulator did not pursue the implementation of the plan. As a matter of fact, the plan did not achieve the objectives set for the first phase. As of today, SEC remains a vertically integrated monopoly with the exception of the transmission activity being legally unbundled and operated by a recently established entity (National Grid). From an organizational point of view, National Grid still reports to SEC's management.

3. Regulatory reform options:

The role of regulations is to maximize social welfare. This entails the protection of customers by ensuring reliability and high quality of supply, affordability and highest level of customer service. On the other hand, regulations shall also protect the interest of investors by ensuring fair competition, clarity of rules and transparency in the implemented mechanisms.

Generally speaking, the paradigm of Electrical system regulations can be broken down into two main frameworks. 1) Monopolistic. 2) Competitive. In both frameworks the participation of the private sector can be achieved, albeit to a different extent. Private investors are naturally risk averse, as such whenever the risk associated with any investment is high, the likelihood of the investment being made is low, and this is especially the case for investments in utilities that naturally entail a long-term commitment. Therefore, participation of private investors in systems regulated as a monopoly is often based on long-term contracts that significantly reduce the risk of investment and guarantee a reasonable rate of return. If done well, the participation of the private sector in this case can improve the system's overall efficiency, however, if not, the system is stranded with additional costs that could have been avoided. Thus the goal of regulation is to avoid cases where private enterprises can achieve significant above average profits via long-term arbitrage. This coupled with the inherited inefficiency of the command and control regulation of monopolies that encourages the monopolist to overinvest to be able to achieve higher returns further deteriorates the system efficiency and subject customers to higher costs. As a system evolve in size, this issue if often exacerbated.

The solution to this dilemma is around the conviction that electrical systems can be run competitively, albeit while adhering to its physical characteristics. This paradigm shift in the management of electrical systems allowed the emergence of competitive framework regulations as a compromise between the traditional command and control one the one hand and pure competition that allow market forces to play unbounded on the other hand. The latter is understood to be too risky given what is at stake and thus has been considered to be infeasible by many. As such regulations from a middle ground between the two extremes and are set in place to maintain a level play field and govern the interactions and functionality of players and the system, respectively. As such the role of regulations can be summed up into three main elements (Carlos Batlle and Ocana 2013):

1. Develop rules and guidelines that govern the interaction between participants to achieve the main objective of maximizing social welfare.
2. Design market structure to achieve the desire competition. In order for the market mechanisms to be effective the size and number of players need to be sufficient enough to enable competition.
3. Continuously monitor the behavior of the participating agents to ensure the adequacy of regulations put in place and that not a single agent is taking advantage of the others.

The first question that comes to mind when designing a given system's regulations is which functions to unbundle and which to deregulate? The answer to this question comes into two parts: unbundling is needed whenever the status quo gives the proponent an unfair strategic advantage over other agents in the form of market power that eventually dilutes market competition. The answer to deregulation evolves around the presence of economies of scale. Segments of the system that are inherently subjected to significant economies of scale (Chapter 1: exponent $b \ll 1.0$) are better left regulated (Transmission and Distribution). On the other hand, generation and retail both have the potential of being run competitively subject to the precondition that economies of scale have been exhausted. Following the same line, electrical systems that have a relatively small size generation capacity base where economies of scale still prevail are better off remaining under the traditional regulated regime. Therefore, the system's size is a precondition to the introduction of competition in the generation segment. With that in mind, international experience prescribes a textbook formula for successful deregulation of the electricity industry, which includes (Joskow and others 2008)

1. Privatization of state-owned utilities to create an incentive for efficient operation and to limit the ability of the state to pass on political agendas.
2. Vertical unbundling of regulated and deregulated sectors to facilitate competition.
3. Horizontal unbundling of the generation and retail (when applicable) sectors into an adequate number of entities that enables competition.
4. Integration of transmission and system operation to maintain grid stability and facilitate competition.
5. Creation of voluntary wholesale spot energy, ancillary services and contract markets that facilitate the balancing of supply and demand.
6. Guaranteeing free access to the transmission network for both buyers and sellers of electricity. Additionally, incentives should be put in place to encourage optimum location of new generation asset and allocation of scarce transmission capacity.
7. Unbundling of retail tariffs into a regulated tariff (transmission and distribution access charge) and retail power supply to promote retail market competition. Customers will see separate components on their bills for generation and transmission/distribution.
8. Creation of arrangements for supplying customers in case reforms do not entail the establishment of a retail market or until a retail market is established.
9. Creation of independent regulatory agencies that carry out the development and monitoring of regulatory guidelines and market performance.
10. Creation of transition mechanisms to deal with problems likely to emerge during the gradual introduction of reforms.

Despite the common functional requirements that form the building blocks of electricity markets, no two markets are identical. Variations consist of mainly the assignment of function to organization and in the underlying regulations or guidelines that govern the operation of the system. As such, regulators designing reform plans have a range of options to choose from. However, the final market architecture is heavily influenced by the state of the sector, hence the practicality and feasibility of the available options.

In the case of Saudi Arabia, the government has announced plans for deregulating the electricity industry. As discussed, the first step towards deregulation involves the restructuring of the electricity industry.

3.1. Structural reforms:

Structural reforms can be looked at as a two steps process: First, vertical unbundling of generation, transmission, distribution and retail. The second step is horizontal unbundling of segments where competition is to be introduced.

3.1.1. Vertical unbundling:

The options for vertical unbundling are as follows (Carlos Batlle and Ocana 2013):

1. Accounting separation: in which the company that is involved in both regulated and liberalized activities is required to keep separate accounts for each activity and charge its liberalized business unit the same fee charged to a third party.
2. Management separation: in addition to maintaining separate account, the company with the liberalized and regulated activates appoints separate management teams for each business unit.
3. Legal separation: both activities are run by two separate entities that could be reporting to the same holding company.
4. Ownership separation: the liberalized and regulated activities are conducted by two separate entities that do not share ownership.

Saudi Arabia has already taken some steps toward vertical unbundling through the establishment of "National Grid" which is a legally separate company from the incumbent utility company (SEC). However, vertical integration remains present between generation, distribution and retail.

Legal unbundling of the transmission activity, although in theory is a valid option is less preferred to ownership unbundling whenever the latter is possible. In essence, vertical unbundling is needed to offset the incumbent's incentive and ability to distort competition and to create market barriers to new entrants. The incumbent player through cross subsidies can distort market competition. Specifically, the incumbent can charge high prices for regulated activities and apply the additional earnings to better the position of its liberalized activity. Additionally, market barriers to new entrants can be achieved by depriving the right of third party access to the network. Even in cases where an independent system operator is responsible for network operations, the incumbent still has the ability to create technical obstacles that can be used to his advantage to manipulate the market performance. As such, ownership unbundling not only eliminates the incentive to the incumbent player but also its ability of taking such measures. The transmission activity is a corner stone to the functionality of electricity markets as such in almost all successful reforms; ownership unbundling has been a key step toward market liberalization.

Similarly, ownership unbundling of the distribution activity from the generation and transmission activities is a perfect remedy to remove the incumbent's ability to distort market efficiency. However, the unbundling of the distribution and retail activities has long been a subject of debate. This issue is directly linked to whether a retail market will be established or not. In case it is, then unbundling is a requirement. When ownership unbundling is not chosen, a solution available to regulators is to prohibit a company owning a distribution and retailing businesses from operating both businesses in the same area.

