Utilities Primer

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Mats Larsson, August 25, 2018

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8.1 Introduction

Definition

A utility is a company that produces and/or provides electricity, gas or water or handles waste. Electricity utilities, more commonly called power utilities, generate power, manage power transport networks and supply end users with electricity. Prior to the deregulation of the power utility industry all this was handled by the same often publicly owned organization – an integrated utility. Today, many markets are deregulated and this has split up the value chain in separate companies, although there are some integrated companies left. As parts of the power utility business are natural monopolies, regulation is a dominating factor.

Our long-term view

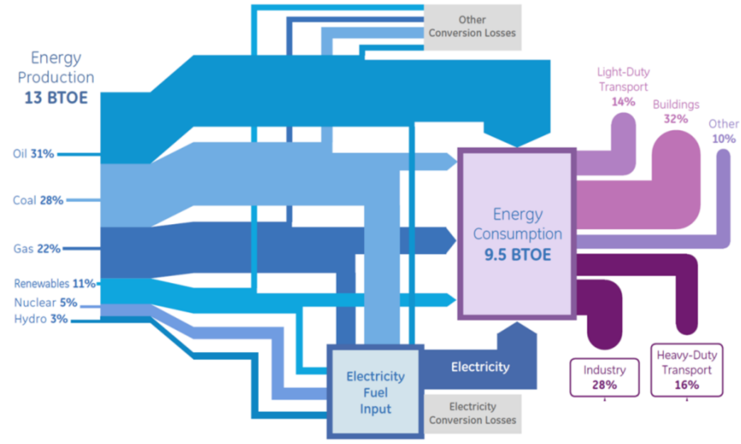
Our long-term view of utilities stocks is rather muted. The combination of slow growth due to peaking populations, a less energy intensive GDP-mix and energy efficiency measures has left the energy usage in the OECD area unchanged for over a decade. At the same time distributed generation of wind power and especially solar risk introducing a negative spiral of lower volumes and declining competitiveness for the conventional, high fixed cost power generation plants and power networks. The key to the disruption is the exponential cost improvement for solar and the caveat is the development of electrical vehicles.

A large part of the energy flow

Below are two pictures describing the global energy flows of which electricity production is a large part. Looking at the box "Electricity Fuel Input" in the bottom of the picture below from General Electric, it is evident that the main inputs in making electricity are coal and natural gas. Nuclear, hydro, oil and renewables are smaller inputs on a global scale but could regionally be very important. The picture is from 2011 and although changes in power generation are slow, renewables have made meaningful inroads in certain regions the last few years.

Picture 8.1. Global Energy Flows 2011.

BTOE – Billion tons of oil equivalents



Source: General Electric

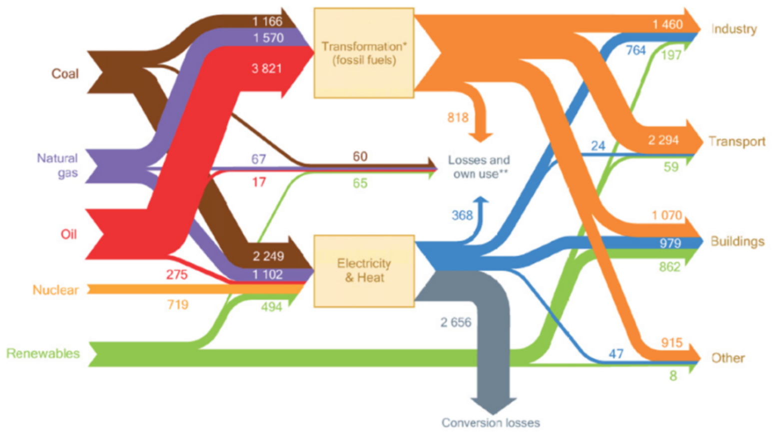
Conversion losses

What is also evident from the picture above is the huge amount of conversion losses in electricity production where energy is turned into heat. In the total system almost ¼ of the energy is lost and the conversion processes in power plants is a major contributor to this. In EIAs 2013 estimate in the picture below the conversion losses in power generation are about 59 percent or 2.656 Mtoe. This is a larger number than the entire energy usage for transport. Other analysts estimate that conversion losses are even larger than this. It is also evident that electricity predominantly is used for a) lighting, heating and cooling of buildings and powering of the appliances in buildings and b) for industrial production. What is also apparent in the picture is that the main use of oil is as fuel for vehicles.

An interesting footnote: only about 35 percent of the energy stored in gasoline is converted into forward motion in a car with an internal combustion engine – the rest is converted to heat and noise. Tesla Motors claim that their Tesla Roadster Sports has an efficiency of 88 percent thanks to the very few moving parts in the electric motor. Say that the conversion losses in producing electricity are 60 percent, then the overall energy efficiency of the Tesla is 0.4 * 0.88 = 35 percent. Fancy that.

Picture 8.2. The Global Energy System (Mtoe) 2013.

Mtoe – Million tons of oil equivalents



Source: EIA

It starts at JP's place

Power utilities today is a natural part of everyday life taken for granted to "keep the light on" but their history is actually not more than 140 years. The story starts with Thomas Edison in 1882 turning a switch at 23 Wall Street, Manhattan, NY and by this lighting 200 light bulbs in the office of John Pierpont Morgan. The power came from a small coal fired generating plant a few blocks away. Edison started to develop a number of power plants spread out over Manhattan to enable the lighting of offices and homes of the affluent.

Thomas Edison, Nikola Tesla and General Electric

However, the limited traveling distance of Edison's direct current technology created the need for power generation plants on every second block. George Westinghouse, who had bought a patent from the Serbian inventor Nikola Tesla, could solve this by offering alternating current that traveled longer, allowing for centralization of the generation and scale benefits. Edison had to admit defeat and his company was merged into Westinghouse's and was renamed General Electric.

In the traditional US manner a vast range of small electric utilities sprung up to provide high paying clients with the luxury of electric lighting. Quickly the business spread to the UK and some major European cities, notably Berlin where Werner von Siemens and Emil Rathenau had acquired the European rights to Edison's inventions. Rathenau and von Siemens would later fall out and start Allgemeine Elektrizitäts Gesellschaft - AEG - and Siemens to compete for customers.

Samuel Insull

However, the real founding father of the power utility industry is rather Samuel Insull. Insull had been instrumental in managing Edison's power business and when he didn't get to lead the newly formed General Electric he instead went on to lead Western Edison Light Co in Chicago. During a trip to Brighton, UK he stumbled on the invention of metering as a way to charge for power. Importing this idea of payment for consumption volume, Insull took the industry from being a luxury for the few to something for the great masses.

A politically versed person, Insull realized that this type of business when extended to the general public would come to catch the eye of regulators. Arguing to Chicago officials that the industry was a natural monopoly and that increased scale would give lower prices for consumers, Insull was given the permission to consolidate the industry in return for allowing his company to be regulated to make sure that his company would serve the interest of the public. Network effects arise from interconnecting customers that diversify each other's load patterns and by spreading a fixed generation plant cost over larger volumes. An integrated utility can optimize the entire value chain without transaction costs between the steps in the chain.

The regulated natural monopoly

By this, much of today's business model was set. Using a huge amount of leverage Insull set off to repeat the trick over the rest of the US, creating a vast empire of integrated power utilities spreading the business model nationally at a remarkable speed - only to see his small equity being wiped out by the great depression. In many states the power utilities now came into public hands.

Leverage works both ways

Helped by the security of the regulated returns in the industry, the grid over time expanded from the metropolitan areas to cover larger geographies and eventually networks were connected to each other. A larger network is connected to more customers and to more generators, smoothing out supply and demand even further. It also opens up to the opportunity of doing price arbitrages.

Picture 8.3. Insull and Thatcher: Shapers of the Power Industry

One consolidator and one disintegrator

Source: wikipedia.org and britannica.com

The industry would be relatively unchanged for four decades and with increasing demand it grew in size but also in bureaucracy and inefficiency. British Prime Minister Margret Thatcher set off on a major privatization of UK industries to foster competition and drive down prices for consumers. The state owned Central Electricity Generating Board was broken up into three generating companies and a grid. Each step of the value chain got separate regulation to allow for competition where possible – mainly in the initial power generation and in the retail offering to end-customers. This then set the scene for deregulation of most of the European market and parts of the US, but so far less so for Asia.

The first step in the US was to deregulate the wholesale market for electricity and force the integrated utilities to allow independent power producers with non-discriminatory access to the grid. With retail prices still regulated, this later resulted in massive losses for utilities when the wholesale prices rose up to 10 times the retail level and caused gigantic blackouts in California in 2000 and 2001. Utilities either were reluctant to sell at a loss or went bankrupt. The California blackouts pretty much drew the US deregulation to a grind in the midst of the process. The US market structure is still highly fragmented and diverse as regulation varies by state and areas vary from being almost totally deregulated to hosting one publicly owned or co-op owned monopoly utility. This would be today's situation if not for the rise of renewables as a source of power that again is causing industry to change rapidly.

Deregulation stopped halfway by California blackouts

In 1978 the US approved a regulation that would become of utmost importance for the development of renewable power generation. Utilities were required to buy power from independent power generators. This created a market for a host of solar power companies whose fortunes varied with the oil price cycles but that by the early 2000's had pretty much all expired. The focus had now instead turned to wind power. In 1999 George W. Bush had mandated utilities to purchase a certain amount of renewable power, kick starting a boom-bust cycle in clean tech and what became called the Texas Wind Rush and the California Wind Rush. Several states subsidized the building of new wind parks. The quality of the wind turbines was however poor so they didn't deliver much power and this wasn't solved until Danish technology from Vestas was introduced. In the late 1980s about 90 percent of US wind power was generated on Danish turbines. As with all booms, there came a bust and then the market came back again supported by the now infamous Enron.

Renewables enter the stage

Japan with little internal access to hydrocarbons in 1979 decided to diversify its energy supply sources to liquefied natural gas, nuclear and renewables after the second oil shock. With its knowledge in semiconductors Japan quickly turned into the early dominant in solar cell manufacturing. In Germany the Green Party since long has had a strong position and with the nuclear accident in Chernobyl Germany introduced the type of feed-in-tariffs that had previously been implemented in the US. These tariffs by favorable pricing effectively subsidized renewables to be able to compete successfully.

Japan and Germany

Germany now became the world's largest solar power market. Their position was soon to be overtaken by a giant in the east – China. With its meteoric rise in wealth China is now "the largest" in a number of areas and this includes both the use of coal as well as renewable power. Further, a Chinese investment frenzy caused a massive overcapacity in solar cell production that destroyed the economics of the industry - but on the other hand lowered prices with 80 percent over just a few years.

Germany & China

We talk about electricity as something obvious, but what is it really? Let's go through some basic physics. Electricity is a form of energy, identified as a flow of electrons. It's measured in Ampere, often shorted to Amps. An atom consists of a core of protons with a positive charge and neutrons with neutral charge. To balance the charge of the protons there are further electrons with a negative charge surrounding the core. Some electrons can be disconnected

What is electricity?

from the core if disturbed by an outside force. Electric current are disconnected negatively charged electrons flowing in one direction through a conducting material to reach a point with positive charge. The speed of this wave of electrons is an impressive 100.000.000 m/s.

Voltage

There are two parameters that decide how much electric current will flow through a conductor – the voltage and the resistance. The voltage is the difference in electrical potential between two end points on an electrical circuit such as an electrical cable. The larger the difference in positive and negative charge the larger the tension between them and the larger the electrical potential. An analogy might be pressure on something. That is, “the pull” on the electrons increases if the difference in positive and negative charge of the two points increases.

Resistance

The resistance is what it sounds like; it’s the amount of difficulty for the electrons to travel in the conductor. A higher resistance will reduce the electric current that reaches the receiving end of an electrical cable. The cables and the components in the electrical circuit hinder the flow of electrons as the electrons bounce off the ions (positively charged atoms) in the conducting material. This slows them down and makes them loose energy which is instead transformed to heat. This is a major industry problem when it comes to transporting electricity over longer distances. A longer electrical cable will have higher resistance, as there are more collisions along the way than in a shorter one. A thinner electrical cable will have higher resistance, as there is less space for the electrons to spread around the ions. Further, some materials will have higher resistance than others.

Picture 8.4. Electrical Parameters – Ohm’s Law

“It’s not the volts that kill you, it’s the amps.”

Electrical Parameter	Measuring Unit	Symbol	Description
Voltage	Volt	V or E	Unit of Electrical Potential **V = I × R**
Current	Ampere	I or i	Unit of Electrical Current **I = V ÷ R**
Resistance	Ohm	R or Ω	Unit of DC Resistance **R = V ÷ I**

Power

Now, so-called power is measured in watts (W) and is the “rate of work” the electrical current performs during a second. There is for example an amount of work required to turn the blades of a fan or to light a light bulb. The power transmitted (P) is given by P = I * V (equation 1). That is, for a fixed amount of power transmitted a higher voltage gives a smaller current, or I = P / V (equation 2). For a fixed amount of power transmitted P, the current is inversely proportional to the voltage V.

Power loss

The power loss by heat (P_{loss}) on a segment of wire with a resistance R is given by $P_{loss} = I^2 * R$ (equation 3). The power loss is proportional to the square to the current, i.e. a smaller current (I) reduces heat loss. A smaller current in relative terms can be achieved by using a high voltage, everything else alike. The effects from cranking up the voltage can be seen in equation 2. Sorry for bringing back memories of old physics classes but the conclusion is that if you want a low energy loss in electricity transmission the cable should be of the right material, it should be fat, short and use high voltage. In the power grid the short part isn't really optional though.

kWh – Kilowatt-hour

Not surprisingly for anyone keeping track of their broadband speed, 1.000 watts are called kilowatts (kW), 1.000.000 watts are called megawatts (MW), 1.000.000.000 watts are called gigawatts (GW) and finally 1.000.000.000.000 watts are called terawatts (TW). The electricity bill will be expressed in the amount of used power during a period of time, namely an hour, and the usual unit of measurement unit is kWh. The generating capacity of a power plant is similarly measured in MWh.

An electric current that flows in one direction only is called direct current (DC), distinguishing it from alternating current (AC) where the flow periodically reverses direction. The periods in questions are milliseconds. The most common method of transporting electric current is as AC since the voltage here can be adjusted by a transformer to the higher volts that overcome the resistance of the conductor and allow for efficient transmission of large volumes.

A versatile generic commodity

Electricity is a so-called secondary source of energy as it comes from the conversion of other primary sources of such as coal, natural gas etc. Electricity as a product, the flow of electrons, is a generic commodity that is very versatile in its use and exactly the same irrespective of the underlying energy source that generated it. These generic qualities make it hard to differentiate electricity as a product – the quality is always the same (given the same frequency).

Alas, the power utilities sell power for a time period (kWh) but the actual commodity produced and transported is electrical current, i.e. electricity. The oft-used convention in the industry is still to call this flow of electrons for "power" – perhaps because it sounds cooler. We'll similarly use the concepts somewhat intermittently in this text.

The Value Chain

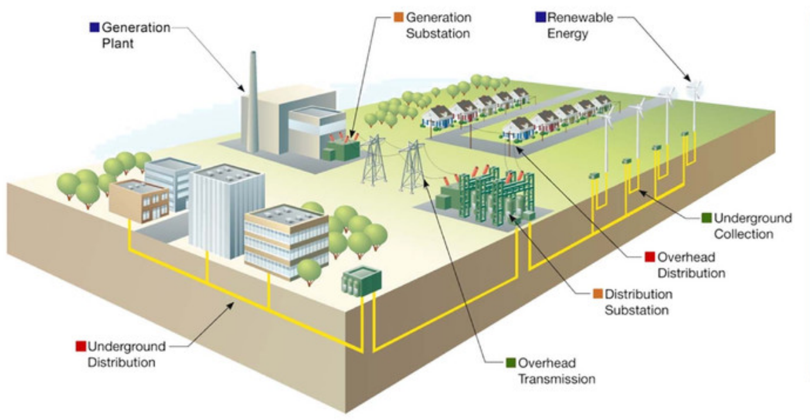
- Generation
- Transmission
- Distribution
- Supply

The power utility value chain follows the flow of electricity and can be segmented into 1) Generation: power generation in power plants, 2) Transmission: power transmission through high voltage long distance wholesale networks, 3) Distribution: power distribution to end customers in lower voltage networks covering geographical zones and 4) Supply: packaging, marketing and billing of electricity. Each part of the value chain has its own character and business model. In Europe the 4 segments are generally clearly separated. Most companies only operate in one or two segments but a few large companies populate them all. In the US, most utilities are still integrated but have completion from independent generators and in all cases distribution and supply is handled by the same operator. The setup and regulation differs between regions, in some markets retail prices will be regulated and in some not.

