The future of renewable energy

A study of the challenges and proposed solutions, for integrating a wide share of renewable energies in the electricity market in OECD countries.

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Acknowledgements:

There are many people along your journey that paves the road for you without you noticing them or them noticing their impact on you. But God almighty said in the Holy Qur'an "Act! Allah will behold your actions and (so will) His messenger and the believers," His prophet also said "He who doesn't thank people, doesn't Thank God". Thus I try my hardest to some the amount of people I'm grateful for knowingly, that I will fail. But my only consolation is that up in the heavens, God knows and God rewards.

I want to thank The Erasmus commission for awarding me this scholarship and giving me the opportunity and a guide to my future career. Little do they know that this master's came as guidance to me in the period of transition in my life after graduation and transition in the country as a whole. My Dearest professors at TU Delft and Comillas that taught me what I know today. I want to Thank Dr. Edmar Almeida, who supervised my thesis and welcomed me at his home in the beginning of my visit to Brazil. I want to Thank Dr. Javier García-González who supervised my whole study and arranged for my thesis with Dr. Almeida, the man who also waited patiently for me to finish my courses for my graduation and was very helpful.

I want to thank my family and friend, my Mother and my father and my sister who have been my backbone and support system my entire life and continue to be so. I want to Thank Irene George the lighting torch of my journey that without my two years' experience wouldn't be nearly as fulfilling.

I dedicate my thesis to the freedom fighters and the martyrs of the Egyptian revolution and the Entire Arab spring who's sacrifice has paved our road for a better tomorrow.

"For any success it's from Allah, and for the Mistakes and error's it's from me".

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1. Acronyms':

- **$** U.S Dollar
- **ANN**: Artificial Neural Network
- **CAES**: Compressed Air Energy Storage
- **CC**: Combined Cycle
- **CO_2**: Carbon Dioxide
- **COE**: Cost of Energy
- **DNI**: Direct Normal Irradiation
- **E.V.**: Electric vehicles
- **EEG** Erneuerbare Energien Gesetz
- **EU** European Union
- **FERC**: United States federal energy regulatory commission
- **IEA**: International Energy Agency
- **IEEE**: The Institute for Electrical and Electronic Engineer
- **IPCC** The international Panel on Climate Change
- **NETA** The New Electricity Trading Arrangements
- **NFFO** Non-Fossil Fuel Obligation
- **NWP**: Numerical wind prediction
- **OECD**: Organization for Economic Cooperation and Development
- **PHS** Pumped Hydro Storage
- **PV**: Photo Voltaic
- **RES**: Renewable Energy Resource
- **ROCs** Renewables Obligation Certificates
- **TPP**: Thermal Power plant
- **U.S**: United States of America
- **UK**: United Kingdom

2. Introduction

This research was done in the field of renewable energy and its future projection. The world Today is focused on changing its energy mix and rely more on renewable energy. Many obstacles face the continuity of the current mixture. Problems such as security of supply which includes; sustainability of current resources and insurance of trade between countries, are raising alarm for decision makers. The environmental concerns are also motivating countries to rely on cleaner sources of energy. The breakthrough in research in renewable energy technologies has motivated countries to make effort in raising its market share. This comes in times were many conventional power plants are reaching the end of their life time cycle and need replacement. The main problem that motivated this study is that renewable energy is not a cheap easily accessible energy as thought. Renewable energies such as solar and wind are intermittent and cannot be relied upon for base load supply. These sources are often more expensive and has much less energy density than conventional power plants. Many countries still face many problems overcoming these obstacles.

The main objective of this thesis is to give a projection of the current situation of renewables. The study was to show the current situation and the obstacles, then present the solutions and real life case studies. These would serve as a guide to better understand why we stand at the point we stand currently at. It would also help answer the question of the future share of renewable energy in the market and whether it's expected to reach 100% as hoped.