On the other hand, if the decision is not to introduce retail competition, distribution and retail remain unbundled and are subject to monopoly regulations. Under this scenario, the distribution company is allowed a stream of revenue to provide customer service including billing and collecting. Additionally, the distribution company could also be required to contract supply of power from the wholesale market on behalf of its customers. An alternative approach to that is to assign the responsibility of buying power to a third party known as the "principle buyer/single buyer".

In retail, in addition to unbundling from distribution, vertical ownership unbundling between retail and generation is encouraged. As discussed in the case of Great Britain, the vertical integration between retail and generation (although legally unbundled) has proved to be problematic. It has contributed to the dysfunction of both the wholesale and retail markets resulting in price signal distortion, shortage of liquidity and creation of barriers to new entrants.

3.1.2. Horizontal unbundling:

Horizontal unbundling is a precondition to introducing competition. As discussed earlier, inadequate unbundling gives rise to advantageous economies of scale and hence negatively impacts competition.

In Saudi Arabia, SEC has a dominant position in the market that would require the divestment of its generation assets to enable competition. The first question to answer in this regard is *how many companies should be formed out of SEC's divested assets?* The answer to this question hinges on many factors but typically the number is influenced by the minimum number entities required to mitigate market power (this part will be discussed in further details in Chapter 4).

Similarly, horizontal unbundling for the retail business should be made on a basis that would guarantee the existence of sufficient competition.

3.2. Wholesale market:

Assuming that the Saudi government achieves adequate structural reforms, the heart of deregulation is based on creating a competitive wholesale electricity market. The wholesale market's main function is to facilitate the trading of power between buyers and sellers. The physical and economical characteristics of the electrical system give rise to secondary support functions that are necessary to achieve the desired level of supply reliability and security. With that being said, wholesale markets can be decomposed into three main segments (Pérez-Arriaga 2013):

1. **Day Ahead Market (DAM):**

   The high-level design decision evolves around the selection of the clearing mechanism. International experience tells us that there are two main options available to Saudi Arabia: 1) The "Electricity Pool" model. 2) The Power Exchange (PX) model.

   The Electricity Pool model is highly centralized and the dispatch schedule is issued based on cost/reliability optimization. The responsibility of running the market can be assigned to the designated system operator or to an independent market operator. As seen in Chapter 2, the marginal unit sets the market price under this model. This model is the most commonly applied worldwide. The reason is that it has proven efficiency and also ease of implementation.

On the other hand, the PX model is based on the conviction of open trade. The establishment of a dispatch schedule for the following day is decentralized. Both sellers and buyers have the option of engaging bilaterally under the condition to inform the system operator of the agreed upon physical position. Specifically, generators and retailers inform the system operator of their dispatch/demand schedule for the following day. Alternatively, the model also provides an exchange platform where generators and retailers submit their bids and offers. In this case a market operator (typically automated system) matches bids and offers. Under this model, there is not a single market price (often the used reference market price is the price of most expensive power exchange done through the exchange platform) but rather prices are based on the bilateral agreements (pay as bid scheme).

2. **Ancillary Services Market:**

The real time supply and demand balancing requirement of electrical system mandates the availability of contingency mechanisms to deal with any deviation from the declared physical positions in the day ahead market. These include the contingency of ramping up/down production or reducing/shedding load. As electricity markets are designed to be competitive, competition in ancillary services should also be targeted (although this is not always the case). There are two main designs of ancillary services market that are linked to the design of the day ahead market: 1) Real Time Markets (used in many places in the US) is basically based on centralized dispatching. 2) Balancing markets, typically coupled with the power exchange model. Under the latter, a balancing mechanism is developed to enable the system operator to take actions toward maintaining system operations. The associated cost of handling system imbalances is also governed by a pricing arrangement that is developed by the regulator. Countries that adopted the balancing mechanism model also developed so-called "intra-day" markets. The idea is to allow market players to adjust their declared physical position in the day-ahead market in order to reduce the overall system imbalance cost.

3. **Long Term Markets:**

   Future markets provide a measure for market players to hedge against market risk. Most market participants do want to be exposed to the volatile market prices; as a result, this allows the emergence of futures markets. Long-term contracts have various formats, which are classified mainly into two categories: physical or purely financial contracts.

3.3. Transmission and distribution regulations:

The transmission activity plays a critical role in the operability of the electrical systems. Under the deregulated era, the transmission activity remains regulated, however, additional functions have been assigned to the designated system operator which depending on the market structure could also be the transmission owner and the market operator. However, despite the additional functions, the conceptual options available to regulate the transmission activity remain the same. Like any regulated activity the main two options are: 1) Cost of service regulations. 2) Incentive based regulations.

3.4. Retail market:

As discussed before, retail competition by itself is an option that many countries did not opt to pursue (most Latin American counties did not liberalize the retail activity). However, in countries that undertook full reforms such as most of the European Union Member States, the cost of retailing for customers is internalized in the energy procurement process itself. In other words, prices are no longer regulated and are subjected to market competition. The role of the regulator in this case is to ensure sufficient level of competition exists and that prices are set competitively.

In addition to the continuous monitoring of market power, retail regulations could include the following measures:

1. Develop rules that encourage customer switching (shopping) between retailers to promote competition.

2. Address the issue of tariff design in a way that it will allow customers to easily compare between retailers (standardize).
3. Limit the maximum duration of retail contract (between retailers and consumers) to one year.
4. Assign a supplier of last resort, typically through an auction format, to serve customers of a defaulted retailer whenever this happens.

3.5. Market structure and operation:

The first step towards deregulation of the Saudi electricity industry is proceeding with structural reforms. As discussed, vertical separation of electricity activities is essential in ensuring the operability of any given deregulated system. This has been witnessed in all electrical systems that went through the deregulation process. This step involves the separation between generation, transmission and distribution. Another common factor about the deregulation process is that competition on the retailing activity (if sought) is only introduced once a competitive wholesale market is presumed functional. It is worth highlighting that many countries have opted not to introduce competition on the retail level. In such countries, typically the retail activity remains bundled with distribution and under monopoly regulations.

On the other hand, the distribution activity can also go through horizontal unbundling although it typically remains regulated. Horizontal unbundling of the distribution activity is typically desired by regulators to allow benchmarking between companies and improve the system efficiency through incentive based regulations.

One of the major corner stones of establishing a wholesale market is the independence of the system and market operator. If the transmission activity successfully undergoes an ownership unbundling from all other activities and proves its independence, both functions of system and market operation can be assigned to the transmission company. However, if this is not the case, then there is a need to establish an independent entity/ies that carries on these activities.

Aside from generation horizontal unbundling, which according the Saudi government officials will be implemented, price reforms need to take place. Price reforms to the fuel supplied to generators and on electricity prices provided to consumers will improve the economic efficiency of the system and provide the necessary price signals required for optimum operation of the grid. The Saudi government announced recently (Dr. Abdulla Alshehri, 2016) that it is considering the removal of financial subsidies to electricity prices, however, until this is achieved, price reforms to the fuel supplied to generators is a step that should be targeted as part of structural reforms. The necessity of fuel price reforms comes from the fact that current prices are biased toward the use of oil and oil liquids product over gas which in turn results in less optimum operation of the system.

Given the aforementioned, the dynamics of the electrical industry after the establishment of a wholesale market can take multiple forms. One option that is adopted by many Latin American countries is when the retailing activity remains bundled with distribution, as shown in Figure 28.