The flow of electrons

Below we can follow the electricity flow from the power generation plant through a generation substation that makes sure the voltage is suited for the transmission network, the transmission network then terminates in a distribution substation that through a so-called transformer lowers the voltage for further transport in the distribution network. Some of the distribution is underground while some is above ground via powerlines fastened on telephone poles and the like. Not visible in the picture, a transformer on a pole steps down the voltage further for home usage. The distribution substation in the picture is also a collector substation as it collects the so-called distributed power generation from a wind farm.

Picture 8.5. The Value Chain



Source: Wesco

A mesh with redundancy

The above picture is in many aspects a misrepresentation of how the power grid actually looks. It is simplified and much too linear. In reality the physical value chain is a mesh of lots of generation plants all over an area, all substations are connected to several transmission lines to allow for redundancy and each area is connected to other areas creating a vast web of interconnected area networks importing and exporting power. Further, there are a number of adjacent service companies along the value chain, of which the trading hubs might be the most important ones as they facilitate the wholesale trade in electricity.

8.2 Generation

Energy to power

In generation the energy in a primary source is transformed into power. By the post-Thatcher deregulations, power generation was separated from the networks of the grid. Thus, in many markets different power generators compete on selling power into the grid to a price set on a wholesale trading market.

Operating range

All power plants have an operating range spanning from their required minimum power generation output to the maximum. The operating range depends on technology. If not closed for refueling or maintenance a nuclear power plant always produces close to maximum capacity. Similarly, a coal-fired plant is expensive to start up so it also runs at a high capacity most of the time and thus has a relatively limited operating range. On the other side of the scale is solar and wind that produce nothing at times but quickly reach full capacity when the sun shines or the wind blows.

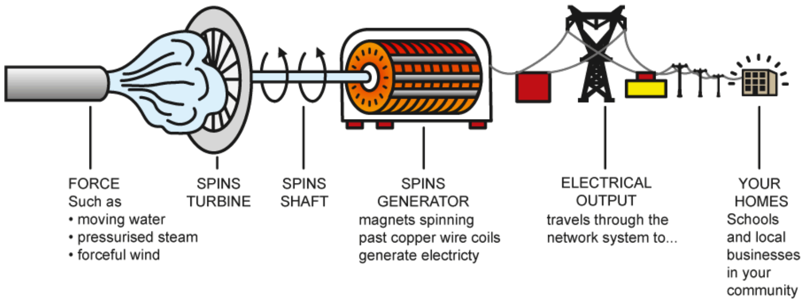
Ramp rate – the speed by which a generating plant can change output

A second feature of generators is their ramp rate, the speed with which they can adjust their power output – the power of the acceleration and the brake. Solar and wind change fast but the change cannot be controlled. Nuclear and coal has slow ramp rates. The plants that have quick ramp rates that also are so-called dispatchable and can be called for to produce when needed are oil fired and natural gas fired plants and hydro power plants. They are used to balance the network loads.

The generator

With few exceptions the below picture describes how electricity is generated. Some type of mechanical force spins the propeller-like blades of a turbine that in turn spins a connected shaft, resulting in a number of magnets being moved past copper wire coils in what is called a generator. This generates the electricity through what's called electromagnetic induction.

Picture 8.6. Electric Generator



Source: faqhow.com

Tearing away electrons

We previously learned that electrons can be disconnected from and escape the atom core if disturbed by an outside force. One such outside force is a magnetic field. The movement of the magnets will tear away electrons from the cooper coils creating an electric current. The faster the spin of the generator and/or the larger the magnet (i.e. the more powerful the magnetic field), the larger the generated volumes of electric current will be. In reality it could instead be the coil that is moving but the effect would be the same. Depending on the use of a commutator (that periodically reverses the direction of the current) or not the output will be direct current or alternating current. The essence of power generation is to keep a generator turning as fast, cheaply and reliably as possible.

It's (almost) all solar power

The forces that are used to spin the turbine are principally of two kinds that both in the end emanate from the energy released from the sun. Either the force comes through blowing wind or flowing water in nature or it comes from the process of boiling water in a so-called boiler to create pressurized steam that spins the turbine in a steam electric plant. Steam is a convenient mechanical force as it can be recycled and reused as it circles back and forth between gaseous and liquid states. So, most of the power plant technologies described below are in effect just different ways of boiling water. Let's start with these water boilers.

Nuclear Power Plants

Nuclear fission

The deployment of nuclear power gathered speed after the 1970s oil crises. Steam is produced by nuclear fission. A nuclear reactor contains a core of nuclear fuel in the form of pins or rods, primarily made by enriched uranium. Uranium has to be enriched before it can be used for nuclear power. Natural uranium contains less than one percent of the unstable substance U-235. The concentration is increased to about 3 to 4 percent for the uranium used in power plants (about 90 percent in nuclear weapons). The low-enriched fuel is formed into pellets that are encased in metal tubes to form fuel rods.

The sun is a nuclear fusion reactor

In the core of the reactor the uranium atoms are bombarded with neutrons which make them split, releasing heat and more neutrons that will hit further uranium atoms. In a chain reaction controlled by so-called control rods a process of continuous fission takes place. The fuel rods are in more or less constant use until they are used up and replaced. About every 18 month the plant is shut down to replace a third of the rods in the core. This process is the only exception from the rule that the energy we use comes from the sun. The sun by the way is a giant nuclear fusion reactor – which is fortunate for us habitants of the Earth as nuclear fusion, in contrast to nuclear fission, creates very little radioactivity.

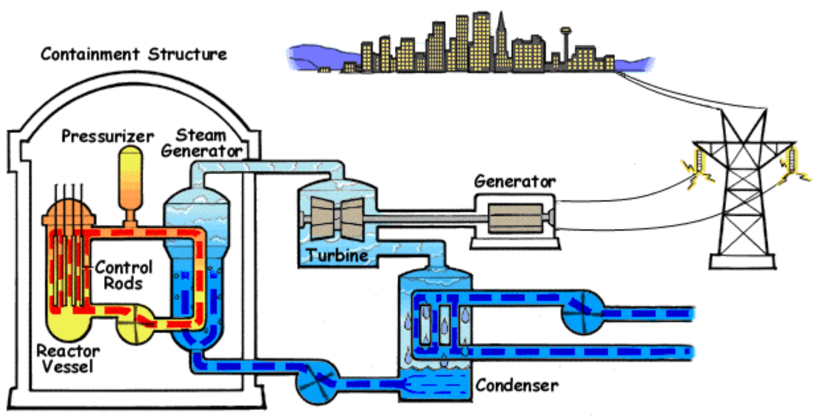
BWR – Boiling water reactor

PWR – Pressurized water reactor

The heat in a boiling water reactor (BWR) boils the water (called the coolant) into steam that turns the turbine. The steam then passes through a condenser to cool it into liquid water that goes back into the reactor. In a pressurized water reactor (PWR) high pressure prevents the water from boiling before turning into steam. Most of the energy will become heat and the conversion losses are about 65 percent. The external water going into the condenser in the picture below could come from a river, a lake or the ocean. If too hot it will be released as water vapor through a cooling tower instead of back into the sea. This water is in a closed-loop system and has never been in contact with radioactive material. The containment shown in the picture is the steel-reinforced concrete structure that separates the reactor from the rest of the world. Chernobyl's containment was basically non-existent.

Picture 8.7. Pressurized Water Reactor

Looks harmless enough…



Source: whatisnuclear.com/articles/nucreactor.html

To control the chain reaction in the nuclear core, neutron absorbing control rods made of cadmium or boron are inserted around the fuel rods. The rate of the chain reaction depends on the amount of control rods inserted and how far they are inserted into the core. The control rods can be moved in or out of the core and with all control rods fully inserted the chain reaction and the power generation stops. Changing the position of the control rods is a slow process giving the slow ramp rate of nuclear power.

The control rods

Building a nuclear power plant costs a serious amount of money, making it a capital intensive business with additional liabilities for the future dismantling of the plant plus the handling and storage of the radioactive waste. On the other hand, the marginal cost of the fuel and of running the plant is very low making the marginal production cost very competitive (not counting taxes, subsidies etc.) as long as other commodity fuel prices aren't too low. The energy content of uranium for nuclear power is massive. On an equal mass basis nuclear reactions release about 10 million times as much energy as many chemical reactions. Fission of 1 kilo of ${}_{92}U^{235}$ releases the energy equivalent to burning 2.700.000 kilos of coal. Uranium is also relatively abundant. The largest exporters are Kazakhstan, Canada, Australia and Russia.

High fixed and low variable cost

Nuclear power plants give countries internally produced power which is positive from an energy security point of view and the plants don't emit any CO_2. The countries with the largest amount of nuclear power capacity are in order the US, France, Japan, China and Russia. France generated over ¾ of its power through nuclear energy in 2014. Sweden was the sixth most nuclear dependent country in the world with 42 percent. Nuclear power should be used as a good stable generator of baseload power as the load factor is between 70 and 95 percent and the life of the plant is up to 60 years.

Nuclear power champ: France

Load factor = the average load as a percent of the maximum load during a period

On the other hand the risk for a nuclear meltdown or a terrorist attack is never zero, the handling of the nuclear waste is a major environmental issue making nuclear power highly political. Given that the security standards have been strengthened over time the construction costs for new nuclear plants have risen and construction times have increased. The yet to be commercialized generation IV reactors will use the previous nuclear waste as fuel, reducing the time of radioactivity of the material after the second iteration by a factor of 100:1. Further, these new reactors cannot have any meltdowns. Whether they will turn out to be economically viable is another issue.

The cons

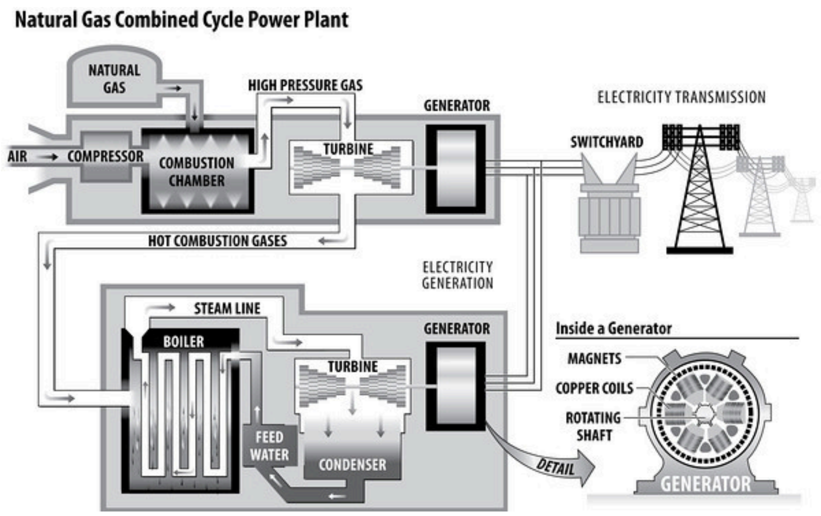
Natural Gas Power Plants

In a gas power plant natural gas and compressed air is burned in a furnace, the exhaust gases are ejected from the combustion chamber and drive a turbine. The efficiency of these Open Cycle Gas Turbines (OCGT) are relatively weak with conversion losses of about 65 percent. More modern gas power plants use a technique called combined cycle, shown in the picture below. In this plant the hot combustion gases from the furnace in a first step spins a turbine before reaching water in a boiler that boils water into steam and spin a second turbine. Thus you get two power generation effects at once decreasing the conversion losses. The conversion losses of these Combined Cycle Gas Turbines (CCGT) are about 40 percent.

OCGT – Open cycle gas turbine

CCGT – Combined cycle gas turbine

Picture 8.8. Combined Cycle Gas Turbine Plant



Source: need-media.smugmug.com

Smaller CCGTs has had great traction the last decade

Gas-fired plants often have lower fixed costs than other conventional fuels and certainly compared to the investment heavy nuclear power. The economically most efficient plant size has actually shrunk over time. This and a large supply of natural gas have made gas plants the primary choice in the US when building new power plants the last 2 decades – shifting the mix away from coal. Compared with coal, burning natural gas emits about half the amount of CO_2 so this is a positive development. However, methane which is the main component of natural gas is in itself a much more potent greenhouse gas than CO_2. Thus, the positive effects of the shift hinges on the prevention of leakage from gas pipelines.

Half the greenhouse gases as long as the pipes don't leak

Coal, Oil and Biomass Power Plants

The power generation using coal, oil or biomass such as wood, municipal waste or agricultural waste and energy crops, is basically the same as the one for natural gas. The principle difference between them is the construction of the furnace. You need different types of ovens to burn different types of material. All fossil fuels are a stored-up kind of solar energy as the hydrocarbon molecules are made up of the organic material of plants and animals that accumulated their energy content directly or indirectly from photosynthesis.

Same, same but different oven

Coal and especially lignite (brown coal) is generally among the cheapest fuels due to its abundance. The coal is grinded into a fine powder that is blown into the furnace and burnt together with or without compressed air. Conversion losses in a coal-fired and an oil-fired plant are about 65 percent (if not combined cycle). In some parts of the world the waste heat in the water from coal-fired plants etc. is recovered as the hot water is distributed to buildings in so-called direct heating systems (or CHP, combined heat-and-power). CHP squeezes out some of the inefficiencies of the generation process but requires a granular network of water pipelines that is hard deploy due to city planning requirements.

Coal is cheap and plentiful

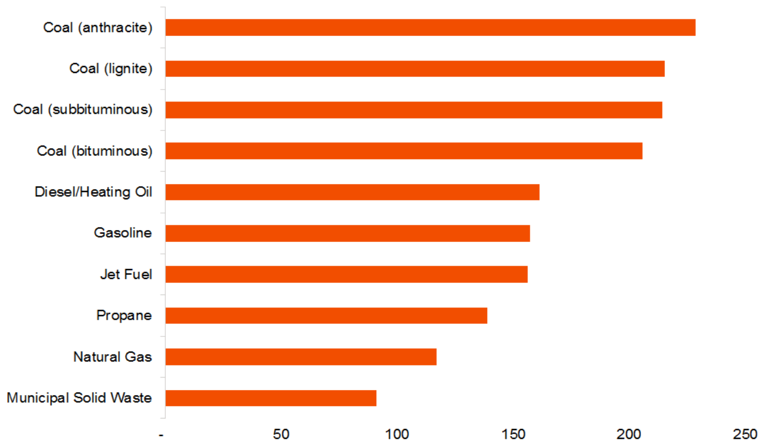
Direct heating

CO_2 – too much of a good thing?

Lignite with characteristics somewhere in between coal and peat is a large emitter of CO_2 compared to its energy output. It also emits of an array of other pollutants like sulfur and nitrogen that create fly ash, the main component of smog. In so-called scrubbers much of the other pollutants can be separated from the coal which is to be burned. The remanding fly ash can through physical and electrostatic filters to a large extent also be separated from the plant exhaust but the combined cleaning procedure obviously adds to the production cost – and it doesn't affect the CO_2 emissions.

