Energy Markets & Economics

Lecture 2: Organisation of the power sector

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Lecture 2: Overview

Lecture 2

Provide an overview of different **models for organising the power sector**, a view as to **the efficient model for organising the sector** and **what happens in practice**.

We will cover the following topics:

- Organisation of the sector
  - Different models for organising the power sector overall
- Organisation of markets for the four segments within the power sector
  - Organisation of markets for electricity networks, plus generation and retail supply
- Brief history of deregulation

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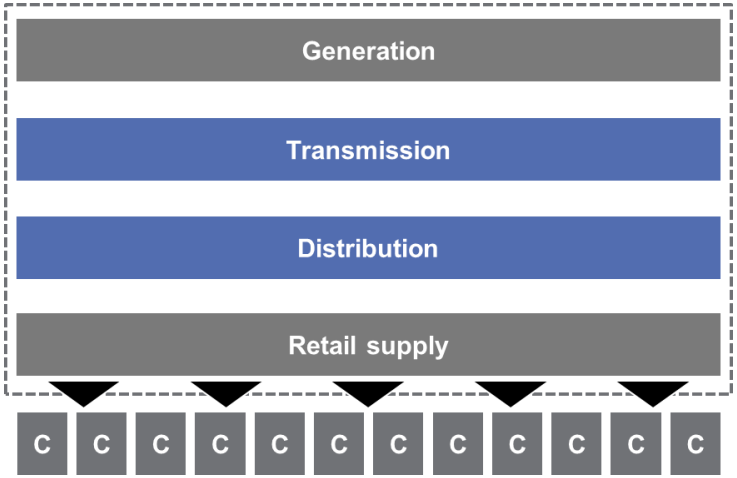
We will cover the following topics:

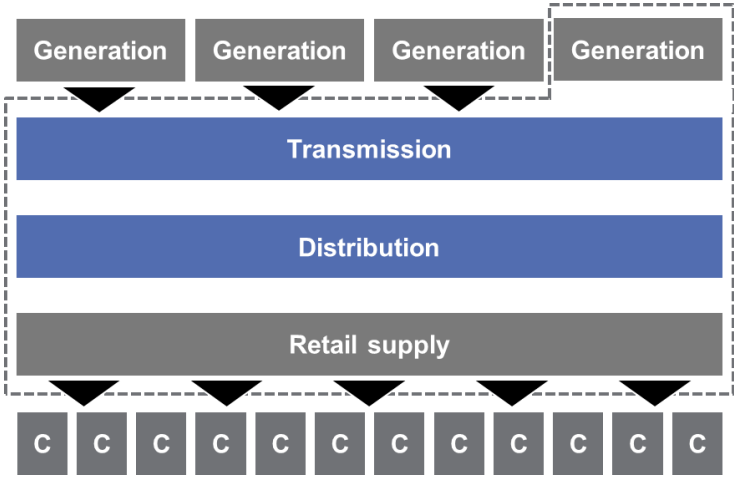
- Organisation of the sector
- Organisation of markets for the four segments within the power sector
- Brief history of deregulation

We describe the four basic models for organising the sector, and briefly discuss why they are used