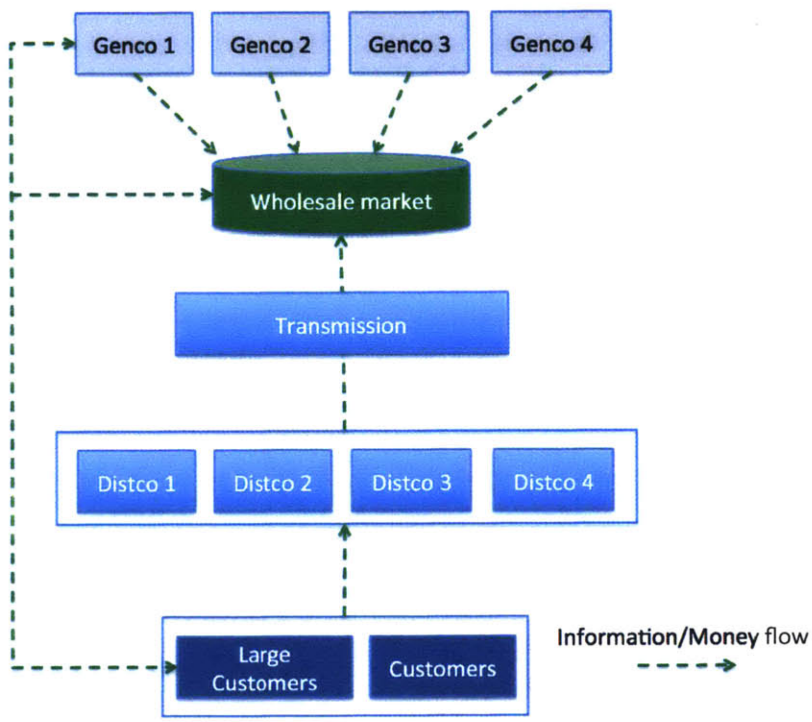

Figure 28 Wholesale market structure, assuming retailing remains bundled with distribution

Under such a scheme and assuming a wholesale market based on an electricity pool model, generators bid their supply curve into the wholesale market. On the other hand, distribution companies bid their demand curve on behalf of customers. The market operator then has the responsibility of commercially matching supply and demand. Additionally, the system operators responsibility will be to ensure the physical balance of supply and demand at all times including the dispatch of any ancillary services shall be required. The advantage of such a scheme is that distribution companies are equipped to act on behalf of their customers given their inherited responsibility of metering and billing. This advantage gives a distribution company the advantage of better forecasting demand for their customers. Under this model large customers (above some regulated threshold) can also be granted the permission to purchase their own electricity supply either bilaterally or through the wholesale market. This has to be done carefully, however, since if this is done very pervasively then the actual fraction of electrical power going through the wholesale market can be very low (see case of the UK in Chapter 2). As highlighted this framework can be considered as the permanent structure of the industry as is currently the case in most Latin American countries or it could be considered as a transition stage as was the case in Great Britain.

An alternative framework to the one presented above is the establishment of an entity typically known as the single/principle buyer, which acts on behalf of captive consumers in the wholesale market. Under such a model, the single buyer entity aggregates the customers' base demand and submit offers on their behalf. This model is adopted in the Italian market. Similar to the model discussed earlier, large consumers can be given the option to purchase their own supply through bilateral agreements or the wholesale market, Figure 29.

In the Saudi case, the principle buyer model brings many advantages. The establishment of a principle buyer entity, which in theory should be a government owned entity, would support the government plans of gradually removing electricity prices subsidies. Essentially, the entity contracts electricity supply from generators assuming a reformed price of fuel and sells it to consumers at the regulated tariff. Additionally, considering the government's plans of introducing nuclear and renewable energy, which would require financial support to reduce investment risk, the entity would be well positioned to be the counterparty (Off taker) of any Feed-In-Tariff or Power Purchase Agreement. It is worth highlighting that the principle buyer model can co-exists with full liberalization framework as long as the remaining power traded through the spot market is sufficient to maintain adequate competition conditions.[14] This is the case in Great Britain who established a Low Carbon Limited Liability company as an off taker to FIT Cfd contracts. This company is essentially a principle buyer.

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[14] The traded power should not allow the emergence of dominant position.

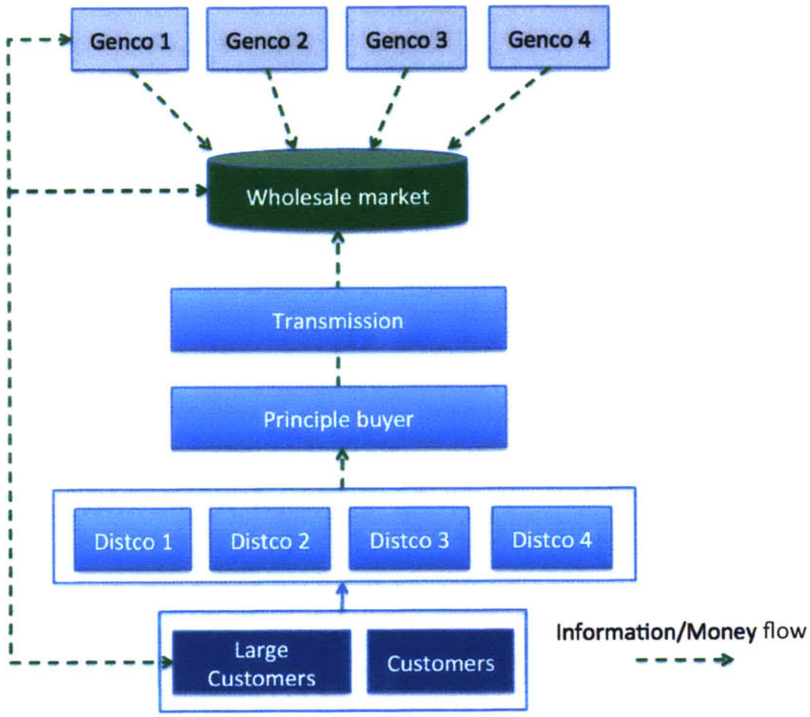

Figure 29 Wholesale market structure assuming the principle buyer model

Finally, after the wholesale market has proven to be functional, the regulator can opt to introduce competition in the retailing activity. Under this framework, retailing is unbundled from distribution and retailers are given the responsibility of submitting offers into the wholesale market. Additionally, electricity prices in theory would not be regulated and are set by retailers. Retailers compete to serve consumers on the bases of prices and offered services. When the retail activity is deregulated, the regulator's responsibility would be to mainly ensure that electricity prices are set competitively, define rules that enable competition such as limiting any contractual agreement between retailers and customers to a certain period of time (typically a year) and provide customers with means of comparing prices between retailers, Figure 30.