So many types of coal…

Picture 8.9. Emitted Pounds CO_2 per Million Btu



Source: EIA (https://www.eia.gov/tools/faqs/faq.cfm?id=73&t=11), Swedbank

CCS – Carbon capture and sequestration

There are technologies to remove much of the CO_2 emitted from coal power. Some are in combination called carbon capture and sequestration (CCS). This is the process of capturing CO_2 from power plants, transporting it to a deposition (often depleted natural gas reservoirs), where the gases are stored instead of emitted to the atmosphere. A further technology is to turn the coal into a type of synthetic natural gas, capturing much of the residue substances in the solid remnants. The big question mark around these and other technologies for "clean coal" is their economic viability rather than their technical one.

Reserve Margin = ((generation capacity – peak demand)/peak demand). In addition there are contingency reserves for the really abnormal deviations

The few oil-powered power plants that still remain are seldom used, they instead contribute to the reserve margin but sometimes also to cover the peak load as they are rapid to turn on to meet demand. The coal content of biomass such as wood or waste is lower than coal or oil but so is the energy density, i.e. the heat content. As can be seen from the picture above the CO_2 emissions per generated unit of power from collecting and burning municipal waste are not too different from that of natural gas. Coal on the other hand emits up to double the amount of natural gas.

China, China, China

Coal supplies 66 percent of China's total energy and they alone use up 51 percent of the yearly global coal consumption globally. The Chinese power production from coal only is larger than the entire energy usage of the EU. An interesting fact is that China sits on about twice the amount of shale gas as the US – but no pipeline network. After the water boilers we move on to other ways to turn turbines.

Hydropower

To generate hydropower, flowing water is used to spin the turbine that is connected to the generator. In traditional run-of-the river hydropower the flow of a river current applies pressure to the turbine blades. Alternatively, in modern day the flowing water is accumulated in reservoirs created by dams. A controlled amount of the water is released though an intake and falls through a pipe called a penstock and applies pressure to the turbine blades. The natural water cycle with evaporation from oceans and lakes, rainfall over land and a flow back to the oceans and lakes through rivers, is powered by the heat of the sun. Alas, hydropower is an indirect form of solar power.

The flow of water

The amount of power generated by hydro plants is directly dependent on the amount of water in the reservoir, which in turn depends on unpredictable amounts of rainfall and melting snow. Hydro is renewable energy with low marginal production cost and it is attractive in the sense that the dam stores energy to be released as power when needed. In the most effective plants 80 to 90 percent of the energy is converted into power. Hydropower has a quick ramp rate allowing it to balance the variations in both demand and of supply of the more variable volumes of other renewables.

Unpredictable storage

However, most of the suitable hydropower plants have already been built and building dams further has negative consequences as it will create a loss of land causing ecosystems to be drowned and forcing people to move. The ideal place for a dam is a narrow gorge with great depth that gives a smaller flood area. The world's overall largest power station is the Three Gorges Dam along the Yangtze River in China. The power station has a generation capacity of 22.5 TW but building it also meant relocating 1.24 million people. Many moved to nearby Chongqing taking the town's population up to 31.4 million.

Chongqing – the largest town in China

Picture 8.10. Three Gorges Dam

Source: faculty.washington.edu

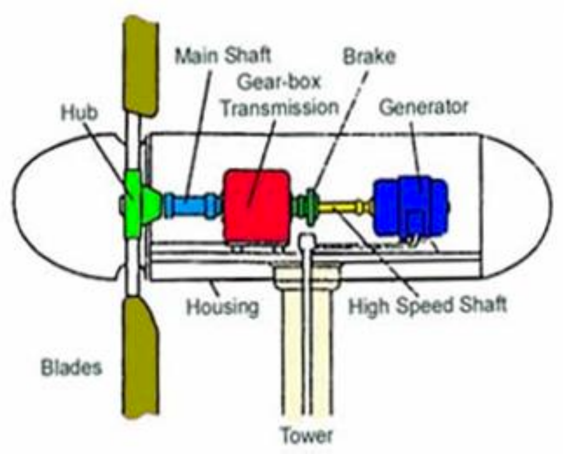
Wind power

Blowing wind

In these modern days windmills called wind turbines, the energy in the wind is converted into electricity by turning a rotor blade which drives the shaft that goes into the generator. The type of wind turbines you normally see are so-called horizontal axis machines. The blades are connected to a gearbox, which increases the spin of the shaft that goes into the generator. A wind turbine also has a brake in case the wind starts blowing too fast causing risk of damage to the equipment. The housing that covers the wind turbine is generally called the nacelle. Power cables will lead the electricity down through the tower and a transformer will adjust the voltage to suite further use. Again, wind power is a form of solar power. Wind is generated by the uneven heating of the atmosphere by the sun.

Picture 8.11. Wind Turbine

A horizontal axis wind turbine (HAWT) as opposed to vertical axis wind turbines (VAWT)



Source: teachengineering.org

Windy good, remote bad

The amount of generation will depend on wind speeds, rotor blade diameters and aerodynamics and the efficiency of the generator. The economics of a wind farm will also vary due to the remoteness of the geographic location as it must be possible to get access to the towers and as they will need connections to the main grid. Offshore farms often get better, more dependable wind conditions, there are no complaining neighbors and they can have larger blades and turbines but they call for expensive shipping, complicated engineering and the transmission costs to the mainland grid will be high. The largest rotor diameters are now around 170 meters. This compares to the wingspan of a Boeing 747 of about 67 meters. Mounting these blades on a tower in the midst of a stormy sea is no picnic. The cost of offshore wind power is 2 to 3 times that of onshore wind power.

No WPEC…☺

Obvious benefits of wind power are the low fuel costs as wind is free, there are positive energy security aspects as no organization can try to create a cartel for the wind rich countries á la OPEC and the absence of CO_2 emissions in the power generation is an obvious plus (even though the production of the steel and concrete that make up the wind turbine is not emission free). There is a slow but steady decline in the cost structure of the equipment, gradually making it more competitive.

On the other hand wind power is non-dispatchable, meaning that all the available output must be used when it is available. When the wind doesn't blow or when it blows too hard the turbines cannot generate electricity. Here there are two kinds of wind turbines: constant-speed and variable-speed turbines. Through an electrical control system the variable-speed turbine can operate at higher wind speeds without risk of breaking. The utilization, or load factor, of wind turbines is about 30 to 40 percent which is much lower than most other power plants but out of the mechanical work about 90 percent is converted to power by the generator. For a network that has to balance supply and demand at all times, the volatile generation is not an attractive feature. Also, the areas with the best wind characteristics are rarely very close to those that are the most populated.

Load factor 35%

Finally, we come to a way to generate electricity without turbines, shafts and generators but instead with something as Silicon Valley-ish as semiconductors.

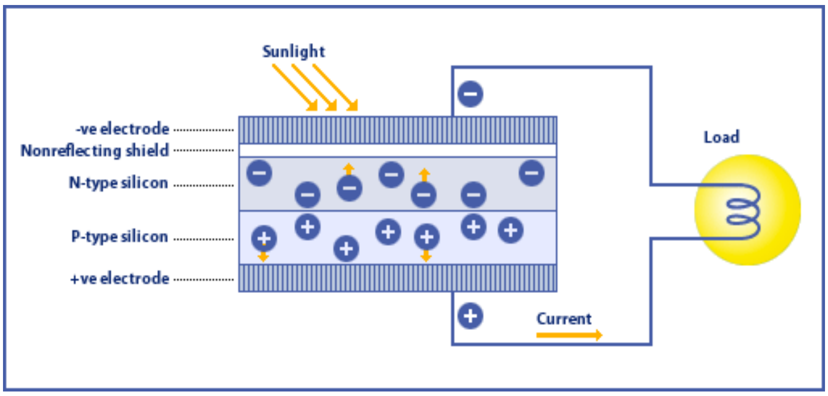
Solar power

The fraction of the suns radiation that hits the Earth is about 0.00000005 percent of its total output. Yet with a hypothetical 100 percent conversion ratio the content of 40 minutes of the sunlight that hits us is equal to the energy needs of the Earth for a full year.

The solar power we describe below is called photovoltaic generation, or simply PV. The photovoltaic effect occurs when light strikes two dissimilar materials and produces an electrical current. In photovoltaic conversion the direct sunlight of the sun is converted into power in a solar cell (or PV cell) made by a semiconducting material such as silicon. Different parts of the silicon material are doped with different substances to either carry a negative charge (n-type) or a positive charge (p-type). The solar cells absorb the sunlight and the energy released by the absorbed photons creates the disturbance needed to free electrons from their atoms and produce electricity. The energy added to the material also makes the silicon conductive. Metal contacts on the top and the bottom of the cell allow the current to be drawn off. The current must be converted to alternating current by an inverter and an attached charge regulator controls the voltage before connecting the system to the home circuit breaker.

PV - photovoltaic

Picture 8.12. Photovoltaic Conversion



Source: mitsubishielectric.com

For more on semiconductors see The Companion 2015:1, March 3, 2015

The availability of sunlight is fickle. At a given spot the sun doesn't shine when it's cloudy, the sunlight is weaker in the winter and the sun doesn't shine at night. The latter is in contrast to wind that on average blows harder at night. The load factor of solar power varies between 10 and 25 percent depending on geographic region. Even when the sun shines we cannot convert all the energy into power. In the photovoltaic conversion process the theoretical maximum conversion ratio is about 34 percent. With multi-junction solar cells that pack multiple semiconducting materials together in a cell the theoretical maximum moves to about 87 percent. Conventional solar cells have moved from a technically feasible efficiency of about 15 percent in the early 1980s to about 25 percent today. Lab examples of multi-junction cells now have efficiencies of almost 45 percent. An additional feature of solar power is the large areas that have to be covered for large scale generation.

Load factor and conversion ratio of about 25%

One of the advantages of solar energy is that it's part of the semiconductor industry with its exponential development as expressed by Moore's Law. This means solar cells will only become better and cheaper with time. The economics of solar is very different from for example coal or gas. When the demand increases the production cost of solar goes down thanks to scale economies. When demand for coal or natural gas goes up the cost goes up. The global installations of PV increased by more than 100x between 2000 and 2013. Also, the existing equipment doesn't wear and tear much. The efficiency of installed solar cells is estimated to lose about 0.5 percent of its generation capacity per year.

Moore's Law – the prediction that the computing power per unit cost would double every 18 months

In 1973 the cost per peak watt for the average solar cell was USD 100. In the first quarter of 2015 it was USD 0.31. This is an annual compounded price drop of about 13 percent and if the pace of change is kept, the price will be USD 0.02 in the first quarter of 2035. Unfortunately this does not include panels, other equipment or installation. If the oil price had kept up with the same price development as solar from 1973 onwards a barrel of Brent Crude Oil would have traded for 1.5 cent in the first quarter of 2015.

Brent at 1.5 cents/bbl

Discussion

There are a number of ways to generate electricity that we haven't mentioned such as geothermal, solar-thermal, tidal, wave-power etc. The exclusions are not made due to prejudice but instead because they are so infinitely small when it comes to supplying the world with electricity.

However, there is one "fuel" more worth mentioning – energy efficiency. In 2014 energy consumption in the EU was at its lowest level since 1985. The energy usage of the OECD countries has despite growing economies been flat for almost two decades. If it weren't for the very fortunate wealth development in the Emerging Markets, the energy usage of the world wouldn't be growing. At the same time as we are moving from a manufacturing lead economy to a service lead one, companies and people are investing time and money in all sorts of energy productivity and energy conservation measures and it is having ample effects. In Europe and the US utilities no longer can count on certain future demand growth.

Energy efficiency

Grid parity

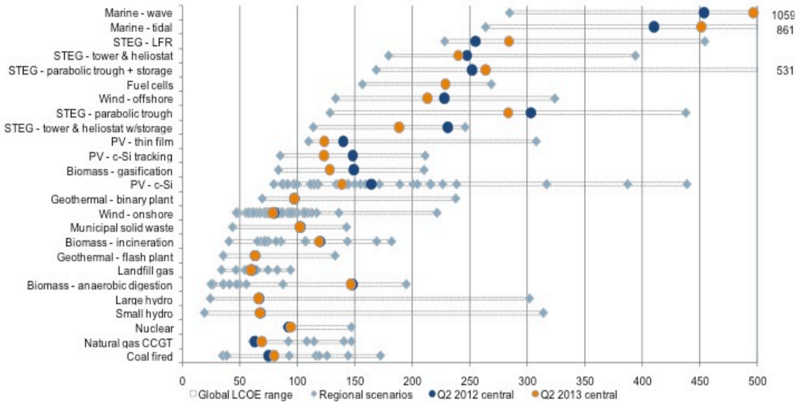
The concept of grid parity refers to the point when an emerging technology will be able to compete on its own merits. With all the taxes, subsidies and targeted pricing schemes in this sector it is very hard to get a grip on the actual economic cost of generation technologies. Another difficulty is that there are both secular and cyclical fuel price changes that constantly alter the calculations.

LLOE – Levalised cost of electricity

By trying to estimate the Levalised Cost of Electricity, the LCOE, you add up the capital cost for building a plant, the fuel costs and the operational cost for running the operations to a total cost and divide this with an expected life span of production. There are no taxes, fees or subsidies, i.e. it’s a level playing field. The picture below shows a global estimate for 2013. For each generation technology there is a cost range rather than a single point as variations are large between geographies, power plant size and depending on the age of the assets.

Picture 8.13. Levelised Cost of Electricity, 2013 (USD/MWh)

Expensive waves



Source: worldenergy.org. STEG refers to thermal solar energy.

PV not at grid parity in 2013…

Low cost technologies were coal, natural gas, nuclear and hydro. High cost technologies were some fringe methods like wave and tidal generation plus thermal solar energy (STEG). Wind onshore was clearly cheaper than wind offshore. PV, that is photovoltaic solar power that we covered above, was at best almost as cheap as coal etc. but the cost range was huge meaning the average wasn’t at grid parity in 2013. Now, the interesting thing is that with the help of Moore’s Law it will not take long for solar to become the cheapest technology.

…but in 80% of countries 2018?

In reality the price decline the last few years has been much higher than the historical norm. In just the last 5 to 6 years the prices have dropped almost 80 percent. In 2015 the average price of solar in Germany was only about 20 percent higher than the low cost technology which was coal. Deutsche Bank predicts that solar will reach grid parity in Germany this year. National Bank of Abu Dhabi predicts that solar energy will reach grid parity in 80 percent of all countries within 2 years. It doesn’t really matter much if they get the timing wrong a year or two as the price of conventional fuels fluctuate. The thing is that it will happen within a relatively short timeframe. First large scale solar plants, but then smaller rooftop installations will become cheaper than competing power sources. Wind power also has a price decline but since we are here dealing with a more mechanical process it is slower than for the semiconductor based PV generation.

Externalities

The environmentalist would perhaps argue that renewables already are the cheaper fuels if you would factor in the environmental costs caused by fossil fuels, the so-called externalities. The thing is that the cost of renewables doesn't include another set of externalities – the costs they place on the total network, such as the need for a more granular and interconnected grid, for battery installations and importantly for the keeping of back-up balancing power generation capacity.

Solar domination is just a matter of time

Our conclusion is still that renewables and especially solar over the long-term will crowd out other energy sources. Partly, this is thanks to the political support for "sustainable" power sources but even more importantly it's because solar sooner or later will become cheaper than the alternatives. Also, one shouldn't underestimate the customer attraction of a solution that promises the independence from the generally disliked power utilities.

8.3 The Grid

The transporter of electrons

Power in a network flows one-way along the path of least resistance from the power plant to the user. When new lines are added to a network the flow automatically rearranges to flow according to the new lowest-resistance pathway. The networks of the grid are seen as natural monopolies and are highly regulated. The transmission network is a natural monopoly on a national level. There might be several distribution networks in a country but they are still natural monopolies within the specific region they cover. Finally, the supply part of the value chain facing the end-customer is in Europe generally the most deregulated one allowing for full competition.