The hypothesis made by the general public rather than the author was that; the world could solely rely on sun and wind energies to supply energy for the entire globe. From this hypothesis come ideas like covering parking lots with solar panels and flooding seashores with windmills. The hypothesis of this thesis however is the contrary. In fact this hypothesis wasn't reached until half way along the research. In the beginning it was a matter of asking "can we rely solely on renewable energy as our main source of energy?"

In order to investigate this hypothesis, a research was conducted among OECD countries that have already developed a decent share of renewable energy in its grid. The plan was to research for the opinions of academic researchers and policy makers regarding the future of renewable energy. The thesis was based solely on descriptive research not modelling. However some of the academic papers referenced were based on models themselves. The data taken were based on realistic scenarios rather than optimistic or pessimistic ones. And reliance was always on recent data as it's a very volatile market.

The thesis was divided to four chapters,. The first chapter is a theoretical background. First, the motivation for change that came from the problem of security and greenhouse gas emission. Then, we present the current renewable energy technologies. Lastly, an overview the different storage techniques is discussed. The second chapter discusses the core of the thesis which the problems faced by OECD countries stopping them from increasing the share of renewable energy in their grid. Problems include intermittency, economic viability of renewables, its effects on conventional energy sources, and last but not least legal barriers. The third chapter looks into the different solutions for these problems. These solutions mainly came from models done by academic researchers relying on data published by governments or its delegated bodies. The first solution was coupling different types of renewables with different types of storage techniques to solve the intermittency problem. Other solutions including market reform, demand side management and improving the grid connections. The last chapter was a case study of different countries that discussed the problems and solutions from different angles. Countries mentioned in the study were Brazil, the USA, the UK and some Islands in OECD countri

3. Current and Future status of the Electricity market

The electricity market is currently witnessing revolutionary changes worldwide compared with the past decades. As demand for electricity rose, voices calling for cleaner energy become louder. To add to that, fast technological advancements, has all created new world vision for the future. After a century of complete reliance on coal as the main source of energy worldwide, new technologies such renewables and storage are beginning to emerge while others such as nuclear are losing its share. Figure 1.1 shows the current energy mix in different developed countries around the world. The figure shows how the world stands at different points towards different technologies. However most countries agree on the inevitable rise of renewable energy as the second largest source of electricity generation in 2035 (according to the IEA energy outlook express 2013).

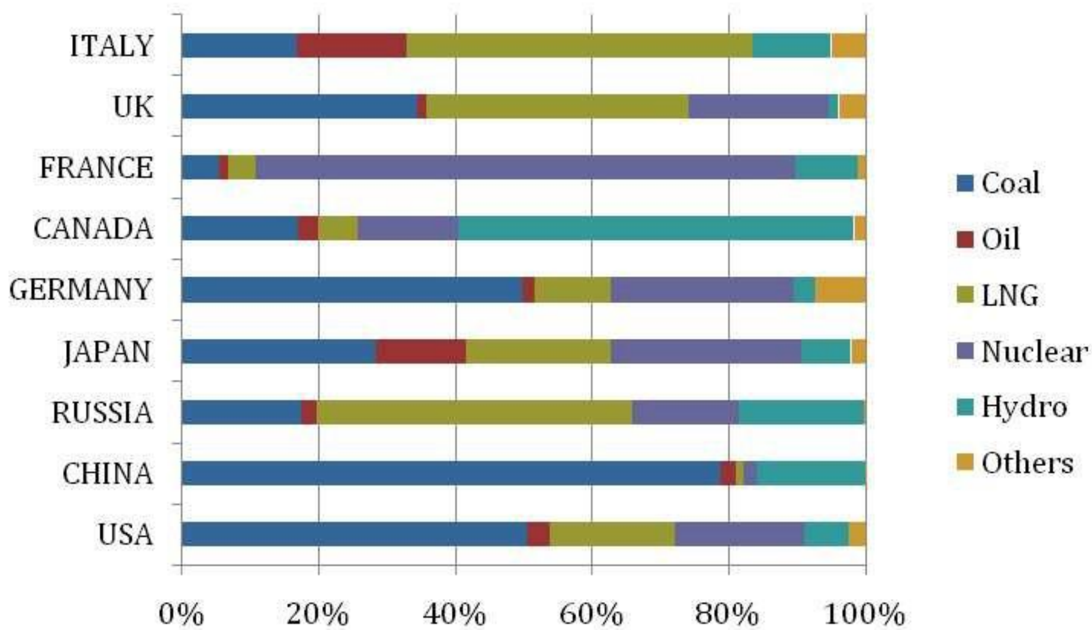

Figure 1.1 Source: comparison of generation mix source: IEA Electricity Information, 2006

