

The Future of Energy

How to power a modern civilization in a sustainable way

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1 Introduction

There have been many great inventions throughout the history of mankind. But one development was particularly astonishing as it would change the world forever.

In the 19th century electricity was a seemingly magical force to common people. But Thomas Alva Edison (1847-1931) worked tirelessly to change this fact. While many inventors had struggled to develop a form of lighting that would be cheaper, safer and brighter than traditional methods such as candles, whale oil, and gas, Edison succeeded in creating the first electric light bulb that would burn for more than a few minutes. In order to capitalize on this invention he also patented the first power distribution system and started to supply electric power to customers in New York City in 1882. Today Edison's General Electric Company is known as GE.¹

Electricity changed our world in many ways because it is the most convenient form of energy. It is easily transformed into mechanical work, light, or heat. Thus, almost all devices and machines – from air conditioning to our beloved TVs – are powered by electricity making the mastery of this phenomenon one of the most important accomplishments in the history of mankind. The need for power is growing rapidly as the population on earth continues to grow. This makes it all the more important to discuss how to power a modern civilization in a sustainable way. As this topic is very complex, I will put emphasis on the situation in Germany because all countries have different, very specific problems to deal with.

2 The Future of Energy

2.1 A Case for Renewable Energy Sources

2.1.1 Climate Change

There are two main reasons why renewable energy sources will eventually prevail over fossil energy sources. The first one has been discussed at length by a lot of people, which is why I will keep this part short. While some people still doubt the causal relation between the greenhouse effect and climate change, most scientists agree that our carbon emissions are the

¹ Appleby et al (2003)

cause of it. In order to keep the rising temperature and, hence, all of its consequences to a minimum we need to minimize our carbon emissions with the help of renewable energy sources which are carbon emission free.

2.1.2 Resource Scarcity and Market Prices

Although the logical chain above is irrefutable, I believe the second reason will be the deciding factor. Somehow, it seems the human race refuses to deal with problems that might occur in the distant future. Consequently, the threat of droughts, the extinction of species losing their natural habitat, and the destruction of entire ecosystems are not of concern to a lot of people.

Fortunately, everyone will eventually make use of renewable energy sources. Even the most adamant climate change doubters must admit that we will ultimately run out of fossil fuels. The scarcity of fossil fuels will make them much more expensive than renewable energy sources which are practically indefinitely accessible. The oil prices have made this trend abundantly clear over the past few years. Money, as always, will be the decisive force when making choices about the future of energy and, hopefully, will force us onto the right path.

2.1.3 The Nuclear Alternative

Of course, there is always the nuclear alternative which produces power reliably and is carbon emission free. However, nuclear fission is not a seminal technology because there is no safe way to dispose of the nuclear waste. Some fission products are strongly radioactive and have very long half lives of over 100,000 years (^{99}Tc).² Hence, nuclear fission cannot be a sustainable method of powering our civilization.

But there is another method: nuclear fusion. Nuclear fusion is the reaction powering our sun. It is the fusion of light nuclei into heavier ones under hot temperatures of up to 100,000,000 °C creating huge amounts of energy. Our sun, for example, uses hydrogen to create helium. A controlled nuclear fusion in a reactor would allow us to harvest the energy of stars.³ Nuclear fusion has quite some advantages over nuclear fission as it creates more energy and less nuclear waste. Nonetheless, it is still unclear where the nuclear waste can be disposed of. Moreover, fusion is still in the research phase. The hot temperatures makes designing reactors a very tough challenge as the plasma within would melt any material it touches. Hence, the plasma needs to be held in place by a strong magnetic field. Over the last 50 years

² Korea Atomic Energy Research Institute (2000)

³ Hoche et al (2003)

the scientists and engineers have learned that they need larger reactors in order to have the fusion process actually create more energy than it consumes. Unfortunately, these endeavors are highly expensive and do not seem to be as promising as the sponsors hoped it would be.^{4 5} As there is no large scale funding of nuclear fusion research like the Manhattan Project, I doubt it will become a profitable method within the next 40 years which is why renewable energy sources will have the edge over nuclear and fossil ones in the near future.