Transmission

HVDC – High voltage direct current

The transmission network is the long-distance national backbone of the grid. To efficiently send alternating current over long distances the voltage must be high and the cables must be thick. In Sweden the voltage of the transmission network is generally 400.000 volts. Transmission lines are of copper or aluminum and mostly use three-phase alternating current. High voltage direct current (HVDC) is used for point-to-point transmission when distances are above 5-600 km (and for undersea cables) to reduce the power loss. Unlike AC cables there are no physical restriction limiting the length of HVDC cables underwater or underground. Still, transporting electricity over long distances by the annoying physical law always gives rise to energy losses along the wires - especially on ill-maintained ones with higher resistance. Energy losses overall in the grid are about 5 percent of the total volume or about 3 percent per 1.000 km.

Picture 8.14. A Scenic View of the Transmission Network

Source: cooperindustries.com

TSO – Transmission system operator

In Europe each country's transmission network has a Transmission System Operator (TSO) which is responsible for the national transmission network. In Sweden this is the state-owned enterprise Svenska Kraftnät situated about 3 minutes away from Swedbank's headquarters in the metropolis of Sundbyberg. The TSO provides access to the network for both generators and direct customers in power intensive industries plus for the distribution network. The TSO must provide access in a non-discriminatory and transparent way. New power generators ask to be connected and are put in a queue. The TSO is further responsible for the security of supply including reserve margins, for balancing supply and demand in the system and for facilitating the wholesale power trading. Also, it is the TSO that manages the interconnecting power lines to other countries.

ISO – Independent system operator

RTO – Regional transmission organization

The TSO can be seen as an independent network operator with a public service mission. In the US there are a number of private non-profit organizations called ISOs and RTOs that own various parts of the transmission network. The most difficult and time consuming part of constructing a transmission network is not putting up towers and cables but getting the permission to do so. Transmission networks must be free from obstructions so vegetation on both sides is cleared with a distance depending on the transmitted voltage. Carving new pathways in populated areas and by this expand the transmission network is a nightmare.

Sundbyberg is in control

Transmission networks usually consist of overhead cables since underground cables are about 10 times as expensive to deploy. Underground transmission is mostly used in densely populated areas. Sweden has a transmission network with a combined length of about 15.000 km, all managed from the control room in Sundbyberg. This is one of the oldest transmission networks in the world and much of the cabling is nearing its end, meaning a need for investments. The older the network, the more dispersion of clients and the more variable the demand, the more expensive will it be to operate the grid. With the distributed power generation of wind and solar these power generation sources will have to feed into the grid in more substations complicating the structure of the network. On the other hand the more the network is connected to a large number of power plants and the more interconnected it is to other networks, the more reliable it is.

Power zones

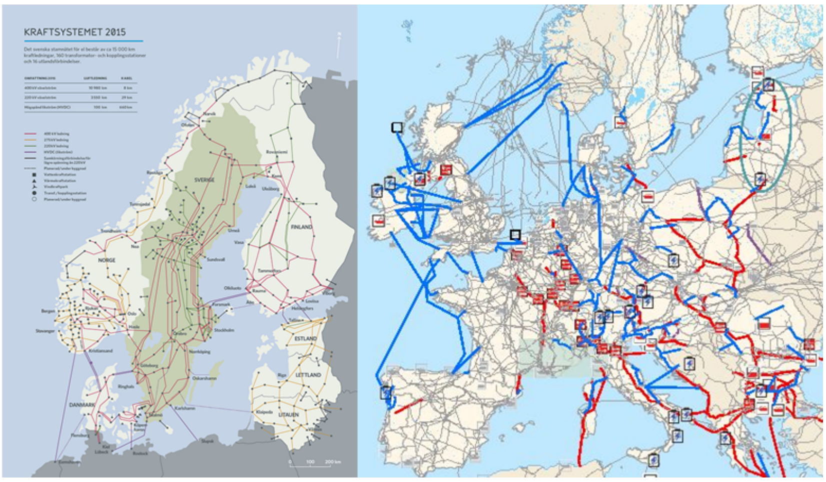
Europe is generally divided into five zones for power: the UK, Central Europe, Iberia, Italy and the Nordics, all with quite different sources of power generation. North America is divided into four zones: the Western Interconnection (covering the western part of both US and Canada), the Eastern Interconnection and Quebec in Canada and Texas in the US which are separate. Power grids like for example those in the US haven't been planned top-down - they have historically grown organically out from populated areas according to the operators' business interests. Central US is scarcely inhabited, hence few transmission lines and little capacity to interconnect the west with the east.

Swedish interconnection

There are one main import cable and one export cable between Sweden and Denmark. Some less powerful lines connect us to Germany, Finland and Norway. Underwater cables are also being built between Sweden and Lithuania. Denmark is in turn connected to Germany which is connected to Poland, Austria, France, Norway etc. Despite that the interconnections as shown in the picture are constantly improving the installed transmission capacity between countries in Europe or the four regional grids in North America is quite limited.

Too few cables

Picture 8.15. Map of the Interconnected (?) Nordics and Europe



Source: Svenska Kraftnät (left), targetukenergy.com (right) Blue = power, red = gas.

Odd Japanese network planning

The world of electricity is still more domestic than you might think. In Europe the largest interconnection capacity is between the Central European countries, including France. In Japan the transmission between the two regional grids is even more limited as the two areas operate on different Hertz, i.e. the frequency of the alternating currents differs. This had the consequence that after the Fukushima disaster when northern Japan desperately lacked power, southern Japan had a surplus but there was very limited ability to transfer any of that power surplus as the conversion stations connecting the two areas had such small capacity. Fantastic! – or not really.

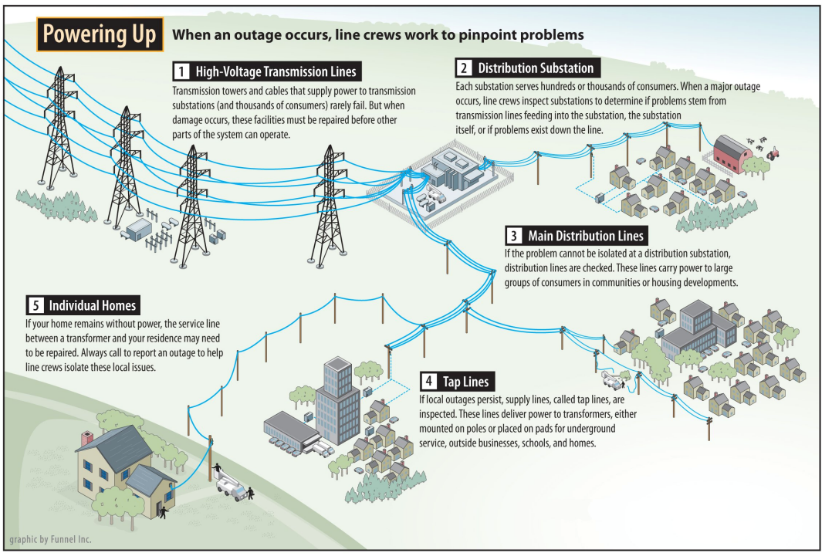
Distribution

The last mile

The distribution network is the final physical component of the power delivery system and it distributes from the substations interconnecting with the transmission network to the end customer and their meters. A large part of the distribution network runs alongside roads on telephone poles. In contrast to the transmission network where substations are connected to several power lines to give redundancy the distribution network is more linear, i.e. there is only one way to reach the end customer. The distribution network is a natural monopoly on a regional scale. Sweden has a number of distribution networks with a combined length of about 33.000 km. Three operators E.ON Elnät, Vattenfall Eldistribution and Ellevio own the majority of these networks. Ellevio is in turn owned by Borealis, Tredje AP-fonden, Folksam and Första AP-fonden.

Picture 8.16. Error Handling in Distribution Systems (2 – 5)

A linear system



Source: teammidwest.com

Distributing bits not just electrons

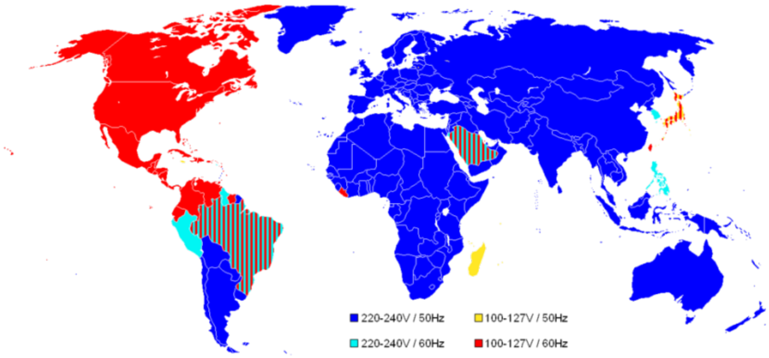
The distribution substation is one of the key components of the distribution network. A power grid substation is amongst other used to allow power from a generating plant to be fed into the grid and it hosts control and metering equipment. It is with this equipment that the load levels of the grid are monitored and it also allows for the error detection in case of power failures. The substations of the grid are connected to control rooms with a separate communications network. The major parts of the Swedish distribution networks are managed and supervised centrally by combined communications networks and software systems.

The substation

However, the distribution substation's main task is to transform incoming voltages to a volt that suites the distribution network. In Sweden the voltage in the distribution network is gradually stepped down in a series of substations from a maximum of 130.000 volts to 400 volts. In a final transformation in a street cabinet near your home the volt is reduced to the level of your indoor sockets. In most parts of the world the delivered alternating current will have a voltage between 220 and 240V and the frequency will be 50 Hz. In North America the voltage will be between 100 and 127V at 60 Hz. To not make usage to easy, Europe uses 6 different shapes of sockets despite having the same voltage.

Picture 8.17. Global Power Map

Europe: 6 sockets but the same voltage…



Source: Wikipedia.com

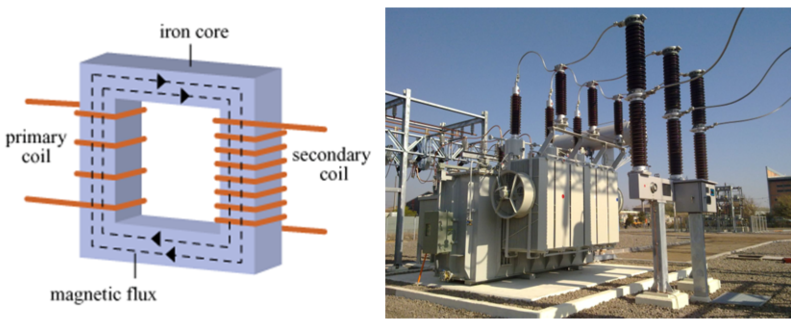
To change the voltage of alternating current to become either higher or lower a transformer is used. Remember, voltage is the difference in electrical potential between two end points on a cable. The larger the difference in positive and negative charge, the larger the tension between them and the more potent the pull on the electrons.

Transformers

A transformer changes the strength of the pull. The pull is created by a similar type of coil as we saw in the generator. Just as a moving magnetic field then generated an electric current, a flowing electrical current also generates a magnetic field. Thanks to the flow in the iron core of the picture below the coil stores energy in a fluctuating magnetic field. The coil handling the incoming current is called the primary coil and the one handling the outgoing current is called the secondary coil. By having a different number of windings in the primary coil from the secondary coil the voltage will change proportionally. The transformer to the left in the picture below is a step-up transformer, doubling the voltage as the number of windings in the secondary coil is twice as many as in the primary one. In distribution networks the opposite is more common where a step-down transformer lowers the voltage by having fewer windings in the secondary coil than in the primary.

Picture 8.18. Transformer

Windings make all the difference



Source: hk-phy.org (left) & en.chint.com (right). To the right we see a three-phase transformer where the primary and secondary coils are fitted into each other in the dark cylinders.

Exactly as in the cables there are power losses in the transformer and up to 2 percent of the total 5 percent losses occur in the substations. In the picture we see a core cabinet that will contain a cooling oil to dissipate the heat from the losses and also fans to keep the equipment at the right temperature.

Supply and Trading

Power retailers

The retailer of electricity to end-customers buys power on a wholesale market and sells it to customers like retail consumers or businesses and organizations. The focuses of the retail operation are on increasing the customer base, on successful pass-through of electricity and T&D costs and of hedging the risks of margin squeezes. The value add is small in this step of the value chain and the competition is tough so margins are low.

Marketing skills

The way to increase profits is then to increase the sales volume and retail businesses are often large advertisers. Since electricity is a generic commodity with uniform quality the marketing either focuses on the price level, on some type of inventive price plan or alternatively on the supposed origin of the power, i.e. that it is supposed to be generated by renewable power sources. The thing is, even though the retailer is purchasing green energy certificates or is purchasing its power capacity through a contract from say a wind park, the power grid doesn't differentiate between electrons and the end-customer will receive the same mix of electrons as everybody else. The total mix in the grid might change but no regular end customer can purchase and receive exclusively wind-generated power.

Fixed retail price

In some markets the retail prices are regulated to shield consumers from price volatility. This gives retailers a clearer view of the revenues that will be generated. Retail tariffs will be altered only periodically to reflect changing cost levels. Price changes in the wholesale price of procured electricity and to a lesser amount in T&D costs will prior to any changes in regulation have a direct impact on margins. As commodity price changes aren't very predictable it is in these regimes, despite the higher cost, generally wise to purchase power on long contracts.

Varying retail price

In many markets the retail pricing is unregulated and set by competition. Although the risk for margin squeezes are lower as businesses operate with a cost-plus mindset and small fixed costs of perhaps 10 percent of the cost base, the fierce price competition between retailers could bring the margins of less efficient, smaller players down to around zero. For the more successful ones even slim profit margins will mean good ROIC as the asset base is small.

Wholesale trading

In deregulated markets there is an arbitrage driven wholesale electricity trading market with a number of derivative instruments to trade. The trading activity creates the economic link between generation and supply to end customers in the same way that the cables of the grid provide the physical link. The retailer in Sweden will purchase the physical spot electricity at Nord Pool which runs the Nordic trading for power and is owned by the Nordic TSOs, among them Svenska kraftnät. Through the trading generators optimize their supply and demand situation on various time horizons. They try to sell their power generation on a number of different types of contracts to diversify their risks.

Heading

Change in the price of electricity does have a negative impact on the financial results of a utility. Most companies therefore hedge at least parts of their electricity generation and sales through the use of financial forward contracts or long-term customer contracts. This way the companies even out the effects of volatility in electricity pricing. The long-term customer contracts usually pertain to time horizons in which there is no possibility to hedge prices in the liquid part of the futures market. In the Nordic region financial contracts are traded through Nasdaq Commodities. The contracts have a time horizon up to six years, covering daily, weekly, monthly, quarterly and annual contracts.

50 to 80% hedged

There is no physical delivery for financial power market contracts. Cash settlement takes place throughout trading – and/or the delivery period, starting at the due date of each contract, depending on whether the product is a futures or a forward. The hedging ratio, i.e. the fraction of estimated production/sales volumes hedged, is typically between 50 and 80 percent in the shorter term and then usually a lower fraction for time periods up to three years or so. To measure electricity price risk, companies use methods such as Value at Risk (VaR) and Gross Margin at Risk along with various stress tests.

Bidding on the load

The TSOs predict how large the electricity load will be for anything from the next five minutes to the next 30 days, or longer. The forecasts are constantly adjusted and the closer in time the more accurate they will become. At the same time the actual load is measured every few seconds with equipment in the substations. The total load will sum up to all the power that is produced by generators connected to the network plus the imported power on ingoing power lines connecting to other networks minus the exported power on outgoing interconnecting power lines.

Balance or blackout

The generation and the load of the grid have to balance around the clock or the network will face a blackout. At any moment the demand can change and this will have to be balanced by either changed internal generation or a change of the net change of export/import power. Alternatively, a change in internal supply due to a plant malfunctioning will be handled by either increasing internal generation from another plant or by the net change of export/import power. The balancing act is complicated by the constraints set by the regulation where the network must function despite the loss of the one single largest generator or with the loss of the single largest interconnection line. However, the largest complication is posed by large volumes of intermittent power from solar and wind as they introduce a second non-controllable parameter apart from the demand development. Penetration rates of 20 % of intermittent power generation are often mentioned as a level that threatens grid stability.