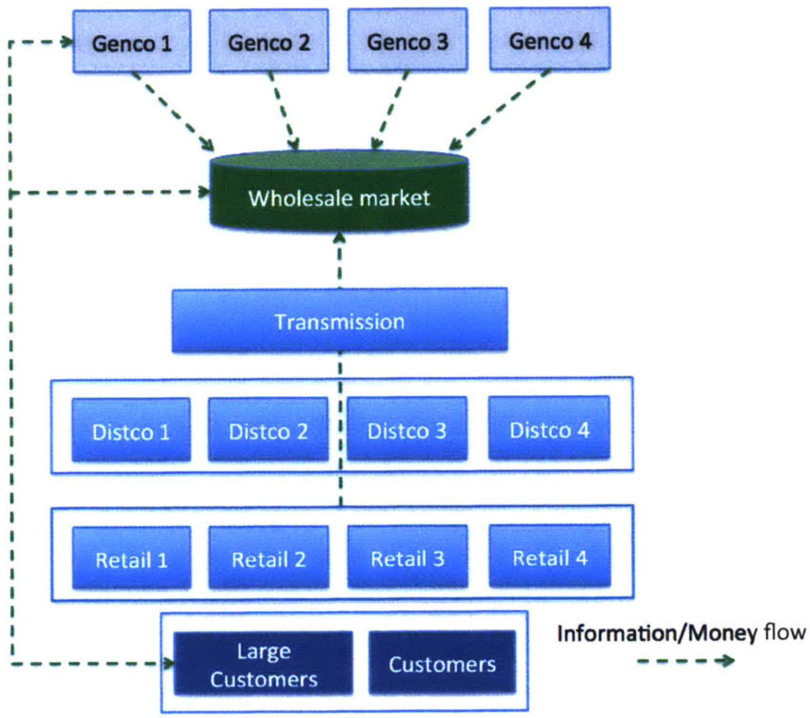

Figure 30 Full Liberalization

In summary, the size of the generation capacity base is adequate to introduce competition in the generation sector. As a first step, the regulator should seek ownership unbundling of electricity activities. Secondly, the SEC generation assets should be divested between an adequate number of generation firms to create competition in the wholesale sector. The creation of the new generation firms can be achieved through by establishing new entities as a first step and then floating their stocks into the stock market. On the hand, the established National Grid should presume responsibility as the sole system operator and provide nondiscriminatory access to the grid. Transmission and distribution activities should remain regulated. However, Competition into the retail activity should only be introduced once a wholesale market is proven to be functional.

From an architecture point of view, the single buyer model provides the Saudi government with more flexibility during the transient phase into market liberalization as it can be used to facilitate the gradual removal of energy subsidies. However, given the existence of isolated areas, wholesale markets should only be introduced into areas that are grid connected, while isolated pockets should remain regulated.

Chapter 4

GENERATION UNBUNLING AND IMPLICATIONS FOR MARKET POWER

1. Market power:

The functioning of a wholesale electricity market is closely related to its structure. As discussed in Chapter 1, exhaustion of economies of scale of a power system is a pre-condition for determining whether deregulation of a given system is a viable option or not. Additionally, barriers to entry including technical and regulatory factors contribute significantly to the achieved level of competition. In highly competitive markets when economies of scale are not a concern and barriers to entry are low, the number of competing firms tends to be high in the long run, which in turn encourages competitive pricing.

After the decision to deregulate the electrical system is made, the next obvious question is how to structure the market and specifically, when there is an incumbent player with a significant dominant position, what should be done to ensure the highest level of competition. International experience tells us that countries, which went through deregulation often, reverted to interventionist measures to dilute the dominant position of the incumbent player. It is typically the case that an incumbent player is forced to divest some or all of its generation assets. This is easier to implement when the incumbent entity is publically owned and much more difficult when it is owned by the private sector. The advantage of such a measure is that it eliminates the ability of dominant market players to exercise market power. However, this option is not always feasible to implement. In such cases regulators often revert to instruments that aim at either lowering the incentives for players to manipulate prices or limiting their ability to do so. Examples of such measures include setting price caps or introduce pay as bid rules[15], imposing long-term contracts for a certain share of the asset and strengthening interconnectivity with neighboring markets.

When the divestment of the generation assets is perceived to be a feasible option, then the next question to come is *how many competing firms should the system* have post deregulation to enable

[15] Price caps and pay as bid rule are typically not recommended as they suppress/distort price signals and as such could lead to major barriers to entry.

competition? The answer to this question is again directly related to economies of scale. A "dominant position" or "market power" is defined as the ability of an agent in the market to manipulate short-term prices to its own benefit. Incumbent agents with strong economies of scale have the ability to either increase or decrease prices to benefit its market position in the short and/or long run.

A simple example of the exercise of market power is when the incumbent player enjoying vertical integration (in systems that only require legal unbundling between power system related activates), such as between generation and distribution or retail, can dump wholesale electricity prices to push competitors who are more sensitive to prices out of the market.

Another important example is when an agent owning both base load assets and most of the peak generation capacity withdraws the marginal unit to achieve higher income. This was mentioned earlier as one of the mechanisms by which generators declare certain units as unavailable, even though they would be technically available to produce electricity. As shown in Figure 31, an agent that owns both infra-marginal units and the system's marginal unit can withdraw the marginal unit, therefore increasing the market price and achieving higher income.

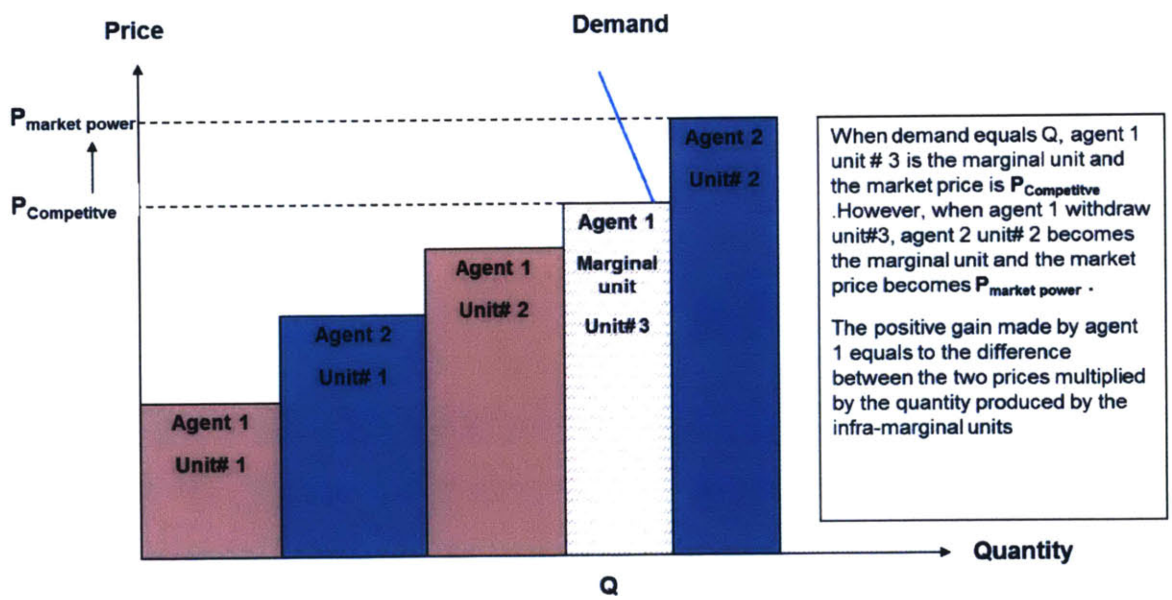

Figure 31 (Exercise of Market Power) – Example of Agent 1 withdrawing the marginal unit

To measure and mitigate market power[16], regulators often relied on two classes of methodologies. 1) Indices that measure either market concentration, or impact on prices or residual demand analysis. 2) Competitive Electricity Market models

1.1. Market power indices:

As market power is closely correlated to the horizontal concentration in the generation segment, a number of indices have been developed and applied to measure market power in electricity markets. Such measures were intended for slower paced industries, but nevertheless were and are still used by regulators to evaluate anti-trust policy, market monitoring and merger valuation. All developed indices are used as indicative measures rather than deterministic, as such are used as a supplement to measurement of market power[17] (M. Ventosa, 2013).