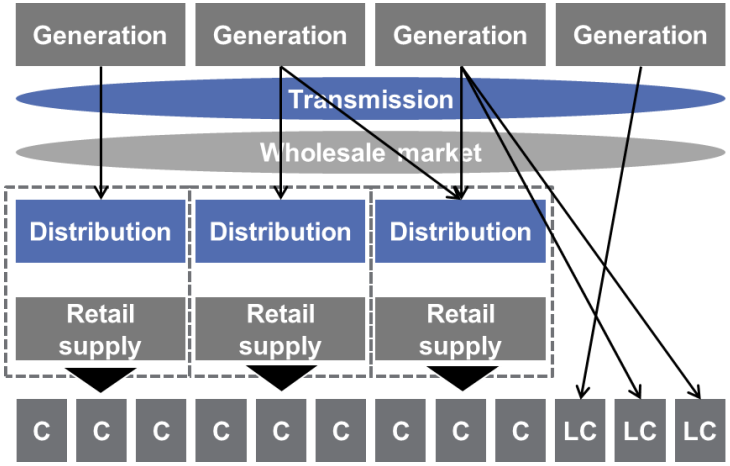
Model 1: Vertical integrated monopoly



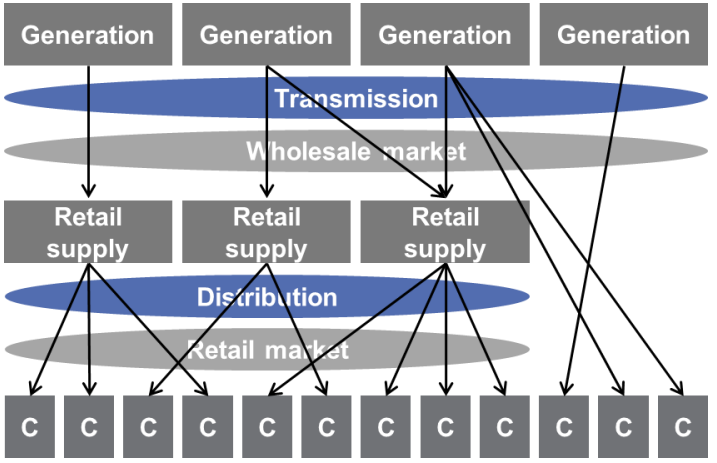
Model 2: Single buyer



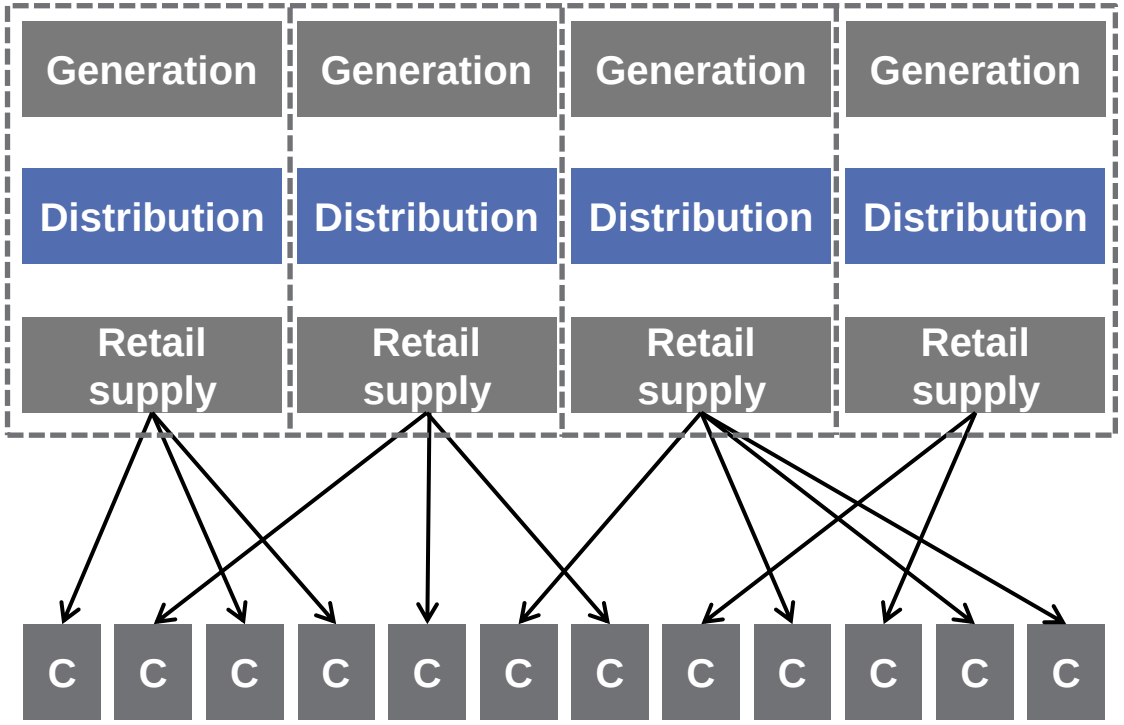
Model 3: Wholesale competition



Model 4: Wholesale & retail competition



First, some history. When the power sector was first established, small vertically integrated firms competed for customers …

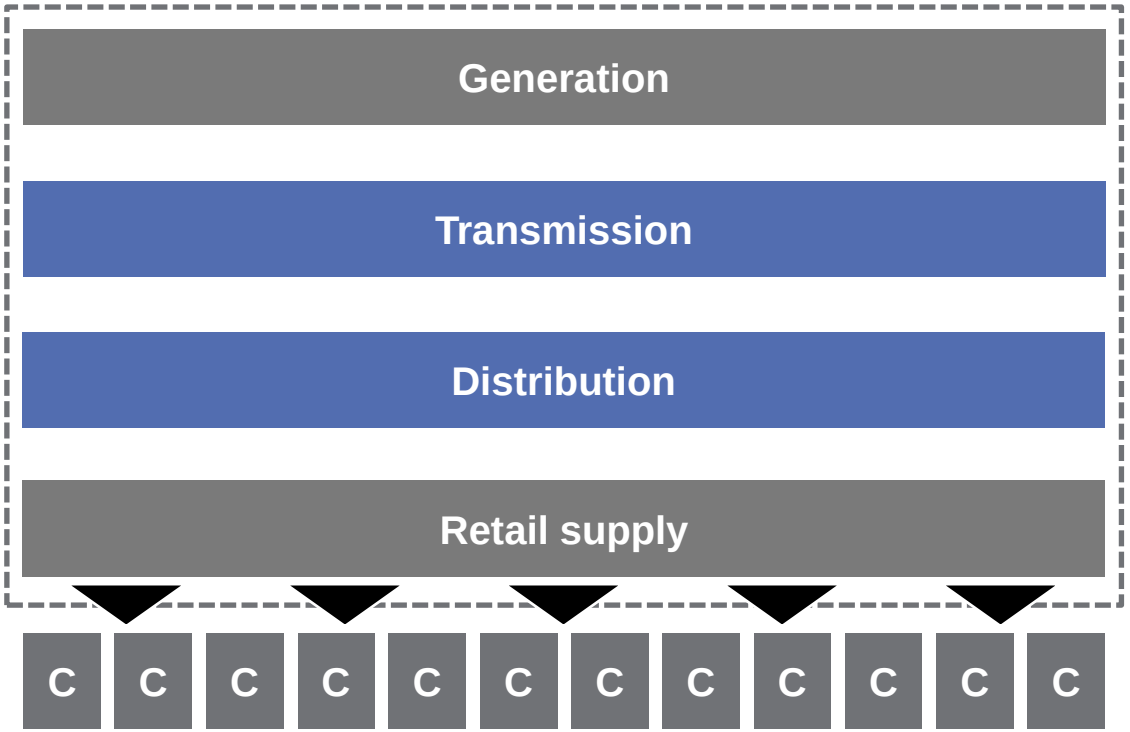


- Initially the power sector was privately owned with many competing firms
- The first electricity companies to supply the public were established in the 1880s, for example
  - Godalming (UK) 1881
  - Manhattan (USA) 1882, Edison initially connected 85 customers to a power plant
  - London (UK) 1882

Notes:
C = customer
= a firm
= contract sale of electricity

- The technology of the time meant it was **economically efficient to have small distribution networks**.
  - Direct current (DC) was used, making transformation of voltages difficult. Therefore, the voltage of distribution networks was the same as the voltage of the electricity produced, about 110 volts. This low voltage in turn meant high electrical losses in distribution grids, with losses rising with the length of the power lines and cables.
- **Few economies of scale** led to many competing small vertically integrated companies in a small area.
  - For example, in Chicago 24 vertically integrated power companies were establish between 1887 and 1893, with overlapping networks, competing for customers.

Model 1 – Technological change and economics led the sector to integrate horizontally, and to establish **vertically integrated monopolies**



- With this model all activities of the sector are within a single vertically integrated monopoly (in a given region).
- Some competition is possible for construction.
- Model 1 is sometimes still seen in less developed countries, e.g. Africa.