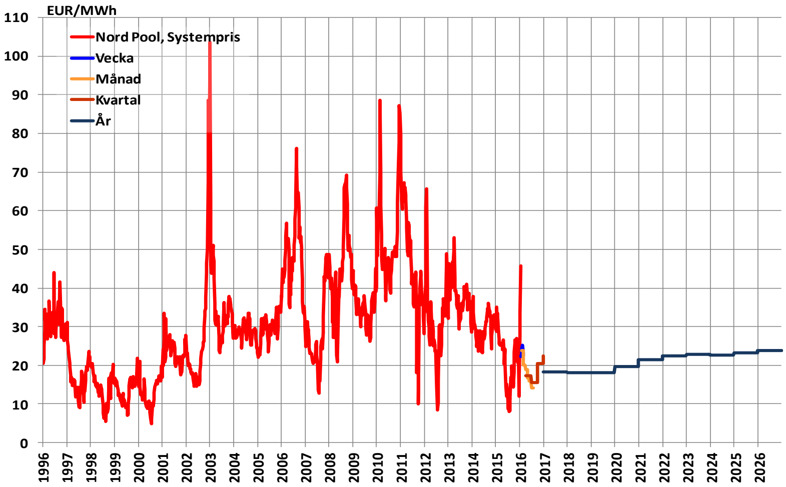
Ripples

When changing the net export/import balance of a network this will affect the neighboring network's load and the secondary effects of an event in one network can ripple through several interconnecting ones. Thus, the needs of the neighboring areas must be taken into consideration and in all this the aim is additionally to balance the load at the lowest possible cost. This is handled by the trading mechanism.

The generators bid on the forecasted load on varying time intervals. The bids will generally be made in accordance to marginal cost of the generator and the trading fills the volume with the lowest bid first as long as the ramp rate for the generator is quick enough.

Picture 8.19. Swedish Wholesale Power Prices

The forward pricing reflects low long-term price levels. Will the market get it right?



Source: Nord Pool Spot, Nasdaq/OMX Commodities, Svensk Energi

The Smart Grid

The smart grid - an intelligent monitoring system that keeps track of and manages the electricity flows

Despite its complexity and the growing interconnectivity between regions, the basic structure of the grid hasn't seen much change over time. Technological development and the proliferation of energy generation is now about to upset the old order: enter the smart grid. This smart grid is a catch phrase for a number of developments but most would describe its main feature as an intelligent monitoring system that keeps track of and manages the electricity flows in a system.

Two-way traffic…

One of its features is two-way traffic of electricity. With the deployment of solar cells on residential rooftops retail customers are no longer only consumers but also producers of power. If the retail customer would happen to have an excess supply of power it's not a farfetched thought that he should be able to sell it to the grid. After all, this is what solar power plants do on a larger scale.

…on a one-way network

However, from a network perspective this is not as simple as it sounds as the network is designed to run in one direction. It's like switching from an entire road network built on-one way traffic to one built on two-way traffic. It can be done but it takes time and costs money to reengineer. The network would also have to invest more in information technology to manage the network and the increased interconnectedness will create more potentially insecure entry points for those who want to hack the power network. The emergence of an array of new small-scale power generators has also caught the interest of the taxman who would want to collect taxes and VAT on the business, bringing cumbersome administrative consequences. In Sweden there is even a proposal that legal entities should pay tax on the estimated amount of grid power they don't use due to their own solar power generation!

Another development is smart metering giving way to dynamic real-time pricing and interactive reactions to prices. Current meters are only read infrequently and they bill the average usage per hour. The smart meter is a two-way device that instantly reads the usage and also reports real time prices to the end-customer. The billing could now be made for the power usage per minute to that particular price. Combined with distributed generation the smart meter opens up for so-called net metering - the consumer only pays for the net amount of power used. Smart meter penetration is nearing 50 percent in the US. For the first time utility customers will start to have live interaction with their provider of power. This could be an important opportunity also for the utility.

Smart metering

Net metering

This might mean a small revolution as the customer gains an instant awareness about his usage and costs and can start to adjust his behavior accordingly. Why start the washing machine right now when the price is high and when the price probably will be lower right before you go to bed? This means that the demand curve goes from previously being vertical (as demand was inelastic) to having a negative slope, i.e. high prices suddenly mean lower demand. Obviously, there are significant costs in swapping out old equipment and there will be several interoperability plus integration issues to solve to automate the process.

- A demand with slope, please

A next step where the information from the smart meter is used for an app that runs a number of home appliances is easy to envision. The app might for example wait to start the washing machine until a certain price occurs or it might vary the temperature of the house so that it isn't unnecessarily warm when no one is home. According to NEST, the much hyped intelligent thermostat company owned by Google, UK consumers waste up to 20 percent due to inefficient scheduling. From the utilities point of view there is a risk that the app provider will be an interface between them and the end customer.

Power apps

The secondary effect would be that the behavior of the customers helps the TSO in balancing of the network and that peak demand goes down as the power usage spreads out during the day. Utilities can by this save investments in additional power plant capacity. Since capacity has to be in place to cover peak load plus a safety margin a more evenly distributed demand volumes improves the economics of the industry, everything else alike. In some markets there are even demand-response (DR) programs in place where consumers get paid by the utility to withdraw demand when the network runs the risk of being overloaded. However, all this also means that the higher peak demand pricing will be affected so everything else will not be alike for the generators. Some analysts forecast that relatively small shifts in volumes from some customers would lower price a fair amount – a benefit for all customers.

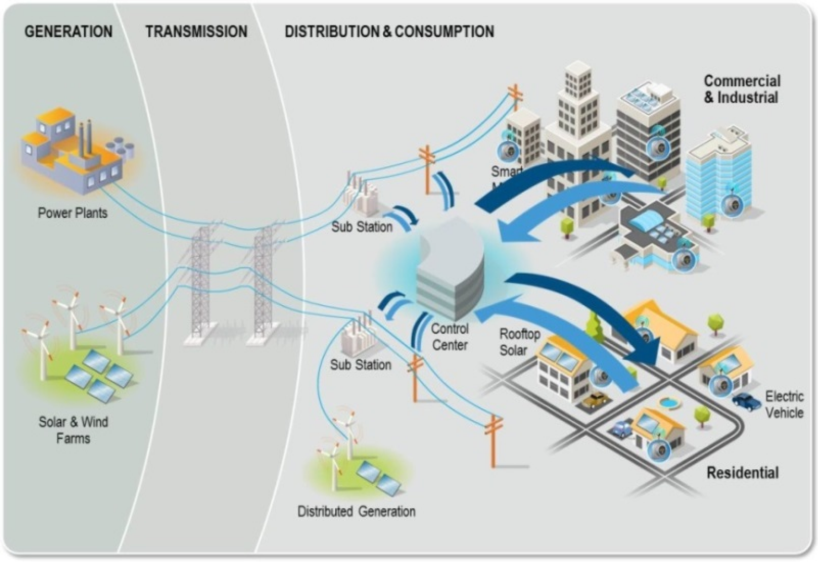
DR program – Demand-response program

Obviously all this is mainly relevant in areas that have deregulated the retail pricing. The smart grid requires investments in more granular communication and management systems handling not only load volumes but also real time pricing in interactive feedback loops. The systems need to co-ordinate the combination of centralized and distributed generators, of end users that suddenly react to the environment and of wholesalers with ever changing volumes and prices without losing system reliability. Oracle, eMeter and Itron are three suppliers of such meter data management (MDM) systems.

MDM – Meter data management

Picture 8.20. The Smart Grid

Investments needed



Source: trilliantic.com

Grid storage

In many discussions a further feature of the smart grid is so-called grid storage. The thought is that with the future proliferation of electric vehicles with battery capacity plus also other distributed power storage units, these units can charge when prices are low and sell power back to the grid when prices are high. This development of course hinges on the success of electric vehicles, but if it would become a reality it would further even out the load of the network.

8.4 The Market

Demand drivers

Demand drivers for electricity includes the consumer mix where different countries have industries of differing energy intensity, climate/weather where high temperatures give need for air conditioning and low for heating, seasonal patterns over both the season of the year and the time of the day, technological changes where a lot of hope is placed on electrical vehicles right now, energy saving politics and, above all, demand is driven by secular and cyclical growth in GDP. Secular GDP growth is in turn driven by population growth and increased productivity. Historically, demand growth has been steadily increasing creating a low risk sector allowing for relatively high leverage. A number of factors are challenging the low risk status and the wisdom of high leverage.

Load balance

The most fundamental aspect of the power market is that electricity cannot be stored in any larger amounts. This is an industry that operates with virtually no inventory. The lighting in your room comes from electricity created in a power plant 1 to 7 seconds ago. Supply has to match demand at every time. This means that power generation capacity has to grow with the secular demand for power and that power plants short-term constantly adjust production to balance the current demand. The transportation of power is almost instant even over long distances. If supply cannot be made to meet demand the result is blackouts. Thus flexibility in quickly changing the amount of generated power, the ramp rate of a plant, is a critical element in power generation. If supply still is too large it will have to be exported from the grid. Germany and Denmark occasionally has had to offer negative prices to be able to get rid of excess solar and wind power, i.e. neighboring grids were paid to purchase the power.

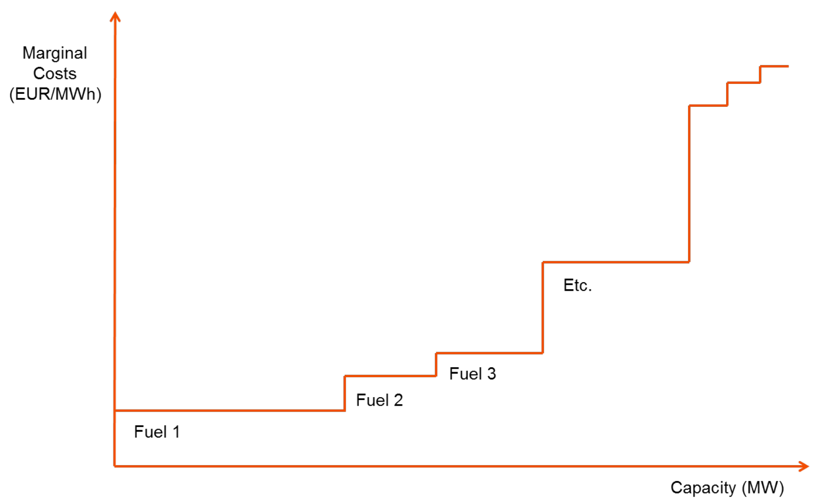
Price = marginal cost

You might think that lower fuel commodity prices are good for utilities but in general the opposite is the case. To understand why, we need to understand the wholesale pricing of electricity as this feeds through to the end-customers. The price is set in an auction process by marginal plants ready to offer power to match the projected demand at any time. Thus, in the short-run the wholesale price is set by the fuel costs plus operating costs of the marginal producer – provided that the ramp up for the power source is quick enough to meet the demand changes and allow dispatch of electricity.

If we arrange the generators by their marginal cost, i.e. how much producing one more MWh will cause the variable costs to increase, sorted by the generator with the lowest marginal cost (in $/MWh) to the left and the highest to the right, we get what's called a merit order curve or a dispatch curve. This curve will in reality be arranged by power plants but it is often more enlightening to arrange it by fuel source as it will have a larger effect on the marginal cost than differences in plant efficiency.

Picture 8.21. Merit Order Curve

The dispatch curve



Source: Swedbank

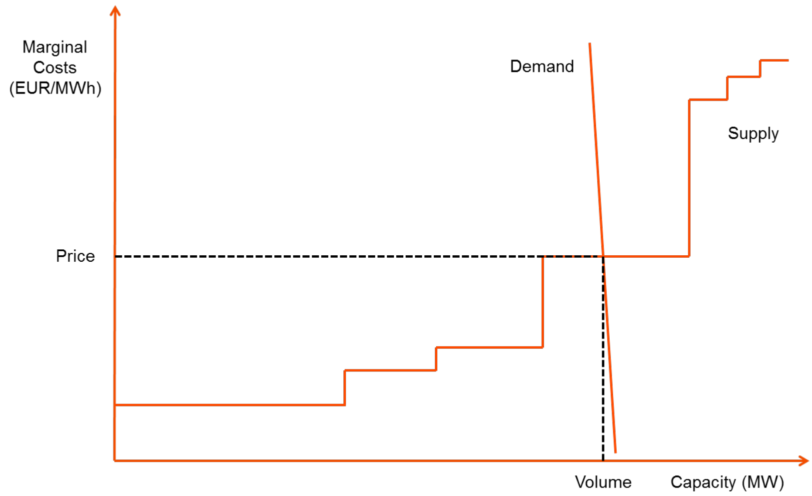
UCP – Uniform clearing price

This merit order curve will form the supply curve of a supply-demand diagram. We have purposely not written out the energy sources in the picture as the marginal cost for them varies between countries and over time. Where the demand meets the supply the market price will be set. This is called the Uniform Clearing Price (UCP) and all the generators will receive the same payment. Those generators with variable costs below the market price will have a positive contribution to cover the fixed costs.

The marginal producer will only cover his variable costs and if it is always the same marginal supplier he will see problems in funding future investments. However, often power generators have diversified over a number of technologies. Those generators with a variable cost higher than the market price will not produce any electricity, as there is no demand for their capacity.

Picture 8.22. Supply and Demand Curve for Electricity

Supply and demand



Source: Swedbank

Supply will change due to new added plants or the closure of aging plants and changes in plant availability caused by outages or maintenance. Power generation plants malfunction, “trips”, about 2 to 10 percent of the time. Demand will change according to the GDP growth, technological change (say a large increase in volume of electrical vehicles), energy conservation policies and practices, import/export situations weather conditions and much more.

Higher demand, higher price

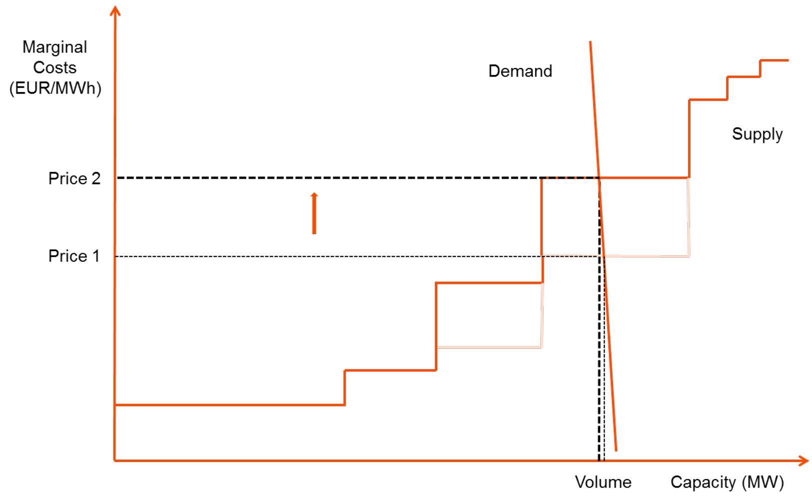
As is evident from the merit order, the higher the level of demand, the greater the cost of producing power and the higher the price. With the absence of a smart-grid, the demand curve will be more or less vertical at a given time. Power is a necessity with few short-term substitutes and is as such demand inelastic.

Higher commodity prices shift the supply curve upwards…

We are now ready to answer the above question why higher fuel commodity prices are good for utilities. As shown below it’s because the increase shifts the supply curve upwards while the volume is largely unchanged. We have increased the price of two commodities in the picture below and this made the supply and demand curves meet at a higher price point. The total amount of profits for the combined industry will increase (i.e. the area below line price 2 and above the supply line). Since commodity prices often are quite volatile, fluctuations in these and mix changes in the fuel sources used, to a large extent explains the changes in electricity prices.