2.2 Powering the Future

2.2.1 The Importance of Space and Time

When talking about renewable energies it is often said that we need more photovoltaic cells and wind turbines. Especially, large-scale projects like Desertec⁶ and offshore wind farms become focal points of many discussions and attract great attention. One might come to the conclusion that all we need to do is build more photovoltaic cells and wind farms, but statistics show that Germany actually does produce more energy than it consumes even after the nuclear phase-out:

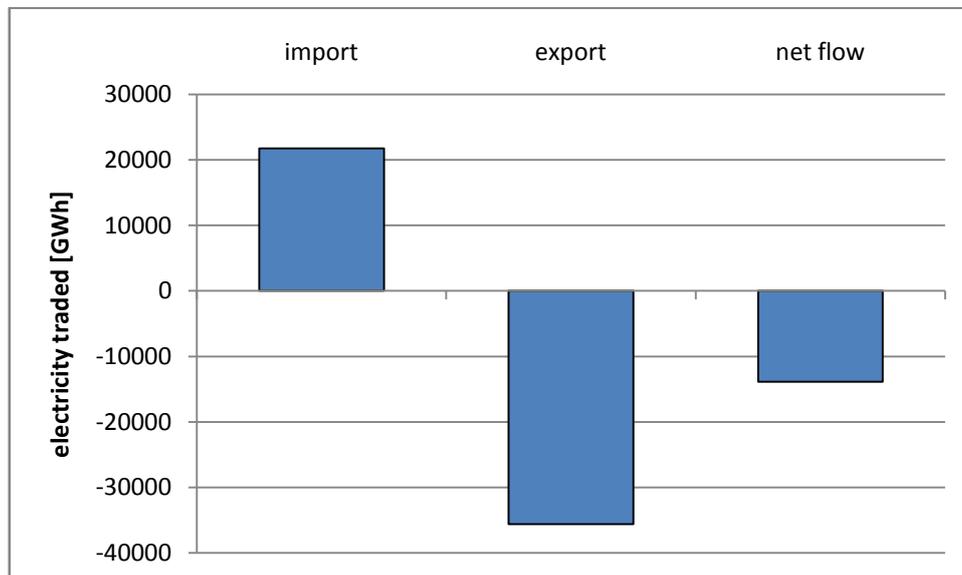


Chart 1: Germany's energy balance in 2012⁷

⁴ Röhlein (2012)

⁵ Meyer (2012)

⁶ DESERTEC Foundation

⁷ Bundesverband der Energie- und Wasserwirtschaft e.V. (2012)

Thus, generating more and more electricity on sunny and windy days cannot be the sole solution. Chart 2 makes the problem apparent: time is of essence. The worst disadvantage of solar and wind energy is its unreliability. Unlike conventional power plants the power output of renewable energy sources cannot be controlled.