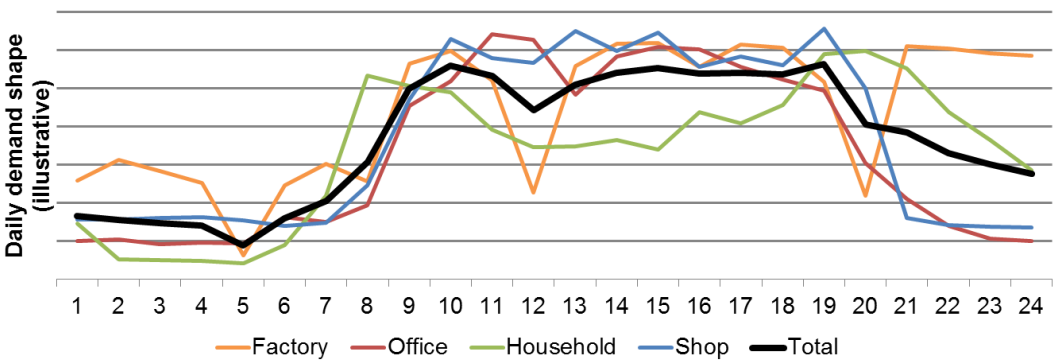
  Much of the discussion of organisation of the sector draws on Hunt and Shuttleworth

Notes:
C = customer
= a firm
= contract sale of electricity

- **New technology reduced grid losses.** Westinghouse introduced alternating current (AC) generators, allowing conversion of electricity to high voltages for transmission, reducing electrical losses on the grid, thereby allowing long distance transmission.
- **This allowed economies of scale** in the sector to be achieved from around the year 1900 by closing small generators and using **large scale generation linked to many customers with diverse loads** through a high voltage transmission grid.

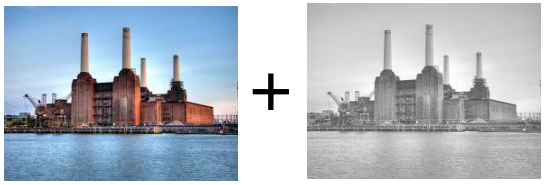
Model 1 – Technical and economic reasons drove the industry to consolidate horizontally while remaining vertically integrated.

Diversified demand smooths system load

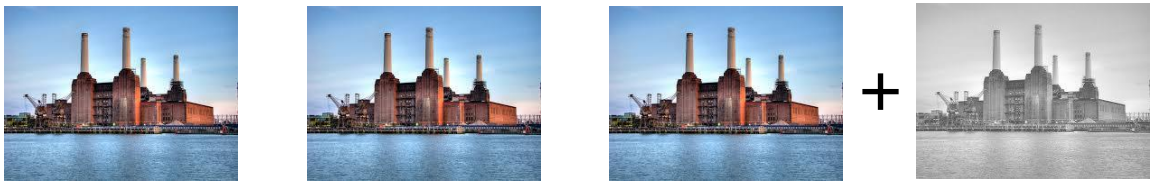


- Smoother load allowed power stations to run at **higher capacity factors**.
- More customers allowed for **larger more efficient power stations**.

Relatively less reserve capacity is needed with bigger systems



- Reserve capacity is needed to very quickly produce when needed, to ensure supply = demand.
- Larger power systems allowed for **less reserve capacity**, reducing average costs of meeting demand.



Model 1 – Technical and economic reasons drove the industry to consolidate horizontally while remaining vertically integrated.

Economies of scale

One or a few firms were more efficient at producing and delivering electricity than many firms.

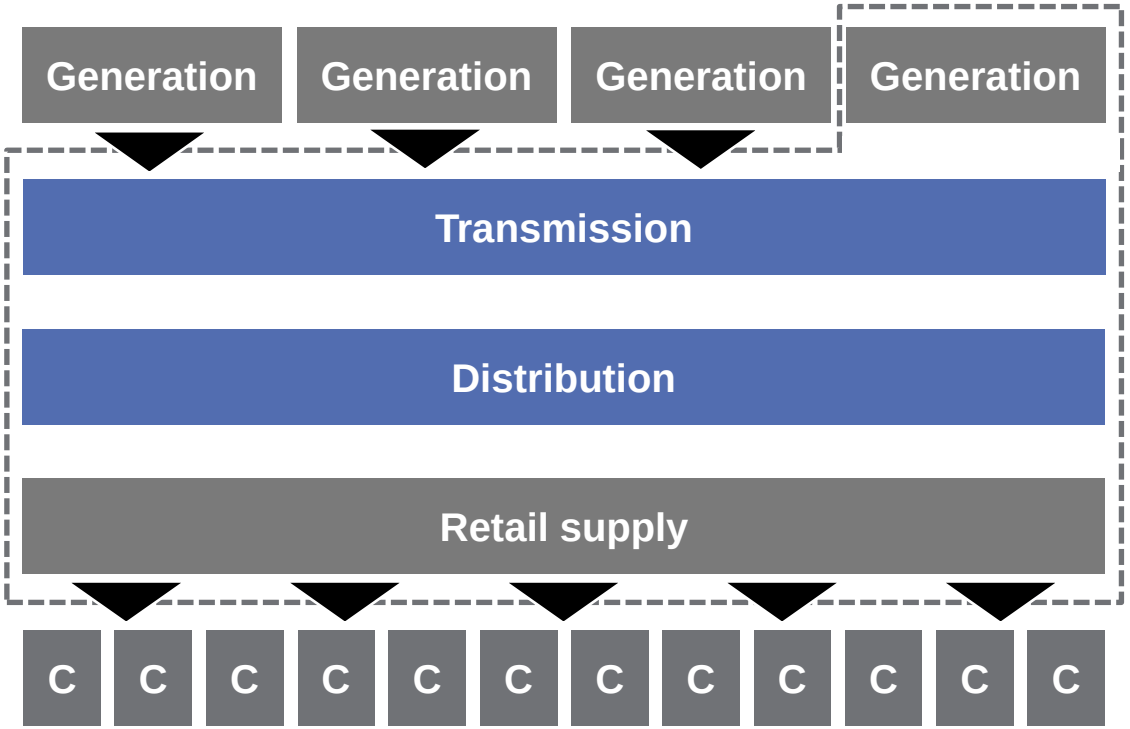
- **Networks are natural monopolies**.
  - Connecting a new customer or generator to an existing network is cheaper than building a new network.
  - Transporting an additional kWh is cheaper with an existing network than building a new network.
- **Larger power plants were more efficient** and had lower average costs. And, plants with **higher capacity factors** (average utilisation) have lower average costs.
  - Linking many customers together via a network smooths load because of diversified demand, allowing generators to run at higher capacity factors.
  - Large networks increase the average level of demand, allowing for larger power stations.
- **Relatively less G reserve required** as more power stations connected by large T systems.
- Large firms had the **capital and human resources required** to plan and develop large power stations and electricity networks.

Benefits of coordination

Common ownership helped **coordination between and within G, T, D, S** segments of the sector.

- Coordination of **investment and operations**:
  - Location and timing of investments in power stations and transmission lines.
  - Timing of maintenance of outages on power stations and transmission lines.
  - Coordination of the development and operation of power plants.