One simple and widely used indicator is the m-firm concentration ratio. The ratio is developed to specifically measure market concentration and is defined as the aggregate market share of the m largest companies using the following formula:

$$C_m = \sum_{f=1}^{f=m} \propto_f \qquad (4\text{-}1)$$

Where $\propto_f$ is the market share of company f.

Typically, the m-firm concentration ratio uses market share of the top four companies, applying this methodology to the Saudi electrical sector as it stands now, the largest four companies are SEC with a market share of 70.8%, SWCC at 6.5%, Hajr at 4.35% and Jubail Water and Power company at 3.7%. Then the concentration ratio equals to C_m= 85.35% indicating that the sector as it stands today is highly concentrated. One major flaw with this ratio is that disregards the market share split between the top four companies, as seen by the market share figures above, SEC has a market share that is about 20 times larger than the smallest of the top four companies (Jubail Water and Power Company).

Another widely used indicator is known as the "Hirschman-Herfindahl Index" (HHI). The HHI measures market concentration as the sum of the squares of each participant's market share.

$$HHI = \sum_f \propto_f^2 \qquad (4\text{-}2)$$

[16] Including the determination of the minimum number of competing firms required achieving the desired level of competition.

[17] Although this has not been historically the case, many early adopters of deregulation relied on indices as a measure of market power.

In a pure monopolistic sector were a single company enjoys a 100% market share, the HHI index value is 10000. In a wholesale electricity market, an HHI value between 1000-1800 is typically considered moderately concentrated. On the other hand, an HHI value of more than 1800 typically indicates a highly concentrated market. The HHI value for the Saudi sector as it stands today is at 5126.2 points indicating a highly concentrated sector that requires structural intervention in the power generation sector.

Concentration indicators such as the ones discussed above are widely used prior to the liberalization of regulated industry. Their main advantage is ease of implantation as such indicators require minimum data to be calculated and are a good high level method to measure market power. Thus identifying the possibility of incurring higher prices as a result of market concentration (or not sufficient competition). Additionally, whenever a concentration ratio is high, both the C_m and HHI indicator provide a clear conclusion regarding the existence of market power.[18]

Due to the discussed limitations of concentration ratio indices, a number of alternative indicators have also been developed. A major class of such indicators is based on demand characteristics. Examples of such are the pivotal supplier indicator (PSI), which is a binary indicator that classifies competing generation firm to be pivotal if demand cannot be met without it. [19]

Finally, a third family of indices is based on market pricing. An example of such is the Lerner index. The Lerner index is calculated by finding the difference between prices assuming perfect competition and actual market prices (Pérez-Arriaga 2013). The ratio calculates the markup price as a percentage of the actual market price. This method is often simplified and typically used once a market is established to monitor abuse of market power. However, the methodology can be used ex-ante given that it is complemented with a simulation model forecasting market prices.

[18] It is only when both indicators are showing moderate or low concentration that a clear conclusion cannot be drawn. This is because both indicators do not address technical or resource constraints that could give rise to market power, examples of such situations include network constraints that could result in market power for an agent with a dominate position at the constrained area.

[19] Another index that falls under this category is based on counting the number of hours a generation firm is marginal.

1.2. Electricity Market Models:

The unique characteristics of electricity required a new set of tools that help explain the market dynamics. This notion has prevailed a relatively new area of research concerned with mathematical and computer-based modeling of electricity markets. Although a variety of modeling approaches have been developed, the major modeling techniques can be grouped into three main categories(Ventosa et al. 2005):

1.1.1. Single firm optimization model
1.1.2. Equilibrium model (commonly based on Cournot model)
1.1.3. Simulation models

From a mathematical structure point of view, single firm optimization models, as the name indicates, optimizes a profit maximization function of a single firm subject to a set of technical and economic constraints. On the other hand, equilibrium and simulation models also optimize profit maximization but for each of the competing firms in the market simultaneously. When analyzing market power, equilibrium and simulation models are often used.[20]

Equilibrium models can also be categorized into two main families: 1) Cournot equilibrium. 2) Supply function equilibrium (SFE).

Both equilibrium-modeling techniques attempt to mimic the market's price clearing process in different ways. This is done based on a mathematical formulation that represents the strategic behavior response to competition. Both modeling approaches are based on identifying a Nash-equilibrium point for each of the competing firms assuming that each of those firms will be behaving rationally to competition.

Under a Cournot equilibrium model, each firm's objective function of profit maximization is factored in. In addition, a set of system constraints is identified and included in part of the formulation. The algebraic formulation contains expressions that represent each generating unit's technical constraints; in addition to network and fuel supply constraints. Finally, an overall system's inverse demand function is used and this is what brings all the pieces together. Thus, Cournot

[20] Equilibrium models are used more often to study market dynamics.

equilibrium models study each firm's behavior response to competition based on the quantity supplied by each firm. The difficulty of implementing this approach to study the consequences of market power in the Saudi case is the fact that electricity prices have not changed significantly in the past decades and have been heavily subsidized suppressing any price signals to consumers. Thus identifying a system's inverse demand function (in other words a price function relating the quantity sold to the unit price) for the Saudi system is a difficult task.

On the other hand, SFE models[21], which are more difficult to implement, model the strategic behavior of competitors based on each firm's supply curve. When each firm's residual demand is uncertain, the best strategic behavior to maximize profit would be to develop a supply curve that identifies the quantity to be produced based on the given price. Therefore, the mathematical formulation of SFE models is based on a set of differential equations. A disadvantage to this approach is that in most cases it does not include a detailed representation of the system being evaluated.

Simulation models are an alternative to equilibrium models. In contrary to equilibrium models that are based on a formal equilibrium definition, simulation models are based on a set of sequential rules that represents the dynamics of each firm's strategic behavior. The quality of any given simulation model is heavily dependent on the rules defined to govern the simulation (Ventosa et al. 2005).

2. Modeling market power in the case of Saudi Arabia:

The deregulation of the generation sector is sought after on the belief that it results in higher system efficiency compared to the traditional regulations. Specifically, the idea is that through introducing competition in the generation segment, the system can achieve efficiency pricing. However, as explained in previous chapters, efficient pricing is subjected to multiple factors including the market structure, ease of market entry among other factors. Therefore, imperfect competitive conditions in a given system coupled with the rational behavior of power producers to maximize their own profit, can yield undesired outcomes. In other words, generators are incentivized to markup electricity prices by as much possible to increase their income.

[21] First developed by Klemperer and Meyer (1989).

To achieve higher profits, assuming a wholesale market that uses a pool scheme[22], generators can do one of two things: 1) Submit bids with prices higher than the marginal cost. 2) withhold production from infra-marginal units in an attempt to increase prices.

To analyze market power in the Saudi electricity sector based on the current government plan of establishing four-generation companies, the first option considered here is using a Cournot equilibrium model. The advantage of using a Cournot model is the flexibility it provides to consider generation units' technical constraints in addition to the network capacity constraints. The difficulty in implementing such an analysis of the Saudi sector comes from the fact that electricity prices have not seen major changes in a very long time therefore coming up with a demand function that represents demand elasticity to prices will be subject to major assumptions. As an alternative, the analysis conducted below is based on the application of the concept of Supply Function Equilibria. Specifically, the subsequent model uses a closed form algorithm that was developed by (Rudkevich, Duckworth, and Rosen 1998).