This chapter is divided into three parts. First it looks at the motivation for changing the energy mix which includes the current legal framework for it in different parts of the world. The chapter then highlights the three main renewable energy technologies discussed in the thesis which are; hydropower, solar and wind energy. The chapter finally gives a brief explanation about the current storage techniques that include: CAES, pumped hydro storage, flywheels and batteries.

1. Motivation to meet future demand with cleaner and cheaper energy

The move towards change in the electricity industry came after the rising alarm of both securities

And environment. Security of resources has been the main motivation for nations for any political changes since the beginning of history. And nowadays these changes are being done through new policies coupled with technological progress. We discuss the issue of security into more detail in the next chapter but a highlight of what exactly is the problem is presented here.

Current and Future status of the Electricity market

Environmental concerns have also triggered the change as seen in the legal framework in the nations worldwide from the beginning of the 1990's. The new policies and regulations set by governments was the first step towards meeting the concerns raised by many researchers and analysts.

1. Security

The main motivation to switch from traditional sources to renewable energy is; security of supply. Security here is defined in three different aspects:

1. Sustainability of energy resources (fossil fuels and uranium).
2. Guarantee of availability and stability of the production and trade of these resources.
3. And affordable energy prices for everyone.

The depletion of energy resources, the rising conflicts in oil rich countries and the strong move towards urbanization (that reflected on increasing demand of affordable electricity), all raised the question of energy security among energy producers.

On the issue of sustainability, the CIA fact book reports that total fossil fuels are being consumed at a rate of 11 billion tons every year, with oil contributing the most with 4 billion tons. This means that theoretically with the current reserves oil will vanish by 2051 and total fossil fuels by 2088 as illustrated in the figure 1.2.