Model 2 – Single buyer is responsible for buying or producing electricity



- Here, a single buyer is responsible for procuring or producing all electricity.
  - Single buyer normally owns and operates the transmission network.
  - Single buyer may own and operate distribution and retail supply, selling directly to end consumers. Or, single buyer sells bulk power to separate distribution and retail firms.
- This model has been seen since 1978 when US utilities were required to buy power from other producers if the cost was below the utility's own avoided cost.
- Model 2 is common in Africa today.

- Model 2 allows for **competition in generation**.
  - Generation companies compete **to sell to the single buyer** – competing in the construction and operation of power plants.
  - Competition is normally through bidding the terms in a long term contract before building the power station. The contract is called a power purchase agreement (PPA). **Long term contracts are needed because of the hold up problem**.
- **PPA defines the rights and obligations of the generator and single buyer**. Normally the PPA would define two payments:
  - **Energy payment**, designed to cover the variable costs of producing each MWh (e.g. fuel, some maintenance); and
  - **Capacity payment**, designed to cover the fixed costs of the plant (capex and some operating costs such as labour, insurance etc.). A minimum annual volume (take or pay volume) of energy purchased is sometimes used in place of a capacity payment.

Model 2 – Why move away from vertically integrated monopoly to a single buyer?

Technology change

- Smaller and cheaper power plants such as combined cycle gas turbines (CCGTs) were developed in the 1980s. This reduced economies of scale in electricity generation, allowing smaller firms to develop and operate power plants.
- Wide-spread transmission networks increased the size of the market relative to the efficient size of generators, allowing for competing firms.
- Improvements in information technology allowed better coordination between disaggregated parts of the sector, allowing vertical and horizontal unbundling.

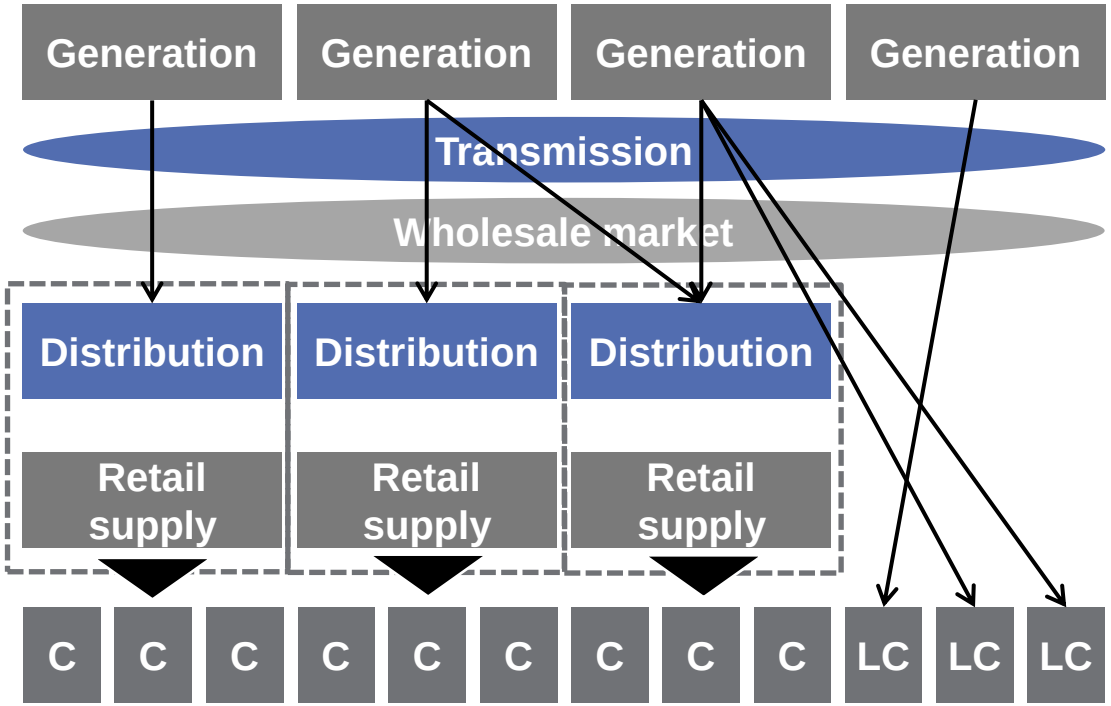
Competition in generation is important

- Generation is the most important segment of the sector in which to introduce efficiency gains and hence competition:
  - Generation investment and operating costs are typically 50% or more of total power system costs.

Donors are working in many countries in Africa to get Governments to introduce effective competition in generation:

- The single buyer or Ministry of Energy develops a long term least cost generation plan.
- The single buyer uses tenders to contract with independent power producers (IPP) in line with the plan. In other words, the single buyer (or Ministry) decides what type of power plant to procure and when to procure it.

Model 3 – Wholesale competition allows for competing large buyers and sellers of electricity



- Model 3 introduces competition at the wholesale level.
  - Distribution / retail supply firms and large customers connected directly to the transmission network are free to choose their wholesale supplier.
  - Generators compete as wholesale suppliers to serve distribution / retail supply firms and large customers.
- In 1990, the UK moved from Model 1 to something similar to Model 3 with the introduction of the Pool (customers >1MW were free to choose their supplier).
- In 1992, the Energy Policy Act gave US distribution / retail supply firms and large customers the right to choose their supplier.