2.1. Model formulation:

The formula is derived from the concept of Supply Function Equilibria developed by (Klemperer and Meyer, 1989). The model calculates the market clearing prices based on the Saudi electrical system's supply and demand data (2014). The market clearing prices are calculated based on the assumption that the market is split into *identical firms* adopting a Nash Equilibrium bidding strategy over the course of one year. The strategy satisfies the Nash Equilibrium condition such that if one company deviates from the strategy then its own profit will not exceed those who adopted the strategy. The model also assumes that demand is inelastic (which is the current case in Saudi), generating firms have perfect knowledge of each other's production cost and that all generating firms have equal accuracy in predicting demand.

Given the assumptions described above, the mathematical formulation of the model is as follows:

22 As explained previously, under a pool mechanism, the market prices are set by the price bid of the system's marginal unit. Under this scheme, all dispatched units receive the same price as the marginal unit regardless of their supply bid.

$$P(Q) = C_k + \sum_{j=k}^{m-1}[C_{j+1} - C_j]\left(\frac{Q}{x_j}\right)^{n-1} \qquad 4\text{-}3$$

Where,

P [$/MWh] is the market clearing price for the given time interval

Q [MW] is the instantaneous demand in a given time interval such that $X_{k-1} < Q \le X_k$

K is the dispatch order number of the marginal generating unit

n is the number of identical firms

$\boldsymbol{C_k}$ [$/MWh] is the variable cost of the marginal unit

j, $\boldsymbol{C_j}$ is the dispatch order number and variable cost of generating units above the marginal unit at the time interval but are below the marginal unit at peak demand

m is the dispatch order number of the marginal unit

$\boldsymbol{X_j}$ **[MW]** Total capacity of all generating units with dispatch order not exceeding j

To apply the model to the Saudi case, the first step involved the construction of a supply curve that reflects SEC's current generation assets. Using ECRA's data portal, I was able to find data on SEC's generation units that include, unit size, technology type, primary fuel and date of installation. Then each unit's heat rate was estimated based on the technology type and date of installation. It was assumed that at deregulation, fuel subsidies will be removed entirely and generators will be paying international fuel prices as follows:

Fuel type	Price ($/MMBTU)
Diesel	9.3
Crude oil	5.55
Natural Gas	2.79
Heavy fuel oil	9.8

Table 6 International Fuel Prices Source EIA

Based on above fuel prices an aggregate cost of supply curve is constructed. To run the simulation, the last step involves determining the annual peak demand seen by SEC. According to SEC's 2014 "Electrical Data Report", the peak demand supplied by SEC's grid connected facilities was 38,202 MW, which represents approximately 60% of the total grid connected capacity highlighted in Chapter 3.

2.2. Results and analysis

Based on the above a simulation of market-clearing prices as a function of the number of competing firms was created, as shown in Figure 32.

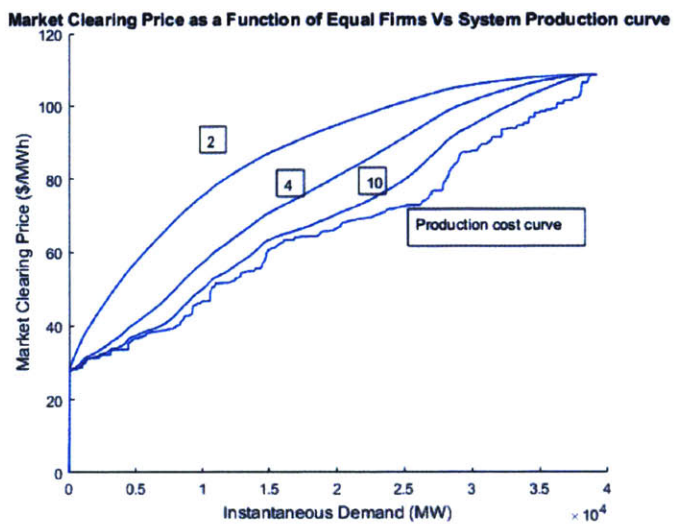

Figure 32 Market Clearing prices as a function of number of equal firms

As expected the results indicate that as the number of competing firms increases, the gap between the market's actual clearing price and production cost shrinks. Additionally, by only visual inspection, one can notice that the government's proposal of divesting SEC's assets into only four-generation companies will still yield significant market power. Although this analysis does not address network constraints and assumes an even split of assets between the competing firms in a national market (no regional characteristics are modeled), which from a market concentration point of view would make the best scenario, the results indicate that market power would remain as an obstacle against achieving perfect competition. A further split into 10 identical generation companies would more closely approximate the production cost curve.

To complement this analysis, the Lerner index explained previously was applied to quantify market power over a period of one year. The Lerner index is formulated as follows:

$$LLI = \frac{Actual\ market\ clearing\ price - Perfectly\ competitive\ price}{Perfectly\ competitive\ price} \times 100\% \qquad 4\text{-}4$$

Using the forecasted market clearing prices the Lerner index can be calculated as a function of the number of competing firms and instantaneous demand as percentage of annual peak load. The US Department of Justice merger guidelines state that a market is classified as competitive only when the actual market prices do not exceed perfect competitive prices by more than 5%.

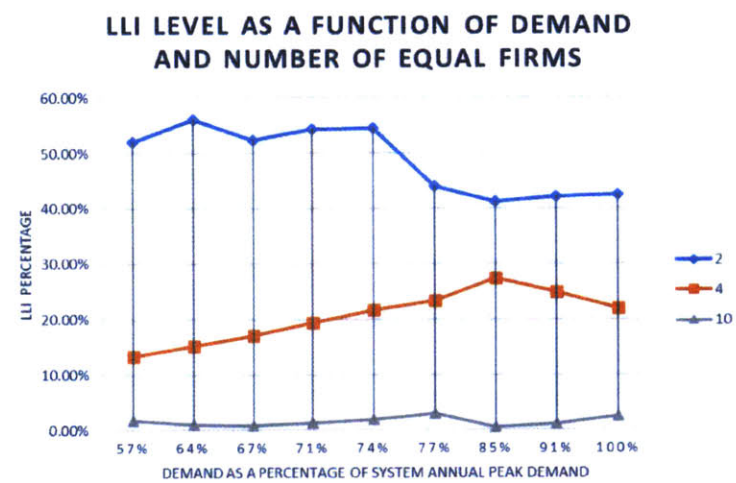

Figure 33 Lerner index analysis

According to Figure 33, the forecasted market clearing prices based on the Saudi government plans of establishing four generation companies exceed perfect competitive prices by over 10% during the entire year[23]. On the other hand, if SEC's generation assets were unbundled into 10-generation firms, the Lerner's index remains under 5, indicating a plausible level of competition.

3. Measures to counter the existence of market power (Pérez-Arriaga 2013):

[23] The x axis in figure 31 represents 10 selected values of demand that reflects the shape of a typical load duration curve in a given year.

3.1. Further asset divestment:

The issue of imperfect competition has been witnessed in almost all electrical systems that went through the deregulation process. To handle the existence of market power, regulators have often reverted to a number of measures with the objectives of either eliminating the ability of a firm to exercise market power or to reduce their incentive for such a behavior. The most effective and obvious measure to tackle market power is to impose further divestments of the generation assets.

3.2. Price caps:

Another option that was mostly in use in the early years of deregulation is price caps. Under this form of regulation, the regulator sets a cap on market clearing prices preventing generators from bidding a high price. This approach can also be done such that the cap is linked to a price index (typically a fuel price index). The major flaw of this type of regulation is that the determination of a price cap is difficult given that high prices can also be a result of scarce supply. Additionally, this measure suppresses long term signals needed to encourage new capacity investments.