Picture 8.23. Effects of Commodity Price Increase

… while the demand curve is vertical = higher price

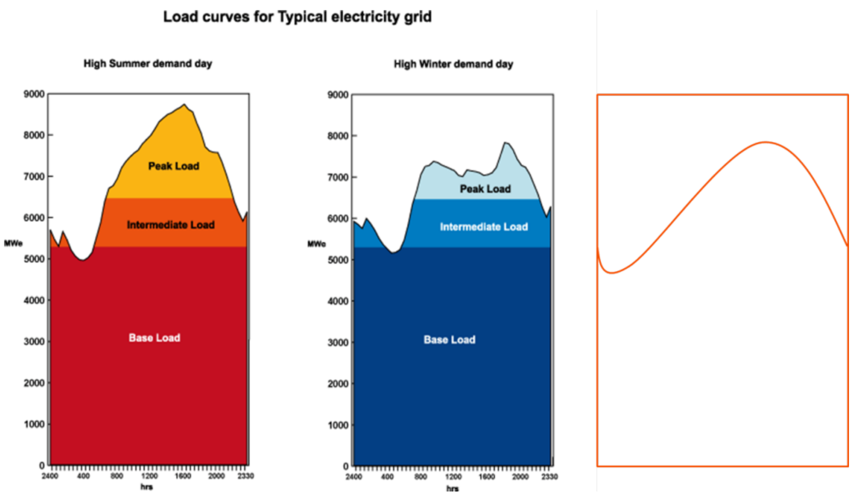


Source: Swedbank

Mid-day peak

Even if demand is stable in any given moment, it will fluctuate both according to season and over the day. Further, weekends see a lower load per day than the rest of the week. In the pictures below we can see how the demand volumes, the load, vary during the hours of a day. In general the use of electricity is high during the day and low during the night. No surprise there. In the summer and in warmer countries the mid-day peak is due to increased usage of air-conditioners during the hottest hours and the smaller late afternoon peak in the colder climate is due to the combination of stoves, TV-sets and washing machines being started when people arrive home from work. To the right we have drawn a schematic combined version.

Picture 8.24. Electricity Load Curves During the 24 Hours of a Day



Source: world-nuclear.org (left) & Swedbank (right)

Base load and…

The varying level of demand will in turn cause various types of generation plants to be used at different times and it will cause the price for electricity to increase and decrease. As we have tried to depict the energy generation plants that, thanks to their low marginal cost run all of the time constitute what's called the base load of the energy generation. The lower half of the generation capacity that is at least used some time is called intermediate or mid load and the upper half is called the peak load. The part of the generation that with this demand is never used forms the reserve margin.

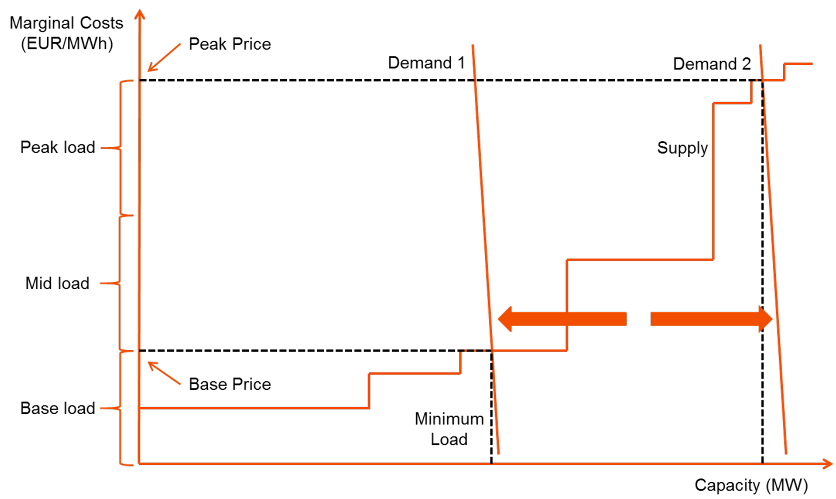
…peak load

Marginal cost and ramp rate

The base load will generally consist of both the generation from the plants that have the lowest variable costs such as wind, solar and hydro plants plus nuclear plants (depending on the level of taxes) but also of the generation from plants that cannot be shut down without great costs such as nuclear plants and coal fired plants. Which plants will deliver the intermediate and peak load will, apart from their marginal cost, depend on the ramp rate of the plant. It's no use having a low cost if you cannot deliver on time. In general gas powered plants, oil powered plants and hydro plants have quick ramp rates and are useful in balancing demand shifts. There are however relatively few oil powered plants left in the world.

Picture 8.25. Base and Peak Load

Demand variation during a day displayed by the two demand curves



Source: Swedbank

Supplied volumes to merit curve varies

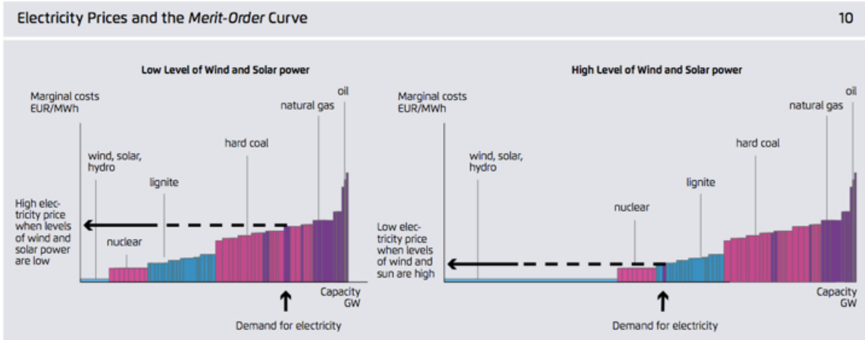
The supply-demand picture also shines light on why solar and wind energy have had such large effects on the energy price. In Germany solar energy supplies about 7 percent of the used power. However, during a sunny day this will be many times more and during night it will be nothing. The variable cost of solar and wind is about zero as sunlight and the breeze come for free. The peak load of the network is in the middle of the day and this is when according to the merit order curve above the pricing will be the highest. However, this is also when the power generation from solar energy is at its peak.

Sun shines at mid-day peak

As is evident from the right part of the picture below solar will add a huge volume of low variable cost generation, taking down the electricity price during exactly those hours that used to bring any real profits for the overall industry. In effect solar has taken over the entire peak load, meaning that the peak load pricing will be lower than otherwise during the day.

Picture 8.26. Effects of Wind and Solar on the Merit Order Curve

Shoot in more low variable cost volume and with stable demand the price will fall



Source: americaspowerplan.com

German politics

Thus, in Germany there will be very little chance for conventional power generation to earn any money to cover the fixed costs that give possibilities for future investments. In contrast, the sometimes relatively high fixed cost of the solar and wind generation is in part covered by state subsidies indirectly paid by taxes and fees among the conventional generators. The pain for the conventional plants will not abate. The German official governmental goal is to increase renewables' contribution so that they at a minimum will supply 35 percent of the power in 2020, 50 percent by 2030 and 80 percent by 2050.

Paid to exist

The problem with this is that energy cannot be stored in any really significant quantities. Thus, there will be a need for of massive amount of flexible energy generation to balance the networks when renewables aren't supplying enough capacity. This type of flexibility with quick ramp up could in Germany almost only come from gas-powered plants and imports. The thing is that with the small average volumes left, the fixed costs of those plants will be hard to cover. The conclusion is that state subsidies in the future will have to go to gas-powered plants that most of the time sit idly waiting. Alternatively, a mandatory "energy security fee" added on the all power bills could have the same effect. The return of these reserve generators would then probably have to be regulated.

Hypothetical example

Below we have tried to picture an example for the load curve and energy mix during a day without and with renewables. To the far left there are no renewables. Nuclear and/or coal supplies a large part of the baseload due to their low cost and limited load factors. The more flexible hydro and natural gas is used to balance the load. When we introduce solar and wind we get a second set of unknown parameters in addition to the varying load.

Decent wind and massive sunshine

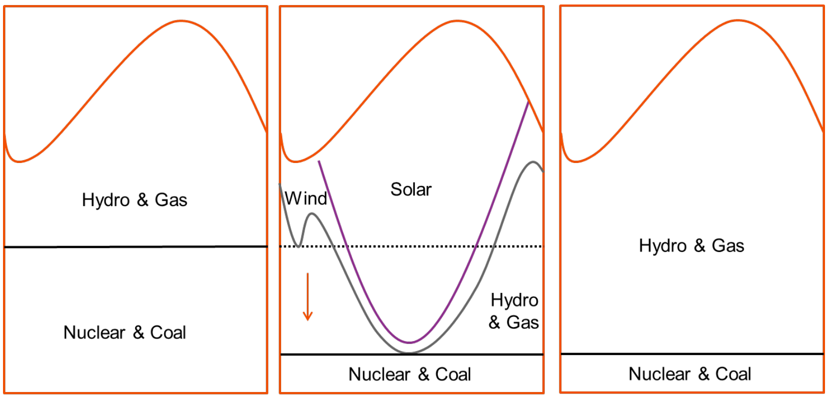
In the middle case there is some decent wind during night and then massive sunshine during the day. Before the dismantling of any nuclear and coal plants has been made there will a surplus of energy in the network that must be exported or the network will overload. After the adjustment of capacity (shown with an arrow) nuclear and coal will have a lower part of the energy mix. Hydro and gas will before the dismantling be squeezed from both solar and wind with near zero marginal cost and nuclear and coal that cannot change volumes. Post closure, hydro and gas will have to supply anything from zero volumes in the middle of the day to almost as much as before in the middle of the night. Note that at traditional high peak prices, it's not only large scale solar plants that undercut prices but also smaller, rooftop solar installations.

No wind or sunshine

But what happens the next day to the far right in the picture when the wind doesn't blow and the sun don't shine? In this case hydro and gas will have to make up for both the volume it had from the beginning plus the volumes from the closed nuclear and coal plants. Alas, there will be massive demands on the flexibility of the system. Depending on the time of the day and the weather this day hydro and gas will have to shift volumes in an unprecedented way. To be able to do this there will have to be gigantic spare capacity of hydro and gas generation in the system that often will be unused.

Unprecedented demands on flexibility

Picture 8.27. Load Curves and Energy Mix With and Without Renewables



Source: Swedbank

More plants and interconnecting lines…

There are some factors that will soften the above blow to the energy system – if not to the traditional power generation plants. The more solar and wind plants that are deployed the smoother the renewable generation will be since when more spots are covered the chance is higher that the sun is shining or the wind is blowing at any of these spots. Also, a more interconnected grid with better transmission capacity between countries, regions or even continents will smooth the generation as the sun is always shining and the wind is always blowing somewhere on Earth. For example, Southern Europe has better potential for solar power while Northern Europe has more potential for wind power. Connecting them sounds like a good idea. Transporting power over longer distances will however lead to larger energy losses as a percent of total generation.

…but above all batteries!

The real Holy Grail in all this is battery technology. If electricity could be stored on a large scale, the dynamics of the industry would change completely. Then the variations in the power generation from renewables could simply be balanced by tapping the battery reserves to meet the demanded load. The demands on flexibility delivered by conventional fuels would then disappear. 100 percent renewable power is then suddenly possible. Thus, environmental activists should focus less on marching around in polar bear costumes and more on supporting research on battery technology.

100% renewables…

According to the Swedish Minister of Energy Ibrahim Baylan the aim for Sweden is to have 100 percent renewable power generation. Hydro and nuclear account for roughly 40 to 45 percent each of the Swedish power generation and the rest is mainly renewables. If renewables were to phase out all nuclear then the amount of hydropower would be hard pressed to balance the load variations in the Swedish grid – especially during a year of drought.

…need improved battery technology

There could only be 4 solutions: 1) Build more natural gas plants and in effect increase the Swedish CO_2 emissions, 2) Build out interconnecting lines to neighbors and let import/export balance the network. This brings the risk that other countries haven't been as ambitious in their conversion to renewables and that the Swedish CO_2 emissions rise as we purchase fossil fuel generated power. It also requires a great number of countries to build out interconnecting cabling. 3) To order energy intensive industries to shut down production in a situation of energy shortages, with the consequence that after a while they will migrate. 4) A more extensive use of batteries so that stored electricity can balance the networks. Renewables pretty much need improved battery technology.

8.5 Governance

Price, security and mix

Policy makers care about the consumer price, the security of supply and the energy mix. The two main themes of the public governance of utilities the last three decades have been 1) the regulatory framework put in place in the deregulation era and 2) the aim to support renewable power. With more renewable power the security of supply and balancing of the network has come into focus again.

Need for stability

For an industry that invests heavily in power plants that are meant to last for 40 to 60 and sometimes even 100 years, the frequency of regulatory changes is a major headache. In Europe and Japan the regulation is handled on a national level. In the US there is a mix of federal regulation, state regulation and even regional regulation making it hard for investors to get an overview of the regulatory regime for individual companies and stocks.

Regulation

The deregulations that swept over the world in the 1990s had grand ambitions to encourage competition and by this lower prices for customers, to provide safe supply and to optimize the infrastructure and raise the productivity of the assets. Since then a vast number of new regulations have been targeted at encouraging new renewable technologies.

Supporting renewables

Governments are encouraging investment in renewable power through a vast array of measures that are not always easy to penetrate. There are investment subsidies, feed-in-tariffs that guarantee a fixed price level (or a certain floating additional remuneration added on top of the market price) to guarantee or facilitate a high return on investment, tax credits, green certificate schemes that favor low emitting companies and favorable loans. Most of this is financed by taxes on traditional power generators which have to pass the bill on to the consumers at their best ability.

Smart grid

The emergence of the smart grid now poses a challenge to the regulator. Much of the benefits of the smart grid fall on the consumer but it will have to be the grid operator that makes the investment. Incentivizing this investment is a delicate task as the traditional incentive was to allow a certain return on new investments. The smart grid might lower the capital base that returns are allowed on –

how do you remunerate a monopoly for not building things?

Reserve margin

One of the key points for an energy system is security of supply. This is ensured by stimulation of investments in the generation of new capacity but also by holding a reserve margin. The reserve margin is defined as the available capacity to produce and transmit power above the capacity currently needed to meet normal peak demand levels. Regulators usually demand a buffer of a 10 to 20 percent reserve margin.

FERC – Federal Energy Regulatory Commission

The two main governing bodies of the US grid are FERC and NERC. They are complemented by a small army of Reliability Council Regions and Reliability Coordinators which are responsible for the balancing of the networks. FERC, Federal Energy Regulatory Commission, is an agency within the Department of Energy that has the responsibility for the power grid. FERC regulates, enforces standards and investigates anomalies.

NERC – North American Electric Reliability Corporation

Much of the practical handling of what FERC decides falls on the NERC, North American Electric Reliability Corporation. The NERC is responsible for promoting the reliability of the networks. NERC also investigates major events of the grid and performs research. Further there are so-called RTOs and ISOs that are not-for profit organizations who own the local parts of the transmission networks and organize the wholesale trading markets for power.

<u>Taxes and fees</u>

Apart from the normal corporate taxes there are a number of sector specific initiatives within utilities.

Cap-and…

Cap-and-Trade: In 2003 CO_2 trading was implemented in the EU in the form of CO_2 certificates. This added an extra variable generation cost for plants that had to be reflected in the market pricing. Depending on the level of CO_2 emission the level of added cost will vary. This might even reshuffle the merit order of power plants making those emitting more CO_2 less in demand. These types of schemes are called cap-and-trade. The "cap" reflects that politicians set an aggregated limit on CO_2 emissions in billion tons per year. The CO2 certificates that represent the total allowed emissions are distributed or auctioned to the power generators. The cap is subsequently lowered over time according to a schedule which allows for corporate planning of future investments. The current glide path of the cap in the EU means that emissions in 2020 will have to be 21 percent lower than in 2005. Companies can only emit as much CO_2 as they own certificates and exceeding this level will be penalized, ensuring that the targeted level of emissions are met.

…-trade…

The "trade" part is a market for CO_2 certificates that should help to allocate the costs efficiently. The less generators emit, the less they pay. Some companies will find it easy to match their number of permits with their emissions; others will find it more difficult. Trading lets companies buy and sell certificates. Companies can then on the one hand turn emission cuts into revenue. If a company is able to cut its emissions, it can end up with more certificates than it needs. It can then sell these. This provides an incentive for creativity, energy conservation and investment. On the other hand the option to buy certificates gives flexibility for companies that have trouble reducing their emissions to the required levels. Trading gives these companies another option for how to meet each year's cap.