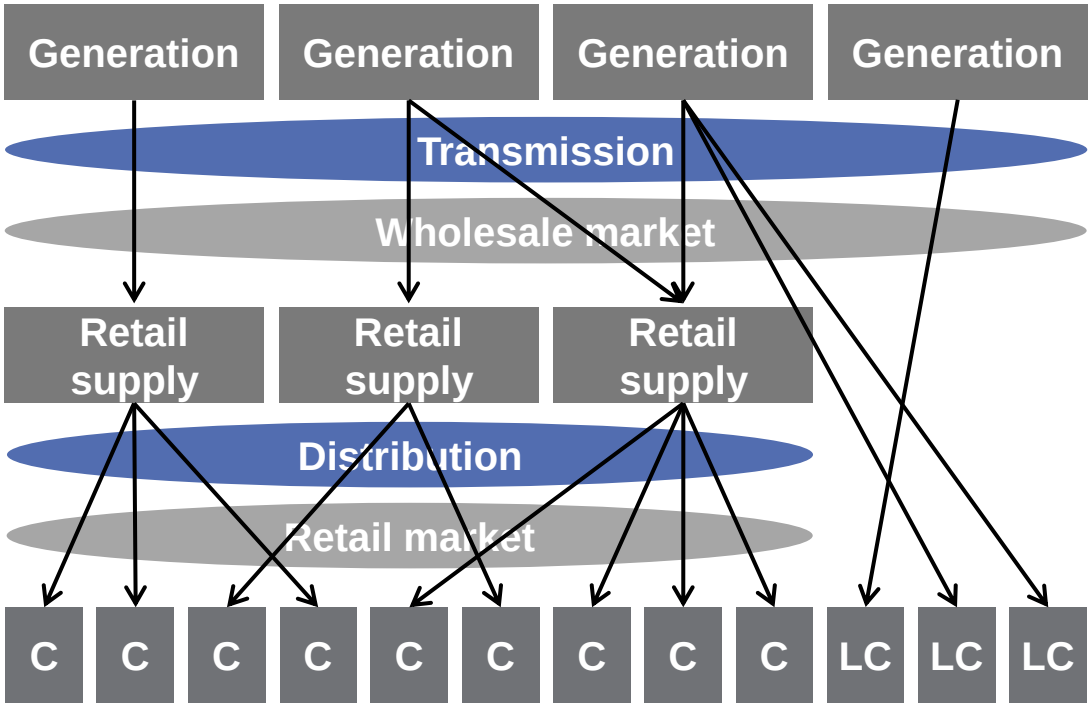
- This model allows for more competition in generation – generators take on more risk and take more decisions.
  - Generation companies compete to sell to distribution / retail supply firms and to serve large customers (LC).
  - Generators compete in the choice, construction and operation of power plants.
- With multiple buyers and sellers, long term contracts aren't needed to guarantee access to the market for generators.
  - A spot or short term wholesale market is organised into which generators sell electricity and retail suppliers buy electricity on a 15, 30 or 60 minute basis (more on this later).
  - However, long term contracts *may* be used for risk management.

Model 3 – Why move away from the single buyer to wholesale competition?

Increase competitive pressure on generation

- Generators compete regarding the choice of fuel and type of power station, in addition to competing regarding construction and operation.
  - Some market risk is taken by generation companies.
  - Increases pressure to make efficient choices of fuel and plant type, and when to build a power station.

Model 4 – Wholesale and retail competition



- Model 4 has competition at the wholesale and retail level.
  - Generators compete to serve retail supply firms and to serve large customers.
  - Some or all customers are free to choose their retail supplier.
  - This model may have vertically integrated distribution and retail supply firms (here we show them as separate).
- This market model is used in liberalised power markets in much of the world. Examples of countries with retail choice for all customers
  - New Zealand (from 1994, in practice later), GB (1999), Australia (2002), Norway (1997), EU (Directive 2003/54/EC required most EU Member States to fully open their retail markets by 1 July 2007), parts of the US.
- This model allows for competition in generation and retail supply.
  - Generation companies compete to sell to distribution / retail supply firms and to serve large customers.
  - Generators compete in the choice, construction and operation of power plants.
  - Retail suppliers compete to sell to customers.
- With multiple buyers and sellers, long term contracts aren't needed to guarantee access to the market for generators and retail suppliers. However, long term contracts are often used for risk management.

Model 4 – Why move from only wholesale competition to wholesale and retail competition?

Increase competitive pressure on retail supplier

- Multiple retail suppliers and ability of generator to bypass retail supplier increases pressure to:
  - Operate retail supply business efficiently (but smaller efficiency gains to be made since retail supply is lower value added than generation)
  - Procure generation efficiently; and
  - Pass through competitive generation costs to customers.

Summary of where competition takes place in each model

1. Vertically integrated monopoly decides what to build and when. It could procure construction of power plants and transmission lines etc. competitively.
2. Monopoly buyer runs tenders to procure generation introducing competition for the construction and operation of generation through long term power purchase agreements (PPAs).
3. Generators compete to sell electricity to distribution / retail supply firms and to very large customers. Short, medium and long term contracts may be used to manage risk.
4. Generators compete to sell electricity to retail supply firms and to large customers. Retail suppliers compete to sell electricity to small customers that are eligible to switch supplier.

We also see a mix of models, e.g. the utility generates its own power and only occasionally buys emergency power from independent power producers (IPPs), only large customers may choose retail supplier, etc.

- Typically competition law is relied upon to protect firms and consumers where competition exists.
- Regulation is needed to protect firms and consumers where competition cannot or does not exist or if competition law is considered inadequate.

Which market model is best?

Developing countries

- Focus tends to be on security of supply and generation adequacy. Competition in generation provides the biggest scope for efficiency gains.
  - Model 1 (with competitive tenders for construction of power plants) or Model 2 are usually preferred.
  - Model 2 has the advantage of using IPPs to organise construction and financing of power plants where the utility has limited financial or human capital.

Developed countries

- The sector normally has several objectives that need to be met: economic efficiency, security of supply and environmental sustainability.
  - Model 3 or Model 4 is preferred, relying more on competition to provide efficient outcomes.
  - Europe, Australia, and New Zealand use Model 4, where the benefits of retail competition are assumed to outweigh the costs of retail competition.
  - Several parts of the US use Model 3 where most customers cannot choose retail supplier and end user tariffs are regulated.

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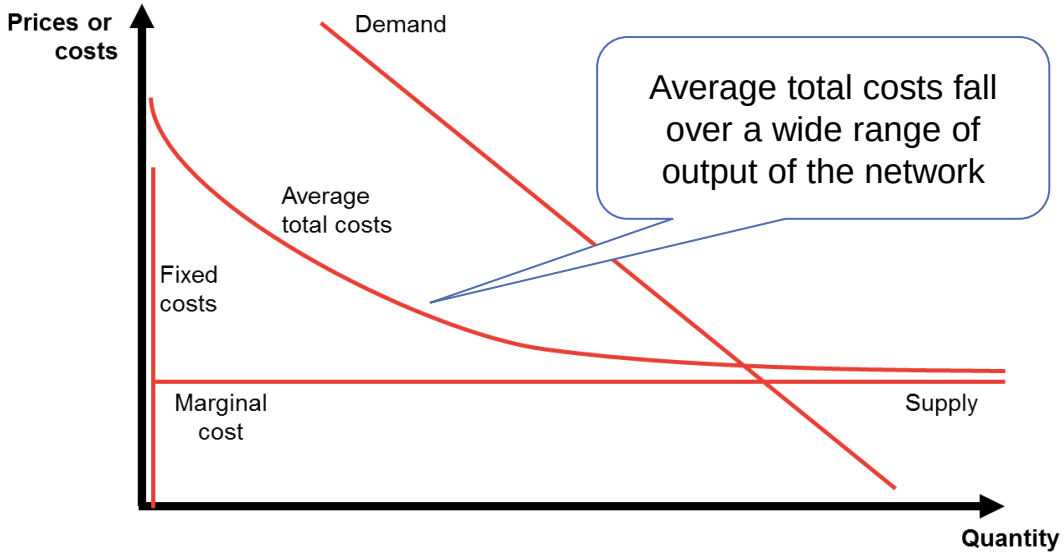
Electricity **transmission and distribution networks** have characteristics of a natural monopoly

Economies of scale

- Average total costs fall as production increases.
  - Fixed costs are spread over more units of output.
  - Variable costs may fall with increasing scale.