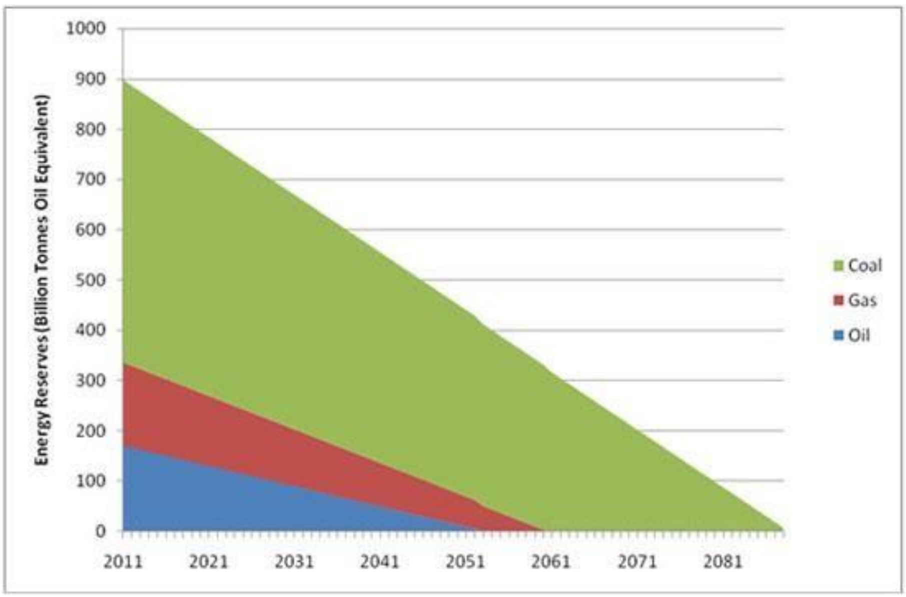

Figure 1.2 Depletion of fossil fuel worldwide Source: CIA fact book

This however is not 100% for gas. Countries around the world are still discovering new gas wells. Israel a country that has suffered since its foundation from lack of energy resources has discovered large amounts of gas in their offshore. Israel decided to switch from importing gas from Egypt to supply the now energy poor country. The US recent technological advancement in shale gas technology drove down their prices of electricity compared to the rest of the world. Therefore the world may not be facing instant danger as projected, but this news does not mitigate the problem but rather decrease or delay the inevitable.

On the second issue of security which is trade; recent disturbance in the Middle East resulted in; militant groups taking control of oil fields in both Libya and Iraq (the latter within few days). Moreover South America, Russia and China faces continuous changes in foreign policies towards the west, Russia (a central supplier of gas to the EU) in particular has a long term dispute with the EU over countries like Ukraine and Syria. These issues put the question of Energy security at continuous risk. In fact the Gulf States (world largest holders of oil reserves) have showed their interest in the expansion of renewable energy market. This comes in line with a famous quote said by Saudi Oil Minister in the 1970s, *"The Stone Age didn't end for lack of stone, and the oil* *age will end long before the world runs out of oil".* The Chairman of the Emirates Solar Industry Association Vahid Fotuhi was quoted discussing Electric vehicles power by solar PVs even saying

"They could one day be as common as BMWs on Sheik Zayed Road"[1].

As for electricity prices, renewable energy (without subsidies) is much more expensive than conventional energy resources; however it's both stable to market shocks and decreasing in price. On the other hand fossil fuels is subject to the demand and supply curve which means that the increase in consumption leads to decrease in supply leading to continues rise in price. The US Energy information association (EIA) conducts annual outlooks to the current and projected prices of fossil fuels such as oil gas and crude oil. The report summarized here[2] sheds some light on the importance of diversifying the energy mix and relying on renewable energy. The report shows change in the forecasted prices for 2014 compared to 2013. For example natural gas prices expected in 2037 is higher in the 2014 report compared to 2013; this is interesting since the US has been an enjoying declining price in electricity due to discovery of shale gas. The price of coal increases from $1.98/MMBtu in 2012 to $2.96/MMBtu in 2040 with an annual increase of 1.4% per year.

2. Environmental impact of energy production

Another motivation for changing the energy mix was the environmental concerns. In 2007 The international Panel on Climate Change (IPCC) compiled a report on the projected effect of global mean temperature. The report aims at expanding the baseline (assuming no changes happen to the current energy production mix) to measure the results of GHG effect on global warming. The report done by the institute; (IPCC, 2007) expects mean temperature over the period between 2000-2100 to witness an increase between 1.1 and 6.4 C with a probability of 65%.

Fossil fuel consumption has led to annual increase in CO_2 emission by 3.4% between 2000 and 2008. Thus the change to cleaner options is inevitable. However, the change towards low carbon plants to meet the rising problem comes with few obstacles. The discussion about cleaner fossil fuel is refuted by many authors and researchers such as (Banks, 2003), who identifies that the substitution of fossil fuels by cleaner ones is limited. Large scale deployment of low carbon technologies that are non-renewables comes with challenges as well. The main available alternatives such as nuclear and carbon capture and storage are not peak load demand generators and are not entirely flexible (DECC, 2010a). Therefore it's considered as necessity that future reliance on such technologies will require storage of some sort such as Combined Cycle Gas Turbines (CCGT) for balancing low capacity factor generators (Ekins et al., 2009).

According to a an IEA report titled The energy Technology Perspectives (IEA, 2008), assuming a scenario where adequate integration of renewable energy is done as projected by governments by 2050; could in fact lead in 21% reduction in energy related CO_2 emission from today's levels. This is given the annual increase due to increase in demand and industrialization. This is assuming a 46% share of renewables in the total electricity power generation.