In the absence of over-allocation of CO_2 certificates, the price of CO_2 should reflect the marginal cost of switching power generation of for example coal to natural gas. Due to a massive over-allocation the prices of the certificates has been extremely low and too low to really matter. The system has received tough critique from environmental groups and it is currently under EU review for change by 2020. Thus, some view the current system as a failure as the most emitting companies aren't sufficiently "punished", but it's really not. Instead it's a consequence of the fact that the amount of emitted CO_2 has been so much lower than the politicians forecasted. The target for 2020 has already been achieved since long. This is due to both the slower economic growth and the increased energy efficiency. The business sector lowered emissions much faster than the politicians ordered it to. Thus, the cap was set much too high to have any relevance. This should be a thing to celebrate rather than the opposite. However, the low prices of CO_2 certificates has meant low subsidies for renewable generation and in combination with low prices most wind power farms are for example in real pain right now.

…flops for the right reasons

Carbon taxes: Carbon taxes is a more direct tool than cap-and-trade but have the same aim to reduce CO_2 emissions. A tax is simply levied on the generation of power in accordance to the carbon content of the fuel. It has the advantage of letting companies know the exact level of additional variable cost placed on them but on the other hand the effect on the total emission level cannot be guaranteed.

Carbon taxes

Generation capacity taxes: A fixed tax on the total generation capacity of nuclear power plants (or on hydro plant). This will have little if any effect on the electricity price as this is determined by the variable cost of the marginal producer. It will mostly be a straight loss for the operator that keeps less cash for future investments. Neither will the tax affect volumes much as nuclear plants are run at more or less full capacity until they don't run at all. In times of low prices or low capacity utilization, a fixed tax level will hit relatively harder. This is the situation today in Sweden. At times the tax has been higher than the total sales for nuclear and hydro plants. Taxes should really be taken out of actual profits, not hypothetical ones.

Generation capacity taxes

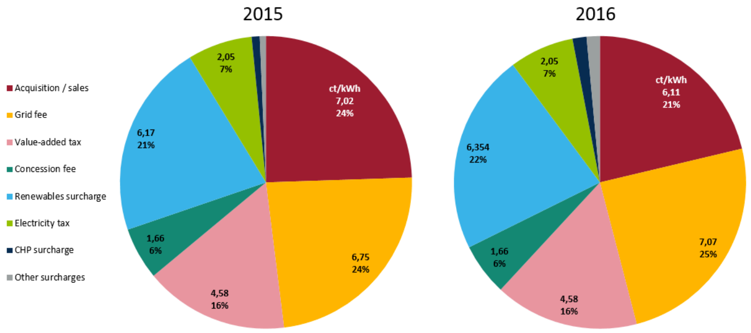
Subsidies

Feed-in tariffs: One way to subsidize renewable power is feed-in tariffs that guarantee generators of wind and solar power a certain price regardless of the market price. In 2004 the German feed-in-tariffs for solar energy peaked at incredible 57 Euro-cent per kWh. They have subsequently been lowered to 13 Euro-cent (and 19 Euro-cent for wind power). The subsidies have been financed by the so-called EEG surcharge placed on the electricity generation from conventional sources. In January 2016 the average German wholesale price for power was about 6 Euro-cent or 21 percent of the total retail bill of 29 Euro-cent. The renewable energy surcharge is a larger part of the total bill than the payment for the electricity so the consumers are paying dearly for the structural change of the market. The Germans have had the highest cost for electricity of any European country the last few years.

Feed-in-tariffs

Picture 8.28. German Household Power Prices 2015 and January 2016

What is the bill for?



Source: German Association of Energy and Water Industries, BDEW

Carbon subsidizes

Fossil subsidies: The sad irony is that on a global scale the subsidies that go to support fossil fuels are even higher than those that support renewable power generation. In 2013, the International Energy Agency (IEA) estimated that consumer subsidies for fossil fuels amounted to USD 548 billion (USD 557 in 2008), while subsidies for renewable energy amounted to USD 121 billion. It isn't exactly the same countries that are doing both types of subsidizing though. The fossil fuel subsidizers are mainly in producing countries like Saudi Arabia, Russia, Iran and Venezuela but the public debate has mainly centered on those that also exist in the US and Europe. The Venezuelan gasoline price was until recently 1.5 US cents, but due to strained state finances it was raised to 19 US cents.

Sweden

Sweden deregulated 1996

The electricity market in Sweden was deregulated in 1996. As the client, you can thus decide who you want to purchase your electricity from. However, electricity distribution via the electricity network takes place in a monopoly so here you will be assigned the network owner in the particular region. Electricity network operations in Sweden are regulated by the Swedish Energy Markets Inspectorate (Ei).

Cap and trade

The Swedish electricity certificate system is a market-based support system that aims to increase the proportion of renewable electricity production. For every MWh of electricity produced by an approved facility from a renewable energy source the owner of the facility receives an electricity certificate that then has a resale value. The buyers of electricity certificates are organizations that have what is known as a quota obligation. These are electricity suppliers and certain electricity users who are obliged to buy a certain proportion of electricity certificates in relation to their electricity sales or electricity use. The size of this proportion is set through a percentage rate (quota) for each year. The quotas are calculated based on the expected expansion of renewable electricity, expected electricity sales and electricity use by the organizations with the quota obligations. As part of the integrated climate and energy policy, Sweden set in motion an action plan for renewable energies. This included a higher ambition for the electricity certificate system going forward.

8.6 Business Models

Generation: Large long-lived assets -> scale economies

Traditional power generators build their long-lived power plant investing huge sums and creating a large asset base that through depreciations gives large fixed costs. This means that there are large economies of scale. Generators need to spread their large fixed costs over large sales volumes. Further, they purchase the primary energy source (like natural gas or coal) at a market price and they produce power to sell at a market price in competition with other power generators. The obvious economic challenges come from the size of the price spread between the input bought and that of the output sold and from selling enough volume to cover the large fixed cost of the plant. Price swings for either the input commodities or the electricity will matter hugely. Other challenges are security and environmental issues.

Spark spread
Dark spread
Quark spread

The so-called spark spread is the gross margin on a gas-fired power plant measuring the price spread between natural gas and electricity. The spark spread must cover all other operational, financial, regulatory costs and taxes. The dark spread is the same for a coal-fired plant and the quark spread for nuclear power. This commodity exposure gives a fairly high risk/reward. A diversified mix of generation plants with different fuel sources is – as long as it doesn't drag down the load factor too much - beneficial for a generating company as it can then adjust volumes depending on relative fluctuations of input prices. This substitution between technologies means that changes in for example the natural gas price will have effects on the sales and profitability of coal plants.

Grid: volume & regulation

The transmission and distribution operators maintain and develop the grid. They build the network, also investing huge sums creating a large asset base that through depreciations gives large fixed costs. The payment is volume based and as such not vulnerable to changes in electricity prices. As they are natural monopolies the pricing is regulated. There is an incentive to invest, as there will be a larger regulated asset base to apply the allowed pricing on. The obvious economic challenges come from a prolonged drop in volumes lowering the utilization in the networks or if the regulated price is changed (or other regulations tightened). Other challenges are handling network congestion, connection of new power generators and of interconnecting sub stations and the security of power supply allowing for stability and power quality. As long as it is business as usual the regulated transmission and distribution assets can be seen as low risk/return. Periodically, say every 4 years, the regulation will change, generally causing the profitability to go down.

Low margin retailers

In supply the retail companies basically trade electricity as they buy the wholesale product and sell the retail product through various pricing schemes in competition with other companies. Further, they read the meters and finally bill and collect their revenue. Instead of buying the electricity that trades on the wholesale market, companies can also buy electricity direct from generators on medium-to-long term contracts. The asset base is very small but on the other hand the retail business is very competitive so the margins are often razor thin. To succeed the companies must be excellent marketers to generate new volumes and have excellent customer service to keep the customers they got. They must be highly efficient to get any margin at all and it is also important to hedge the wholesale price of electricity as it has such large effect on the profitability.

The retail price

The retail price for electricity will over the long-term have to cover all parts of the value chain. Over the short-term the market price does not guarantee this. The price level is in general a good indicator of the financial health of all of the participants of the industry. Out of the value chain's total economic cost, the generation with its raw materials cost is the major part with 50 to 65 percent. Then comes distribution through the finely meshed local distribution networks with 20 to 30 percent and finally supply and transmission will be of about equally small size with 5 to 10 percent. Note that the network costs (T&D costs) are fairly stable but the fuel costs are not. Then, depending on the country, taxes and public fees could be either a very small part of the electricity bill or even the largest part.

Risk margin squeeze

Despite the business model's dependence on sales volumes the regulator has often mandated retail companies and utilities in general to advocate energy efficiency. Further, due to the politically sensitive issue of high and volatile power prices for end-customers there is always a lurking danger of price intervention. In many countries the prices are set to pass through the costs and provide a margin determined by competition. A pass through model is relatively low risk/reward. In some instances there could be price caps introduced. With politically fixated retail prices and volatile wholesale prices the margins for supply companies can quickly turn blood red. In for example France the retail tariffs are set by the government to protect end-consumers from volatility, leading to potential margin squeezes for the retailers. In an, eventually unsuccessful, attempt to win the last UK election the Labor Party promised to freeze retail power prices for 20 months. Companies in retail have internal execution risks and external regulatory risks.

Asset life

With the high amount of fixed costs, i.e. investments in plants and power networks, an investor is well advised to keep track of the asset life of companies. Aging assets that soon will need to be replaced in combination with high leverage that impedes the funding of the required investments are not an attractive duo. The potential asset life varies by technology. Hydro plants could live to see their hundredth birthday. Nuclear plants can have a life of up to 60 years. Most other plants will have a life of perhaps 40 years. In Europe nuclear plants are ageing, while the gas-powered plants are relatively young. This obviously applies to renewables as well.

Attackers: energy efficiency, solar and batteries

The business models of the different traditional utilities are for a long time going to be under severe attack from a combination of energy efficiency, solar power and battery technology. Both conventional power generation plants and the transmission and distribution networks have high fixed costs. Normally, this works as an insurmountable barrier to entry, hence the term "natural monopoly" for the grid. There is simply no point in building a parallel grid. However, a company with high fixed costs that loses volumes will risk getting caught in a negative feedback loop. With a lower volume to cover the fixed cost, a higher price per customer must be charged to cover it. A higher price will further increase the risk of customers leaving, lowering volumes even more and so on.

Harsh backdrop

In the OECD area energy efficiency measures have lowered the underlying demand growth for electricity to zero. Also, with the functionality of the smart grid consumers will have better flexibility and the ability to lower energy consumption. Soon peaking population numbers will not help the demand. The backdrop for traditional utilities in the US and in Europe is hardly cheerful to start with.

Solar is…

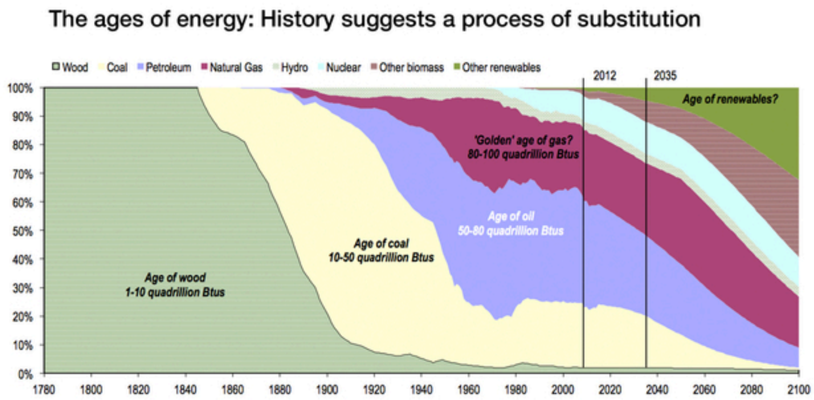
Now, with prices for solar energy going through the floor it is not a daring guess that the amount of solar panels installed on residential rooftops - and why not on the store rooftops of MediaMarks, Targets, Tescos, Wal-Marts and the likes as well? In 2013 about 29 percent of incremental power installations in the US were rooftop solar panels. Out of the houses that the Japanese house builder Sekisui House sells, 60 percent now comes with self-sufficient solar and storage systems. June 9, 2014 at lunchtime solar energy produced 51 percent of the power in Germany (and on November 3, 2013 wind generated more than 100 percent of the power demand in Denmark).

…nearing its tipping point

The tipping point for solar energy is closing in everywhere. A technology that used to be kept alive by subsidies will soon be the cheapest one all by itself. With smart metering consumers will expect to be able to sell their surplus power to the grid. As we have seen previously the maximum sunshine occurs during the traditional peak hours of power load, i.e. those precise hours when the price is high enough to make the utilities profitable. The inflow of large volumes of solar generation instead risks making the peak hours the least profitable – taking the profitability of the entire conventional power generation industry down.

Picture 8.29. Renewables Crowding Out Conventional Power

Historical diversified energy mix right now



Source: IEA & EIA

Model needs to change

Irrespective if the solar power is consumed by the owner of the rooftop panels or is sold back to the grid together with solar and wind energy from larger parks, the consequence is that the demanded volumes will shrink for the conventional generation. The demand from the so-called peakers, that is the traditional plants that generally balance the grid in peak hours will fall away. But, then the flexibility of the grid to balance will suffer and when renewables don't generate power there will be a risk of shortages. The future financing of generation capacity with load rates high enough to balance the grid will be a tough governmental nut to crack, but will probably end in a change of the entire remuneration structure of the power generation industry. Straight payments to keep capacity are not inconceivable. A combination of energy usage payments and capacity keeping payments would probably be seen as a political failure in many countries as it in the intermediate future would sustain fossil fuel generation. However, it would be a temporary solution to provide energy security until better battery technology can facilitate a fossil free generation.

Elon Musk – the friend of renewables and the foe of oil

Since the sun doesn't always shine end-consumers will still have a need for access to the grid the rest of the time and then there could always be a fixed fee charged to make up for the losses – if it weren't for batteries. Battery technology has been lagging, making large-scale energy storage hard and very expensive. Right now the development is however speeding up and Elon Musk of Tesla fame is working hard with a new business proposition, selling large batteries that store energy for households. This would allow consumers to become cord cutters. Their excess solar power wouldn't be sold to the grid but instead stored until the sun doesn't shine. So there it is, the negative feedback loop. With lower volumes and customers leaving, the need arises for higher outtakes of those customers who stay, further adding to their incentive to leave as well. The last remaining customer would have to pay for the entire park of power plants and cable networks - ouch…

Smaller regulated asset base…

But this doesn't concern the regulated profitability of the grid right? Wrong, the business model is indirectly volume based, earning money on the amount of power transported in the grid. Residential rooftop generation (or any distributed technology as long as it is situated close to the customers), battery storage and cord cutters will hardly increase the grid volumes. The secondary effect will be a smaller need for investments in the regulated asset base, i.e. the base that the allowed regulated profit is based on. A percentage based on a shrinking base will mean shrinking profits and since the grid is a high fixed cost business as well, the same type of negative spiral could develop here. With high leverage the lowered credit rating for those caught in this spiral will add to the pain.

…or not?

Now, the situation might not be all this bad for all grid operators – at least not in the medium term future. As we introduce more of the renewable intermittent types of power there will be requirements for more interconnectivity between networks and investments in long-range cables, i.e. in the transmission network. The net fluctuations of many uncorrelated fickle power sources in a large interconnected network are lower than for the few of a smaller isolated network. Further, renewable power generation plants tend to be located further away from the population increasing the need for transmission. And since solar plants and wind parks tend to be smaller than conventional power plants there is a need for a denser transmission network. So, then is the distribution network doomed? No, not if they will be allowed by the regulator to add the investments needed to upgrade the network to the denser, more interconnected two-way network needed for the smart grid to the regulated asset base.