3.3. Long term contracts:

Another more effective remedy is imposing long-term contracts for a sufficient capacity share of generating firms with dominant positions. Under this measure, generators are required to engage in long-term contracts receiving a fixed amount of income per MWh generated. Such a scheme is adopted in both Ireland and Singapore. Essentially, contracting a large share of available capacity to generators removes their incentive to manipulate market prices, as their competitors will only reap the benefit of doing so.

3.4. Virtual power plants auctions:

Under this method, a company with a dominant position is required to auction the commercial management of part of its assets for a long period of time, typically three to five years. This scheme of regulations has been adopted in places such as Alberta, Canada and the Netherlands. The main advantage of this method is that it facilitates the introduction of new players in the market. On the other hand, the disadvantage is that it discourages the company with a dominant position from making further investments in the system.

Chapter 5

CONCLUSIONS

For long, the electrical industry has been regulated based on cost of service regulations. Significant economies of scale that were present across the electricity activities of generation, transmission, distribution and retail have made cost of service regulations the preferred choice for many regulators. As power systems grew larger and generation technology advanced, the significance of economics of scale diminished. Additionally, cost of service regulations require the regulator to have perfect knowledge of the system's cost of service, however, the significant increase in power system size made the job of regulators more difficult. As a result, the implementation of cost of service regulations was often flawed and led to major economic inefficiencies.

As a result of the aforementioned among other factors, regulators were on a mission to find an alternative framework of regulations. This search led a group of Chilean Economists in 1980 to pioneer the introduction of a new framework of regulations that is based on competition. The main fundamental features of the new model include the introduction of competition in the generation sector, guarantee of free access and structural reforms that facilitate competition. Since then many countries have followed and deregulated their electricity industry. Beside the economic inefficiency of cost of service regulations, the rational for deregulation has been driven by a desire to increase the participation of the private sector to reduce the stress on public budget and reallocate risk associated with investment decisions.

In the UK the reforms proceeded in various stages of increasing, yet imperfect liberalization (Chapter 2). Structural reforms remain to be a big challenge hindering the market from reaching optimum efficiency. The market went through several stages of structural reform from the corporatization of publically owned utility companies in 1989, through the force divesture of generation assets in mid-90's and yet the issue of market concentration remains to be a challenge.

Nevertheless, the privatization of the electricity sector brought about significant efficiency gains and net social benefits (Newbery and Pollitt, 1996). Recently, the system regulator (Ofgem) announced plans to implement major reforms. The plan entailed measures that aim for improving the environment for competition. Specifically, the plan focused in removing barriers to entry, facilitating customers switching processes, and support to low carbon emission technologies.

In Saudi the case (Chapter 3) is not any different. The electricity industry is regulated based on a cost of service regulations with heavy subsidies extended to both the fuel supplied to generators and the final electricity prices. The dominant player in the industry "SEC" enjoys a vertical integrated monopoly. The government owns a control share of SEC's stocks. The system has been experiencing a brisk increase in demand; this increase in demand is forecasted to continue over the course of the next fifteen years. On the other hand, the forecasted demand growth coupled with major system upgrades will require significant investments in the future. As a result, the Saudi government is looking achieve active participation of the private sector into the development of the electricity industry.

The Saudi government has recently announced plans to deregulate the electricity industry. International experience provides a wealth of knowledge that can be tapped into by the Saudi system regulator (ECRA) when designing the deregulated market. The large size of Saudi generation sector allows the introduction of competition as economies of scale are exhausted. However, despite a high level of electrification (around 98%), certain parts of the country are yet to be connected to the main power grid, which as a result would need to remain under monopoly regulations until the volume of generation asset is large enough or the areas are grid connected. Additionally, the Saudi government through its relatively new established entity K.A.CARE announced plans aimed at promoting the deployment of renewable and atomic energy as part of the fuel mix. These facts have implications on the design of regulatory reforms in Saudi.

Nevertheless, the first step of deregulation involves undergoing structural reforms. This includes the vertical separation of electricity activities namely, generation, transmission and distribution. Additionally, the process involves horizontal unbundling of generation assets into a number of companies such that none of the created companies have a dominant position associated with power production economies of scale.

The second stage of structural reforms entails the assignment of two new functions specifically system and market operation. These functions can be assigned to the same entity as in the transmission network owner or as an alternative, new entities can be created to cater for these functions. At this stage a wholesale market is established where the established generation companies bid their supply curve into the market, on the hand, ECRA has the option of creating a principle buyer that aggregate demand for each hour and submit an offer curve to the market on behalf of consumers. As an alternative, offer bids can be aggregated and submitted to the market by the regulated distribution companies.

The third stage, which by itself is an option that ECRA can opt to pursue or not, involves the liberalization of the retail activity. This step involves the separation of the retail activity from other electricity activities. The activity is then carried on competitively based on price and services offering available to consumers.

In this thesis a SFE model of the generation side of prospective Saudi electricity market with vertically and horizontally unbundled generation was simulated based on an optimization model (details in Appendix – MATLAB code). It was found that the separation of SEC's generation assets into four separate companies is a step in the right direction, but does not entirely remove market power. A further disaggregation into about 10 companies would lead to more perfect competition and lower consumer prices but a more complex market structure.

Future work includes the following suggested items:

- Additional country-level case studies (e.g. of neighboring markets that are or may be connected to the Saudi grid in the future such as GCC and Egypt)
- Modeling of a liberalized Saudi generation market using the Cournot Equilibrium model using synthetic price curves based on experiences in other privatized countries
- Sensitivity analysis of the SFE model results including sensitivity to different fuel prices at different levels of subsidy (the current model assumes no subsidies), heterogeneity of generation assets by region or generation ownership portfolio and inclusion of network transmission and other constraints
- Creation of a market simulation serious game with bidding and market clearing mechanisms as they are envisioned for the future privatized Saudi electricity market. The

main purpose of the serious game is to check whether participants will indeed behave rationale and approach a Nash Equilibrium.

APPENDIX A – LIST OF ABBREVIATIONS

AC: Alternating Current.
APX: Automated Power Exchange.
BETTA: British Electricity Trade and Transmission Arrangement.
BM: Balancing Mechanism.
BTU: British Thermal Unit.
CEGB: Central Electricity Generating Board.
CCGT: Combined Cycle Gas Turbine.
CFD: Contract for differences.
CMA: Competition and Market Authority.
CHP: Combined Heat and Power.
DECC: Department of Energy and Climate Change.
EMR: Electricity Market Reforms.
FIT: Feed in Tariff.
GEMA: Gas and Electricity Market Authority.
IWPP: Independent Water and Power Producer.
PPA: Power Purchase Agreement.
K.A. CARE: King Abdulla City of Atomic and Renewable Energy.
LCCC: Low Carbon Contracts Company.
LOLP: Loss of load probability.
MOWE: Ministry of Water and Electricity.
MinPet: Ministry of Energy, Industry and Mineral Resources.
NETA: New Electricity Trade Arrangement.
NG: National Grid.
O&M: Operation and maintenance.
Ofgem: Office of Gas and Electricity Markets.
REC: Regional Electricity Company.
RIIO: Revenue = Incentives + Innovation + Outputs
RPI: Retail Price Index.
SEC: Saudi Electricity Company.
SCECO: Saudi Consolidated Electricity Company.
SO: System Operator.
SWCC: Saline Water Conversion Corporation.
WACC: Weighted Average Cost of Capital.
VOLL: Value of lost load.