3. Legal Framework

The set of regulations and policies adapted by countries to push for cleaner and more Sustainable energy was divided into two phases. The first phase that started by the Kyoto protocol was a set of worldwide promises in the form of protocols to increase renewable energy share and decrease GHG emissions and focus more on reforming their energy market. The second phase was the actual laws and regulations set to shift the free market towards higher

[1] http://www.bgreen.ae/opinions/640/green-solutions-for-the-uaes-fuel-shortage-problems/
[2] http://www.eia.gov/forecasts/aeo/er/early_prices.cfm

share of renewable energy. This was done through introduction of incentives for investors to invest in renewable energy as well as customers to introduce personal rooftop solar panels. The main motivation was to subsidize solar and wind energies to make them competitive with traditional sources of electricity.

1. Governmental protocols for cheaper and cleaner energy

A number of OECD and other countries have named renewable energy as the main source for decreasing Green House Gas emission and global warming. Thus policies presented in this subsection discuss how countries use renewable energy to fight CO_2 expansion in the atmosphere. More than 73 Countries worldwide have set targets to increase renewable energy penetration. Typical targeted market share for renewables ranges between 5-30%. However the target goes as low as 2% for some countries and as high as 78% for others (REN21, 2008).

2. Kyoto

The UN Kyoto protocol signed in 1997 is considered as the wake-up call for developed nations to deal with the increasing problem of GHG emission. Figure 1.3 shows a timeline of the different stages that formed the protocol. The protocol did not on itself, obligate world nations with legal obligations to decrease emission. However, many nations around the world have moved individually or collectively (such as the European Union) to meet the recommendations of the conferences held. The protocol defined two periods for applying the mechanisms for reducing emission; 2008-2012 and 2013-2020. The first commitment period 37 industrialized countries alongside with European Commission (the 15 nations at that time) committed to reduce emission level to an average of 5% against levels from 1990. The second period is committing countries to reduce emission by 18% below the level in 1990. The latter, however, seems to be not feasible as some countries (including Canada) have abandoned the treaty.

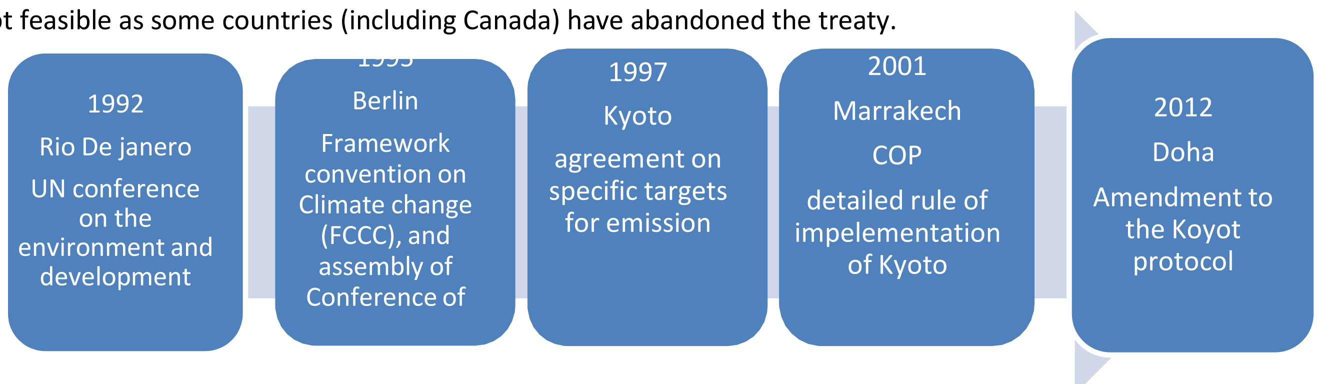

Figure 1.3 Time line for the Kyoto Protocol implementation

The Doha conference brought these amendments according to the website of the FCCC[3]:

- New commitments for Annex I Parties to the Kyoto Protocol who agreed to take on commitments in a second commitment period from 1 January 2013 to 31 December 2020.
- A revised list of greenhouse gases (GHG) to be reported on by parties in the second commitment period.
- Amendments to several articles of the Kyoto Protocol which specifically referenced issues pertaining to the first commitment period and which needed to be updated for the second commitment period.