Characteristics of electricity T&D networks

- Large fixed costs in establishing the network.
- Low marginal costs of connecting one more generator or customer.
- Low marginal costs of delivering 1 MWh more electricity to existing customers. (If the network is not congested, the additional cost relates to the marginal increase in losses on the network, which could even be negative).



An **electricity network is a natural monopoly**

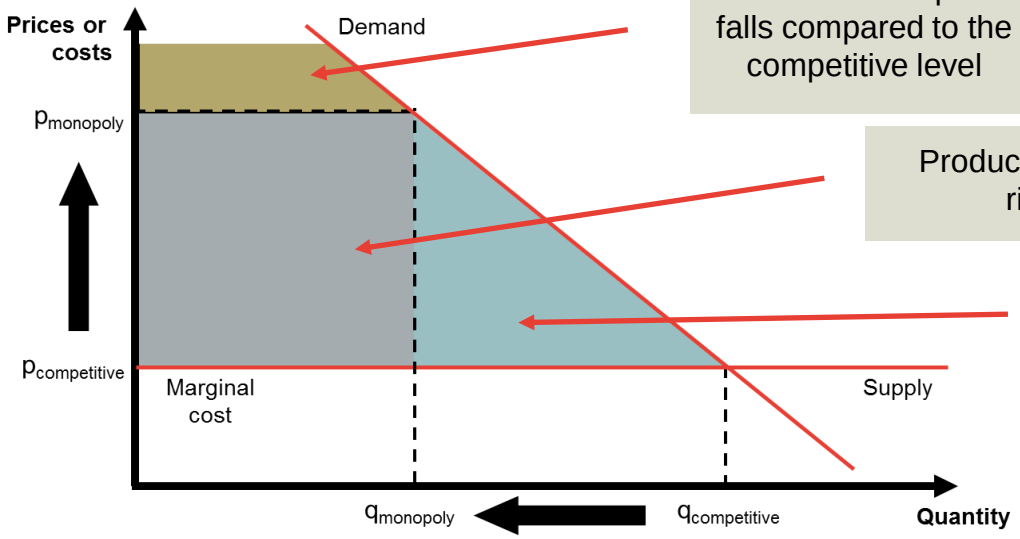
It is not economically efficient to duplicate the network in a given region

The topics discussed in the remainder of the slides can be found in many books about power sector economics, e.g., Stoft, Biggar

An unregulated natural monopoly could price above the competitive level, reducing economic efficiency (welfare loss)

In the case of an unregulated network company

- Average total costs of incumbent network are lower than costs of an actual or potential (smaller) entrant.
- This means the incumbent network is free to price network use above the marginal cost and at the lower of:
  - a little under the average total cost of the potential competitor; and
  - the monopoly level.
- Pricing like this deters entry to the network business while reducing consumer surplus (welfare).



Consumer surplus falls compared to the competitive level

Producer surplus rises

Social welfare falls by the area of this triangle

- Prices are higher than the efficient level
- The quantity of network services consumed is below the efficient level
- Quality of service may be lower than the efficient level

… therefore transmission and distribution networks are typically regulated with respect to prices, quality and access

The sector has peculiar technical characteristics that affect how **generation** and **retail supply** markets work (1/3)

Injections into and offtakes from the network must be closely balanced at all times

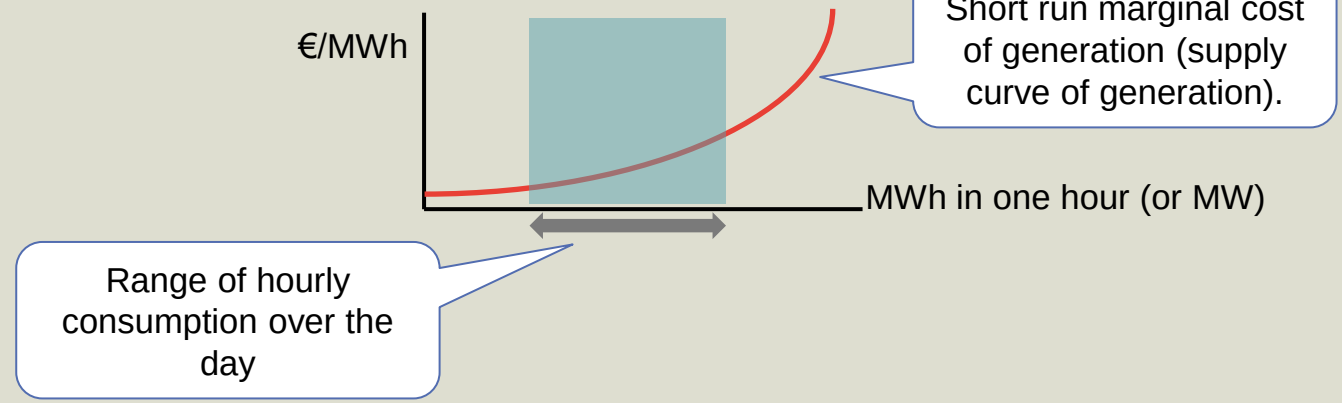
Large scale storage of electricity is very expensive

- Electricity injected onto the network and electricity taken off the network **must be closely balanced at all times**.
  - Excess generation supply causes the system frequency to increase and excess load causes the system frequency to fall.
  - The power system needs to react very quickly, within fractions of a second, to balance supply and demand.
- Parties cannot trade on a bilateral basis in the timescales required to manage supply and demand.
  - A **system operator is needed to manage the supply and demand** on the transmission and distribution network.
  - **Rules are set ex-ante**, specifying how this is achieved.
    - Rules place obligations on generators, loads (customers) and the transmission system operator.
    - Rules are normally established in a grid code and a market or balancing code.
    - The codes are complex legal, commercial and engineering documents that are sometimes available on the internet.