APPENDIX B – SFE MODEL CODE

```
% The original code has abeen developed by Dr Pablo Rodilla and was
% modified by the thesis author with permission from Dr Pablo
%This is an attempt to reproduce the supply functions from the closed-
loop
%form
% calculated by Rudkevich in the case of a symetric and demand-
inelastic
% oligopoly.
% The main objective is to focus in the supply functions shape when
 the
% marginal costs being considered aren't smooth functions.

function productioncurve
clear all
close all
clc
% ***********************************
%        System Characteristics
% ***********************************
figure;
hold;
%find Qmax assuming 10 load segments
% data2014=xlsread('Saudi_Hourly_Demand_2014.xlsx','Sheet1');
% totaldemand14=data2014(:,9);
% NumberOfDays=[10;20;20;30;30;40;40;50;60;65];
% FirstDayOfLoadSegment=[1;11;31;51;81;111;151;191;241;301];
% LastDayofLoadSegment=[10;30;50;80;110;150;190;240;300;365];
% MaximumPeakHourlyLoad=[max(totaldemand14(1:240,1));
% max(totaldemand14(241:720,1));max(totaldemand14(721:1200,1));
% max(totaldemand14(1201:1920,1));max(totaldemand14(1921:2640,1));
% max(totaldemand14(2641:3600,1));max(totaldemand14(3601:4560,1));
% max(totaldemand14(4561:5760,1));max(totaldemand14(5761:7200,1));
% max(totaldemand14(7201:8760,1))];
% MinimumPeakHourlyLoad=[min(totaldemand14(1:240,1));
% min(totaldemand14(241:720,1));min(totaldemand14(721:1200,1));
% min(totaldemand14(1201:1920,1));min(totaldemand14(1921:2640,1));
% min(totaldemand14(2641:3600,1));min(totaldemand14(3601:4560,1));
% min(totaldemand14(4561:5760,1));min(totaldemand14(5761:7200,1));
% min(totaldemand14(7201:8760,1))];
% MedianimumPeakHourlyLoad=[mean(totaldemand14(1:240,1));
% mean(totaldemand14(241:720,1));mean(totaldemand14(721:1200,1));
% mean(totaldemand14(1201:1920,1));mean(totaldemand14(1921:2640,1));
% mean(totaldemand14(2641:3600,1));mean(totaldemand14(3601:4560,1));
% mean(totaldemand14(4561:5760,1));mean(totaldemand14(5761:7200,1));
% mean(totaldemand14(7201:8760,1))];
% loadSegment=[1;2;3;4;5;6;7;8;9;10];
% T= table(loadSegment,NumberOfDays,FirstDayOfLoadSegment,
%LastDayofLoadSegment,MaximumPeakHourlyLoad,MinimumPeakHourlyLoad,
%MedianimumPeakHourlyLoad);
supply='prodcurve.xlsx';
m=xlsread(supply);
   for i = [2,4,10]
```

```
  % The number of symetric firms
   NumberFirms=i;
  % Qmax represent the peak demand value to be considered
  %Qmax = 10*NumberFirms-0.5;
  % NOTE: As solved by Klemperer no asymetric solution could stem
from a symmetric
  % problem, this condition along with the ineasticity of demand
leads us to the
  % equilibrium quantities each firm will be producing (by just
dividing the demand
  % value by the number of firms being considered). So it's also
posible to know
  % wich will be the marginal generator.

  % ************************************
  %        Firms Characteristics (MC)
  % ************************************

  % The values defining each firm marginal cost function
  % The xvalues represent the capacity value (measured from the
origin) from which
  % the cvalue changes to the corresponding value
  Xvalues=m(:,2);
  xvalues=Xvalues/NumberFirms;
  cvalues=m(:,1);
  % ************************************
  %        Oligopoly Characteristics
  % ************************************

  % Kcomp represents the price at the peak value, the lower the value
the
  % more competitive the bid when de demand value is the maximum.
  Kcomp = 1;

  % As it has a lower bound, this condition must be checked
  MarginalGeneratorAtPeak = find(xvalues <= Qmax/NumberFirms);
  MarginalCostAtPeak = cvalues(MarginalGeneratorAtPeak(end));
  MinKcomp = MarginalCostAtPeak;
  Kcomp = max(Kcomp,MinKcomp);

  % The upper bound (Cournot price) has to be calculated in order not
to be
  % exceeded

  % *************************************
  %        Supply function calculation
  % *************************************

  Resolution = 0.01;

  % The Xvalues and Cvalues are calculated (the Xvalues and Cvalues
are referred
  % to the agregated marginal curve)
  %Xvalues = NumberFirms*xvalues;
```

```
   Cvalues = cvalues;
   M_1_Position = sum(Xvalues <= Qmax);

   for IntervalCounter =  1 : M_1_Position
      QvaluesInInterval = ...
         [Xvalues(IntervalCounter):Resolution:Xvalues(IntervalCounter
+1)];
      MaxQInInterval = Xvalues(IntervalCounter+1);
      KPosition = IntervalCounter;

      % (I/III)
      Ck = Cvalues(IntervalCounter);
      FirstVector = Ck*ones(1,length(QvaluesInInterval));

      % (III/III)
      ThirdVector = QvaluesInInterval.^(NumberFirms-1);
      ThirdVector = ...
         ThirdVector*((Kcomp - MarginalCostAtPeak)/
(Qmax^(NumberFirms-1)));

      % (II/III)
      SecondVector = zeros(1,length(QvaluesInInterval));
      for SumatoryElement = KPosition : M_1_Position

         SecondVector = SecondVector + ...
            [Cvalues(SumatoryElement+1) -
 Cvalues(SumatoryElement)]*(QvaluesInInterval/Xvalues(SumatoryElement
+1)).^(NumberFirms-1);

      end
      if IntervalCounter == 1
         AggregatedSupplyFunction(1:length(QvaluesInInterval))= ...
            FirstVector + SecondVector + ThirdVector;
         AggregatedQvalues(1:length(QvaluesInInterval))= ...
            QvaluesInInterval;
         FirmQvalues(1:length(QvaluesInInterval)) = ...
            QvaluesInInterval/NumberFirms;
        %PerfectCompetition(1:length(QvaluesInInterval))= FirstVector;
        %Qvalueperfect(1:length(QvaluesInInterval))
 =QvaluesInInterval;
      else
         AggregatedSupplyFunction(end + 1:end +
 length(QvaluesInInterval))= ...
            FirstVector + SecondVector + ThirdVector;
         AggregatedQvalues(end+ 1:end +
 length(QvaluesInInterval))= ...
            QvaluesInInterval;
         FirmQvalues(end+ 1:end + length(QvaluesInInterval)) = ...
            QvaluesInInterval/NumberFirms;
      end

   end
   plot(AggregatedQvalues,AggregatedSupplyFunction,'b')
   if NumberFirms >= 100
```

```
        plot(FirmQvalues,AggregatedSupplyFunction,'r')
      end
       price(:,i)=AggregatedSupplyFunction;
       qantity(:,i)=AggregatedQvalues;
       clear AggregatedSupplyFunction
       clear FirmQvalues
       clear AggregatedQvalues
       a = 0;
      end
      load 'productioncurve.mat'
      hold on
      plot(Qvalueperfect,PerfectCompetition,'b')
       save('LLI.mat','price','qantity');

end
```

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