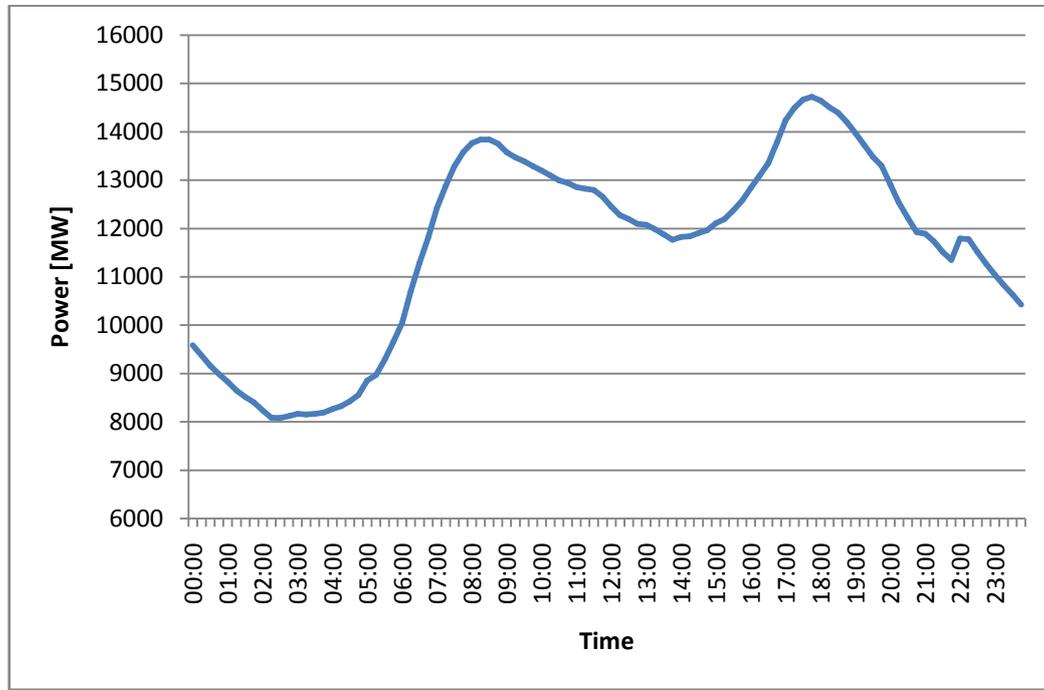


Chart 2: Power load on a winter's day (11th January 2013) in Germany⁸

The graph clearly shows that the load on our power grid is not constant. There are peak hours around 8 a.m. and 6 p.m.. Unfortunately, the sun and the wind cannot be forced to shine or blow at certain times. Currently, so-called peaking power plants are needed to meet the high demand for electricity during peak hours. These peaking power plants are usually gas turbines burning natural gas as they have short start up times, the lowest carbon emissions among fossil fueled power generators as well as an energy efficiency of up to 60.75% (in a combined cycle).⁹ However, this cannot be the future of energy as it should be carbon emission free and sustainable which these peaking power plants are certainly not.

Moreover, the energy transmission must become more efficient because Germany focuses on offshore wind farms. Offshore wind turbines are more reliable power generators as the wind

⁸ E.ON Netz GmbH (2013)

⁹ Siemens Energy, Inc. (2012)

velocity is quite constant and high on the sea. They are capable of producing up to 5 MW.¹⁰ Furthermore, the offshore wind turbines cannot disturb people living nearby as their counterparts ashore do due to the noise they make. Because of the great distance (often over 100 km) between these wind farms and the power grid ashore a lot of energy is already lost just transmitting it.¹¹ In order to minimize these losses HVDC (high voltage direct current) power lines are needed. An HVDC power line has been built in China from Jinsha to Guangzhou. That is a distance of about 1400 km. Compared to an AC line only 5% instead of 13% of the energy are lost due to the transmission.¹² That is about 400 kW per wind turbine that can be saved with the help of an adequate power grid.

In order to make renewable energy sources more reliable, i.e. available at any time and at any place, a new power grid is needed – a smart one.

2.2.2 The Smart Grid & Decentralized Power Generation

If power plants were the heart of a human body, the smart grid would be the brain and the nervous system. With the help of computer systems and a large amount of data for statistical predictions the smart grid could balance supply and demand. Moreover, the electricity prices would not need be fixed anymore but could also be varying in real time. All consumers of energy could become producers as well. The aim is a decentralized power generation that supports the established power plants. Basically, all buildings can be consumers and producers at the same time, e.g. via photovoltaic cells on the roof.

Furthermore, the smart grid can help lowering peaks by controlling part of the consumption. On the one hand, power guzzlers like the air conditioning in large office buildings could be turned off during peak times in order to stabilize the power grid. On the other hand, washing machines and other electrical appliances could be turned on automatically during off-peak times when the electricity rates are low.¹³

But controlling part of the consumption is not enough. The smart grid could also allow us to store energy when it is generated but not needed.

¹⁰ Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (2013)

¹¹ Bundesamt für Seeschifffahrt und Hydrographie

¹² Müller (2009)

¹³ Siemens AG (2013)

2.3 Energy Storage

Energy storages are fundamental for the future energy supply system. They will make renewable energies reliable stabilizing the power grid by taking power off the grid when it is overly abundant and providing the stored energy when it is short. That would solve the problem of varying power consumption depicted in chart 2 without the help of carbon-emitting, peaking power plants. But there is a catch: the second law of thermodynamics forbids us to create energy storages without losses. Thus, the aim must be energy storages that are as efficient as possible.