The sector has peculiar technical characteristics that affect how generation and retail markets work (2/3)

The value of electricity varies from second to second within each day (normally prices are set each 5, 15 30 or 60 minutes in the wholesale market).

- The short run marginal cost of production and therefore the value (marginal cost) of electricity varies within each day.



The generation supply curve may also vary during the day with availability of wind and sunlight, and breakdowns of power plants.

The sector has peculiar technical characteristics that affect how generation and retail markets work (3/3)

Demand is inelastic, at least in the short term

- **Users value electricity highly**.
  - It is a derived demand, often being a relatively low cost input into processes that are highly valued, for example, charging phones, watching TV, washing clothes, and cooking.
  - Electricity is difficult to substitute for many uses, particularly high value uses.
- Consumers **cannot respond to price in real time**.
  - Few consumers have real time metering of consumption (increasing with smart meters).
  - Even those with real time consumption metering may not receive the consumption *information* in real time.
  - Consumers may receive price information after the event although they may be able to respond using short term forecast prices. But, consumer response times are far longer than needed to match supply and demand on the power system.

It is not practical to match the consumption of an end user and its supplier's output (and vice versa)

- The **power system is a network** connecting generators with end consumers
- It is **not practical to precisely match** the amount of **electricity taken** by a consumer **with the output from generators** with whom they have contracts.
  - When a generator unexpectedly stops running, end users with contracts to buy electricity from that generator (directly or indirectly via retail suppliers) continue to consume electricity.
  - Given advances in IT (e.g. blockchain), it is technically possible to link consumption to specific power station output. However, a more efficient market outcome is to trade so that those consumers who value electricity most continued to consume and those generators whose short run marginal costs are lowest continue to run. But, buyers and sellers cannot agree bilateral trades in the short timescales required to match supply and demand.

Implications: wholesale and retail market competition is possible but there must be **managed competition**

- Injections and offtakes must be closely balanced at all times
- Large scale storage is impractical
- Value of electricity varies over time
- Inelastic demand
- Impractical to match individuals' consumption and supply

A System Operator is required to maintain the system balance

- It is impossible for generators or end users to trade or respond to a centrally set price sufficiently quickly to maintain the injections and offtakes in balance.

A centrally organised settlement system is required (Market Operator, MO)

- With wholesale competition (and therefore third party access to the network) there must be arrangements in place to settle (i.e. pay or be paid) the differences between what a generator injects onto the system and what it has contracted to sell, and what a customer (or by proxy its retail supplier) takes off the system and what it has contracted to buy, in short timescales.
- Imbalances are inevitable and the price paid or received should reflect the value of electricity at the time (marginal cost of generation or willingness to pay by a consumer not to be cut off).

An administratively set price is required when demand exceeds supply

- Most consumers cannot choose not to take electricity when prices rise very high in the short term.
- Some wholesale markets set price equal to the Value of Lost Load (VoLL) during periods when consumers are involuntarily disconnected due to a lack of available generation.
- VoLL should be set equal to the price at which consumers are indifferent to consuming or not.

Electricity system is susceptible to market power

- If a generator causes price to increase, the lack of demand side response means the quantity supplied by that generator only falls to the extent other sources of electricity are available.
- Wholesale and retail electricity markets may be more susceptible to market power than other sectors (which have storage, do not need real time balancing and have demand response).

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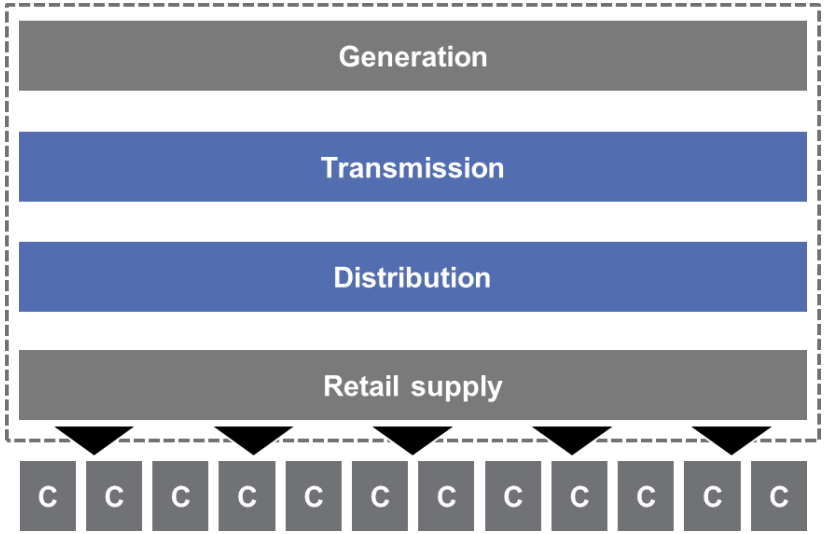
Over time and with technological change, the view as to the efficient organisation of the different markets within the sector has changed



Regulated monopoly (Model 1)

Recently, the environment has been increasingly important for market design, with elements of central planning / single buyer introduced to generation procurement to meet environmental goals.

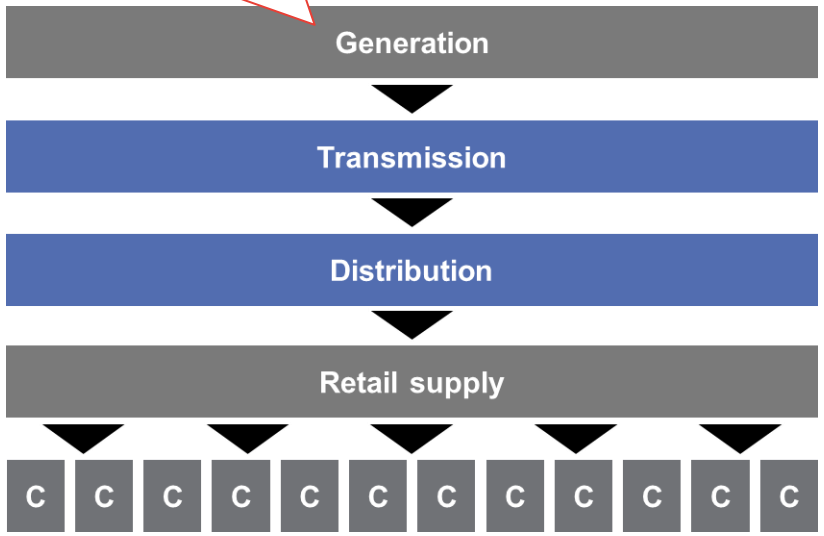
Model 3 or Model 4

Potentially competitive

Regulated

Regulated

Potentially competitive



Power sector liberalisation / deregulation started ~40 years ago and is now widespread throughout Europe, North and South America, Australasia, parts of Asia …

1978 USA

US Public Utility Regulatory Policies Act (PURPA) forced utilities to buy power from other producers if below their own avoided cost.