German role model?

Yes, we know we have extrapolated heavily above when looking into the long-term future and the sun doesn't shine equally bright everywhere, but the development in Germany shows that the description isn't far-fetched. Germany today might be tomorrow's story for the rest of the world displayed. Suddenly the trading operators and retail businesses that don't sit on large fixed asset bases start to look like the relative long-term winners in this industry. The developments within energy efficiency and solar power are relatively assured. The most uncertain link in the line of reasoning is the batteries. They may not develop as fast as pictured above.

The EV-hope

The largest caveat to this gloom and doom case is electric vehicles. Transportation with various vehicles consumes almost as much energy as the entire power production today. The demand consequences of a large scale shift from internal combustion engines to electric motors shouldn't be underestimated. Such a shift would end the age of oil, delay the demise of conventional power generation as all sources will be needed for a while but also kill the peak load through the huge increases in battery capacity.

8.7 Utilities Investing

Don't if not dirt sheep

Our first advice to equity investors on how to invest in utilities would be: don't. High fixed cost businesses that risk seeing declining sales are seldom a good investment prospect. The European utilities sector is in the midst of a huge structural change that will continue for a long time and where the winners are hard to single out. The US utilities sector is still relatively untouched but will probably have to walk the same path later on. Profit margins for utilities in Asia Pacific, Japan and Europe have been trending down for over a decade. The US margins are still stable thanks to a larger degree of regulated profits, constantly lowered financing costs from declining interest rates and less renewable energy in the US generation mix but we wouldn't bank on that continuing. With that said, the merit of an equity investment is obviously always a matter of price.

Boom sectors no profit guarantee

Operators of renewable power will in aggregate surely grow from a volume point of view but are risky as investments as their earnings are at the mercy of a number of political decisions. Also, in general too much money tends to flow into sectors with high demand growth, making the ROIC of these areas low and the areas prone to boom-bust cycles. Anecdotally, the person who had invested in all the car companies that emerged in the transition from horse trolleys would have lost over 90 percent of his money. The safest bet is probably investments in regulated network assets but these could also see potential volume pressure if distributed energy generation takes off and there are always regulatory risks. Politicians are after all politicians.

Corporate bond investing

By tradition, bonds issued by utilities have been perceived as a sort of safe haven investments. Instruments rather expensive (i.e. narrow credit spreads) versus the fundamental rating has been one consequence of this. Often this perception could be a consequence of the ownership structure, several of the large integrated utilities in Northern Europe are still, in full or partly, government owned. Although this is also expressed in ratings, the market seems to incorporate this even beyond its actual impact on the long term credit rating. Obviously, the combination of expensive instruments and a sector exposed to a global structural challenge is not a very attractive one. No doubt, we have seen a certain price correction amid the development but the market pricing is not yet fully aligned with ratings, i.e. spreads still narrow given rating. Furthermore, we will see more downgrades to come.

In several cases utilities have issued hybrid bonds partly with the aim to protect their credit risk profiles, partly as a tool for accessing new capital as a government owned entity without access to the equity market. Investment levels are however historically low, probably limiting the supply side of the bond market going forward. Given the market development as well as regulatory and political challenges, we are underweighting the sector in our general credit market portfolio. Within the sector we prefer companies more oriented towards grid/transmission system operations amid low business risk with highly regulated operations and thus relatively transparent cash flows.

We prefer grid exposure

Investors in European utility stocks have seen three eras with very different market environments. Until the 1990s the listed utilities were partially state owned integrated monopolies or oligopolies. Competition was minimal, prices centrally administered and through long contracts the volatility in commodity prices was limited. Earnings and cash flows were very stable enabling cheap financing via debt and high and growing dividends. Thanks to inelastic demand the stocks were perceived as defensive, although with high capital intensity and heavy regulation. Utilities were seen as dull bond proxies and changes in interest rates were the main share price driver. Declining interest rates not only lower the financing costs but since the regulated, “allowed” return on capital for the grid is changed only infrequently, a decline in rates increases the spread that the utilities earned.

Era 1: Bond proxies

With the strong demand for defensive stocks between mid-2000 and early 2003, the commodities boom being born 2003 and strongly increasing customer demand, a bull market started for the now oft-privatized utilities as the power prices and the sales volumes rose. Regulation incentivized investments in networks and many companies went on shopping sprees with cheap borrowed money, increasing the dependence on capital markets. Since utilities were seen as defensive they could finance their expansion at very attractive interest rates. This made utilities a large part of the debt market as opposed to their rather limited position on the equity market. Although competition was rising and the former incumbents to a varying degree were market share providers to their new competitors the competition was still manageable and the rising sales alleviated any pain. The relative PE-ratios from 2006 until early 2008 were the highest ever.

Era 2: high-life

The turn of the tide came in the form of the one-two punch of the financial crisis in 2008 and an escalating growth in renewable generation. First, in the financial crisis the industrial demand fell away, the commodity prices tanked bringing down electricity prices and to add insult to the injury the indebted Governments needed money and financed some of this through imposing special taxes on the equally indebted utilities. However, when industrial demand in the end slowly returned after the crisis and commodities prices started to rally again the new supply of renewable generation had started to change the market structure, giving a continued bear market for the utilities.

Era 3: the one-two punch

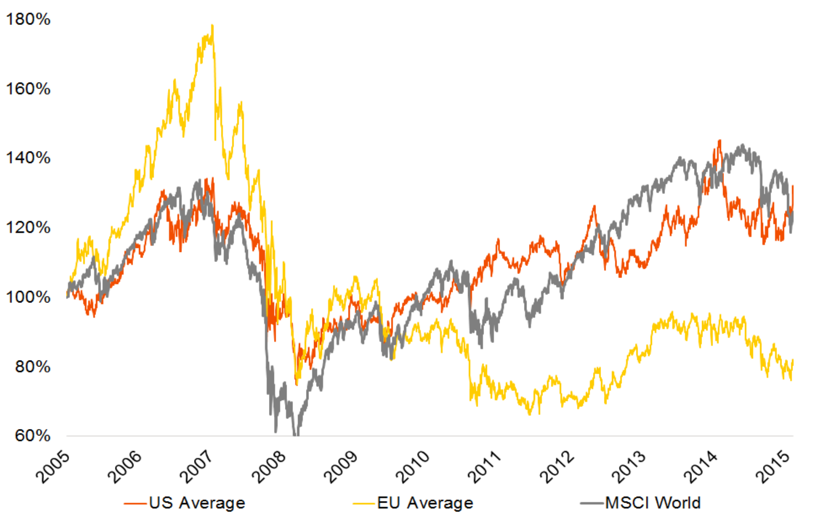
Among the larger US utilities are Southern Company, American Electric Power, Duke Energy and Exelon. They still to a large extent live in an environment similar to the first European era. They have a higher degree of regulated prices, the amount of renewables in the

US still in era 1

energy mix is smaller than in Europe and interest rates are as low as ever. The largest European utilities are e.ON, GDF Suez, Enel, EDF and National Grid. While the more regulated US companies have performed in line with MSCI World, the boom-bust cycle of the European stocks is clearly visible in the picture. The dismal European outcome is still including a 94 percent uptick for National Grid.

A tale of two fates

Picture 8.30. Average Price Performance of US and EU Utilities

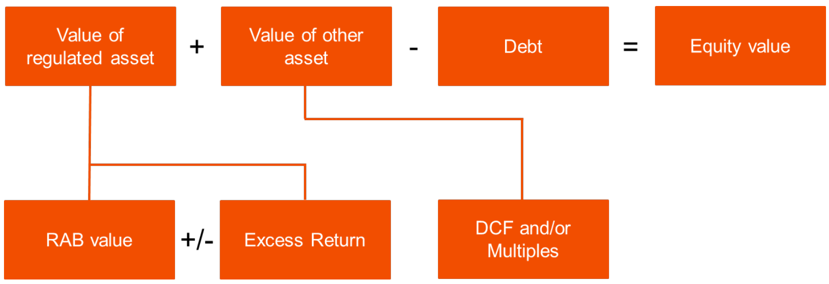


Source. Factset, Swedbank. US average of Southern Company, American Electric Power, Duke Energy and Exelon. EU average of e.ON, Enel, EDF and National Grid. All in local currency. MSCI the World Index in USD.

The largest utilities are to a large extent still integrated companies with the exception of National Grid. This means that the analyst benefits from doing a sum-of-the-parts valuation. The unregulated businesses and the regulated business are simply not similar enough to lump together.

SOTP needed

Picture 8.31. Valuation of an Integrated Utility



Source: Swedbank

Value of unregulated generation

If possible the unregulated generation parts of utilities should be valued plant by plant through a DCF. The revenue is among the trickier parts of this calculation. The DCF will in a first step have to model the yearly installed capacity of the various plants the company operates to reach a total yearly production capacity in MW. A load factor for each plant will have to be estimated based on its positioning in the merit order. Some plants will be in use around the clock and some will mostly be idle. This will result in an estimate of the total number of dispatched MWh for a year. Then an estimate of the mix of power sold on spot vs. at 1 year forward, 2 years forward or 3 years forward prices and also of what these prices will be. After reaching a time series of future revenue projections, costs and investments can be deducted to reach a cash flow.

Little differentiation but understand specific regulation

The cost structure of the power generation plants will differ depending on technology. Capital intensive technologies generally have low fuel costs and vice versa. The relative strength between technologies change due to changes in fuel costs, capital costs and regulatory burden. In general there will be relatively little differentiation between generators using the same technology. The supplied electrons are the same, but if an efficient operator have closer proximity to an urban area than competitors this can give a small edge – until someone else builds a competing plant nearby. Further, high returns will also attract the attention of regulators in this political sector. For an investor in a company that has regulated assets it becomes important to understand the regulation for this specific company or region and the relations it has with authorities.

RAB – Regulated asset base

RAV – Regulated asset value

The enterprise value of the regulated assets in transmission and distribution is generated by the concept of Regulatory Asset Base (RAB) or Regulatory Asset Value (RAV). The regulator of a country will determine the allowed returns on the RAB for a period of 3 to 10 years. The aim for the regulator is to determine an allowed return on assets ("the capital") that equals the economically fair cost of capital for investors. The return on capital will generally be the pretax, return on invested capital, ROIC in Europe and the return on equity, ROE in the US. The cost of capital will be the weighted average cost of capital, WACC in Europe or cost of equity, COE in the US.

Start with RAB, end with price

In this the regulator has to strike a balance between stimulating investments but not allowing the utility to utilize its monopoly situation. In the case that the allowed ROIC equals the WACC, the enterprise value of the regulated business will equal the regulated asset base (EV/RAB = 1). The regulatory process starts with the assets and with the allowed ROIC as a bridge works its way from the allowed profits to allowed sales and further to allowed prices. The allowed prices are then meant to follow inflation minus a factor reflecting efficiency gains (CPI – x). This allowance for inflation means that regulated utilities can work as a lagging inflation hedge if the "x-factor" isn't too severe.

RAB example

Let's look at a European example. The average RAB is set by the regulator by taking the ingoing balance of the assets plus estimated new capex, minus D&A which is determined by deciding the economic life of the assets and finally adding an allowance for inflation to end up with an outgoing balance for the assets. The allowed ROIC that is meant to equal the WACC is applied on the average of the ingoing and the outgoing balance of the RAB. Since an inflation factor is added to the asset base the RAB will generally be higher than the accounting asset or book values. Also, the depreciation sums will not necessarily be the same.

Builds P&L bottom-up

ROIC times average RAB equals allowed EBIT. Notice that a larger RAB means a larger profit. Future investment opportunities due to ageing infrastructure will thus be a way to increase both sales volumes and the profit. The regulator builds the P&L bottom-up. Based on projections of investment needs, future volumes and of increased operational efficiencies, estimated levels of D&A and operating costs are added to EBIT. With this we arrive at allowed revenues. With the allowed revenues and given the volume estimates and the CPI-x the allowed price can be backed out. The allowed revenues are meant to cover investments to secure the supply of power and provide a reasonable return for shareholders.

Premium or discount

The business will be valued with a premium or discount to the RAB depending on whether it generates (or the investors expect it to generate) a ROIC which is above or below the WACC level set by the regulator. The operator can outperform by having higher volumes than expected, by having lower costs of operations or financing or by investing less than expected leading to less D&A. The latter comes with a downside as increasing investments means growth in the asset base that the allowed ROIC is applied on. With scale also follows scale benefits that could lower operational costs. Another obvious way to increase the RAB and thus the allowed size of the profits is by acquiring other companies. Further, the stock market could also assign a premium valuation to the RAB if there are expectations of the company being acquired or a discount if there are fears of future adverse regulatory interventions.

Period give-back

The fact that the regulation runs for a number of years allows companies to optimize their business and lower costs to increase the excess returns. Some of these will then have to be given back to the consumers when the next review comes. The regulator in this tries to emulate the effects of competition. The regulatory regimes in the US vary by region and the allowed return on capital could either be pretax or post tax and stated either in nominal terms or real terms. The return on capital is often ROE where the equity is the regulated asset base. The handling in the US is also somewhat complicated as the distribution and supply steps of the value chain often haven't been unbundled and larger parts of the value chain are regulated on average.

Sweden

The regulated income for each Swedish grid company is capped by the Regulator. The regulated income covers reasonable costs to operate the distribution business and provide a reasonable return on the capital required to run the operations, the capital base. A reasonable return is to correspond with the return required to attract capital investment in competition with alternative investment with a similar risk profile. Before each regulated period, each grid company has to apply for a regulated income level. The Regulator then decides no less than two months prior to the beginning of each regulated period what that income shall be.

The regulated income in Sweden consists of three main elements: 1) Opex that cannot be controlled include taxes, fees or network costs; 2) Opex that can be controlled include operating costs for fixed assets, measuring, monitoring, reporting, net planning, vehicles and administrative systems and finally the 3) Capital base includes the core assets that are actually used in the grid business such as the grid network, but does not include such assets that may be required for the business, but are not directly linked to the grid business, such as land, buildings and vehicles. Whilst WACC is also used for unregulated businesses, there is an important difference between market WACC (rate of return floor) and regulated WACC (rate of return ceiling). This means that whereas an unregulated company would be required to have a minimum WACC to attract investors, regulated distribution businesses are not permitted to have a WACC exceeding a certain percentage.

Multiples

Further, the valuations of the regulated and unregulated businesses should be backed up with valuation multiples. Multiples often used are PE-ratios, EV/EBITDA, dividend yields or even EV/KW. The fact that utilities returns to some part are regulated has lowered the average return on capital to a quite a bit lower level than in the industry at large. This combined with the slow growth has meant that average valuation multiples also have been lower than for the rest of the stock market.

Also look per geography

Given the importance of regulation in the industry it is well worth doing a review of the assets by country. Countries also differ in the degree of competitiveness as could be measured by the Herfindahl-Hirshman Index (HHI). Different companies split by both business type and geography will give stocks different relative performance depending on changes in 1) commodity prices, 2) economic growth and 3) regulatory regimes. For those who think they are able to forecast these swings this opens up for pair trades where you for example go long stable companies with a high degree of regulated assets and short risky generators in a bear market.

Moats of less worth

In some respect you could argue that the regulated businesses have a sustainable competitive advantage as the grid parts are natural monopolies. However, the point of having a competitive advantage is that it gives a possibility of sustainable excess returns on capital of some magnitude. Authorities generally don't give regulated monopolies (or oligopolies as in mobile telephony) this possibility so the grass isn't greener inside the moat than outside.

US resistance will crack

European utilities have declined in market capitalization and their crisis is hardly unknown. However, we fear that the changes that are tormenting the industry group will continue to work against utilities for a long time. The more interesting case is the US utilities as they are still seen as safe bond proxies and have performed really well. We don't know when but our bet would be that this cannot continue. Solar will start to undermine scale economies and hit prices. Also, even if we would be wrong in this assumption; with interest rates at all-time lows – do you really want to own bond proxies?

Happy investing!