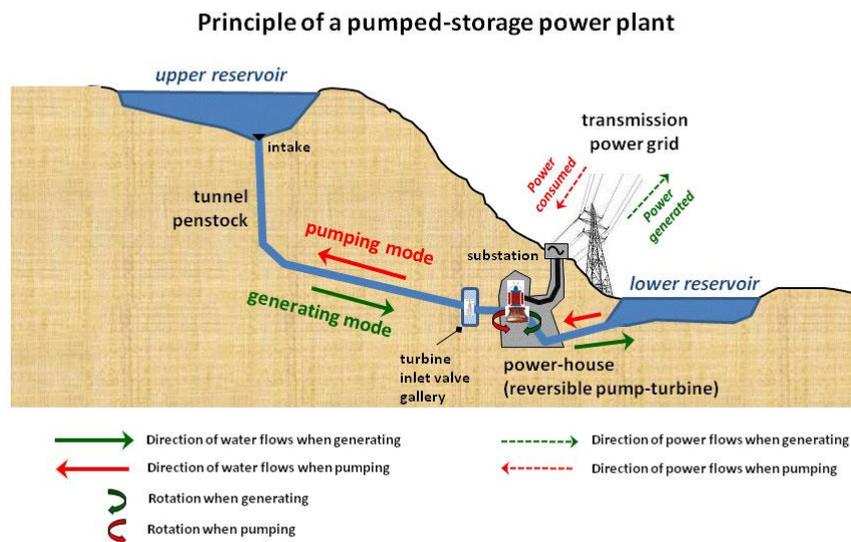


Figure 1: The principle of a pumped-storage power plant¹⁴

Right now the most efficient way to store energy is a pumped-storage hydro power station.¹⁵ Pumped-storage power plants can consume excess power by elevating water to an upper reservoir and generate power by letting water from the upper reservoir drive a turbine. The only disadvantage of this method is the necessity of an upper and lower reservoir. If there are not two natural bodies of water with a sufficient height difference available, artificial ones could be created. But that could cause unforeseen consequences for the surrounding ecosystem and should only be considered if there are no alternatives left.

¹⁴ EDF

¹⁵ Gloor (2010)

Another method to store energy is the electrolysis. The idea is to use overproduced power to split water into hydrogen.¹⁶ Being a clean energy source hydrogen can be used in fuel cells to create electric power again. But the repeated conversion of energy makes this method quite inefficient. As hydrogen is needed for the syntheses of ammonia¹⁷ (basis of almost all fertilizers) and methane¹⁸ (removes carbon monoxide from the Haber-Bosch process¹⁹ and can also be burned in gas turbines), the hydrogen gained from excess power should be used for these reactions because it would be a more efficient process having one less energy conversion.

The next idea takes full advantage of the capabilities of the smart grid. Right now there are about 52.4 million registered cars in Germany.²⁰ As electric cars will eventually become commonplace one can assume that one day there will be at least the same number of e-car batteries. Current e-car batteries already have capacities of 60 kWh.²¹ Neglecting technological progress this would add up to about 3144 GWh creating a huge buffer for the power grid. With the help of the smart grid, parked cars could be charged or discharged in order to compensate the fluctuations in the power grid. Money would serve as an incentive for people to set their cars on this "smart mode" as their cars would be charged at low electricity rates and discharged at high ones due to the nature of supply and demand. The same principle could be applied to stationary batteries. There already are high performance lithium ion batteries with capacities of 500 kWh and power outputs of 1 MW.²² This enables them to charge and discharge very quickly stabilizing the power grid. These batteries will be part of the decentralized power generation as they could be acquired by companies as some kind of investment into the energy market.

3 Conclusion

The future of energy is probably the greatest challenge mankind has to face in the 21st century. Therefore, it is of utter importance to take a responsible stance – not only towards earth and its changing climate but also towards the people paying for all the changes.

¹⁶ $2 H_2O \rightarrow 2 H_2 + O_2$

¹⁷ $N_2 + 3 H_2 \rightarrow 2 NH_3$

¹⁸ $CO + 3 H_2 \rightarrow CH_4 + H_2O$

¹⁹ ammonia synthesis

²⁰ Kraftfahrt-Bundesamt (2013)

²¹ Tesla (2013)

²² Siemens AG (2012)

3 Conclusion

That is why it is crucial to focus on realistic approaches that are feasible in the near future. Pinning too much hope on projects like Desertec might cost us the opportunity to make the necessary decisions now. While the idea is great it depends too heavily on politics. Desertec requires large deserts like the Sahara as the sunny areas in southern Europe are not sufficient. But North Africa has been politically unstable and, thus, unfit for such projects for quite some time, and it took Europe an entire century and two World Wars to become as peaceful and cooperative as it is now.

All in all, I believe the future is full of opportunities. The smart grid could give the people a chance at a return on investment making the necessary development of energy transmission and storage systems quite promising. Moreover, the eventual dominance of renewable energy sources will be the beginning of a sustainable, modern civilization that can stand the test of time.

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