1980s Chile

Chile pioneered power sector liberalisation with unbundling and the introduction of competition.

1990 Great Britain

GB unbundled the Central Electricity Generating Board (CEGB) into competing generators and a separate transmission company, and established the wholesale pool. Over the following 10 years GB unbundled retail supply and distribution, introduced retail competition for all consumers and privatised the sector.

1996 USA

US Energy Policy Act gave large end users the right to choose their retail supplier, and forced networks to give third party access to retail suppliers.

1996 EU

EU introduced the first Electricity Directive which took steps towards unbundling of networks and the introduction of retail competition. The second (2003) and third (2009) Electricity Directives required stricter network unbundling and full retail competition, and provided for better coordination of the power sector between countries. The Clean Energy Package will add to the existing legislation.

1990s Other

Other countries liberalised their power sectors, including Norway, New Zealand and Australia.

2000 USA

California power sector crisis began where flawed liberalisation and market manipulation led to a power shortage and bankruptcy of retail suppliers.

The England and Wales (later expanded to Scotland) power sector reforms are an interesting case study, with many publications

1990

CEGB broken into one nuclear generator and two other generation companies and a transmission company (owned by the RECs). Distribution and retail supply kept bundled in 12 regional electricity companies (RECs). RECs privatised. Wholesale trade made through a gross power Pool. Only large customers (<1 MW) could choose retail supplier. Vesting contracts kept coal plants running and passed on excess costs to RECs.

1991

Two non-nuclear generation companies privatised.

1994

Retail choice extended to customers over 100kW. Investigation by regulator gets agreement from two generation coys to sell 6 GW of capacity and cap offer prices into the Pool.

1995

Transmission company unbundled from the RECs and privatised. Government's 'golden share' in each REC (preventing ownership change) was removed.

1996

Newer nuclear plants privatised. Older magnox nuke plants kept in state ownership.

1998

Full retail opening.

2001

Pool replaced by NETA, a bilateral contracts trading model.

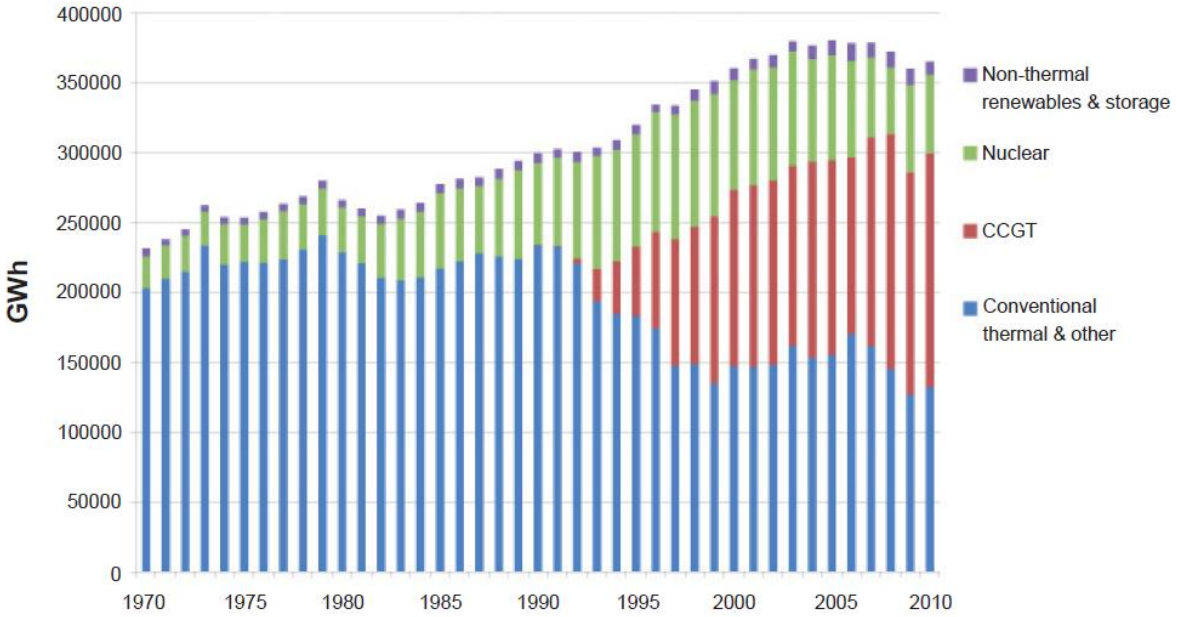
2005

NETA replaced by BETTA – extending the wholesale trading arrangements from England and Wales to include Scotland.

2014

Capacity mechanism introduced, for first delivery of generation capacity in winter of 2018/19.

Is restructuring the sector is worthwhile? Newbery concluded the E&W power sector reforms were worthwhile.



- The main benefits of liberalisation came from …
  - Replacement of coal fired generation by gas fired generation. In 1984/85 over 240,000 coal miners were employed in England and Wales. By 1994 this had fallen to 7,000.
  - Abandoning the nuclear generation expansion plan in 1996.
  - Operating cost savings.
- The main costs came from …
  - Paying a higher price to France for electricity imported to Britain.
  - Restructuring costs.

TABLE 1 THE NET BENEFITS OF PRIVATIZING THE CEGB RELATIVE TO TWO COUNTERFACTUALS, 1995–2010
(£ billions at 1994–95 prices; at a 6 percent discount rate, discounted to April 1995)

	Relative to proprivatization counterfactual	Relative to pro-CEGB counterfactual
Fuel and investment effects		
End of nuclear expansion program	3.3	2.8
Effect on price of French imports	–2.6	–1.5
Net fossil fuel costs	2.9	–2.1
Total	3.6	–0.7
Externality benefits		
Reductions in sulfur dioxide emissions (£125 per metric ton)	1.0	0.7
Reductions in carbon dioxide emissions (£12 per metric ton of carbon)	1.4	1.2
Total	2.3	1.9
Restructuring		
Costs	–2.8	–2.8
Cost savings	8.8	7.6
Total	6.0	4.8
Total net benefits	11.9	6.0
Total net benefits (pence per kWh)	0.21	0.09

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