The Kyoto Mechanism

- International Emissions Trading

[3] http://unfccc.int/kyoto_protocol/items/2830.php

- Clean Development Mechanism (CDM)
- Joint implementation (JI)

The Protocol recognizes the developed countries as being the main contributor for the emission levels resulting from the last 150 years of industrialization. Thus no blame was given to developing countries that currently emit GHGs at much higher levels. The protocol however was the beginning of a set of regulations done to support renewable energy in an effort to mitigate global warming.

3. Brazil

Although Brazil has one of the world highest renewable energy market shares it remains a pollutant country. Emission in Brazil rose by 10% between 2010 -2012, which is higher than the global average. The PROINFA program was introduced to promote the use of renewable energy for electricity generation through incentives and subsidies in a short-term prospect. The Protocol does not mention anything about solar energy and is more interested in adjusting the energy mix market share rather than eliminate CO_2 emission. PROINFA however (as explained in a later chapter) failed to meet its timeline goals. But it served as a gateway for new protocols and legal amendments to increase market share for renewable energy especially solar and wind. Among other market reforms Brazil removed taxes and customs on imports of solar panels. Solar energy now has its own auctions for long term contracts of electricity generation.

4. Europe and UK

The UK has set long-term targets of an 80% reduction in CO2 emissions by 2050 (below 1990 levels), and a 26% reduction by 2020 (DECC, 2009; Ekins et al., 2009). The 2020 target is expected to require 35% of electricity to be provided by renewable generators. The European Union has set a 2020 target of reducing their reliance on fossil fuels and raising renewable´s market share to 20%. The EU also issued the European Union Directive 2008, aiming to decrease CO_2 Emission by 20% and decrease energy prices by 15%. The EU considers the target as a cumulative target and not an individual one. Countries like Norway and Denmark have already exceeded the 20% mark for renewable energy and are beginning to invest in exporting clean energy to countries in need inside the European union. The EU has also created the Emission Trading System (ETS) in accordance with the Kyoto protocol. The system aims at decreasing emission by allocating a cap to allowed emission and opening a market for trading certificates between industries that allow them to emit CO_2 at certain levels. This results in control of the annual CO_2 emission.

4. Incentives for Renewable energy

Markets reforms were thus made to meet the targets set by the UN and the developed countries. Reforms were mainly done to shift the produced electricity towards renewables and incentivize investors and rooftop producers. Most of the schemes showed up in certain countries and given the name by their creators, however nowadays they are standardized and used among different markets around the world. Different schemes were created to suit the different nature between one market and another. However, many of the mentioned schemes come hand in hand with one another such carbon emission certificates that tackles the issue from a different angle than feed in tariffs.

1. Feed in Tariffs (Germany):

The feed in Tariff is the first financial incentive provided by governments to support renewable energy. The concept was first introduced in Germany in 2000 and has been continuously amended to meet the technological changes. The incentive protects operators by law from changes made after they agree with the state on the remuneration they will receive. The act

Was named Erneuerbare Energien Gesetz (EEG) or the Renewable sources Act. The basic principles of the act were:

- Fixed payments for new installations
- No compensation for inflation
- Long reimbursement period depending on the technology[45]
- The amount of the Tariff depends on the used technology, year of Installation and the size of the plant.

The system was amended in 2004 to meet the new EU policy of raising renewable energy market share to 20% by 2020. The amendment was made to incentivize renewable energy operators to continue reducing the cost of the technology and increase efficiency. The act also adjusted the framework for introducing renewables in the central grid including distribution and transmission. The amendment introduced an annual percentage reduction of the reimbursement to meet the annual improvement in technology (Thus becoming more efficient and cost less). The federal and state support is not limited to this incentive but also includes soft loans, tax allowance and investment support. This system is also applied in Spain and Denmark.

2. Auction system vs quota system (U.K):

The United Kingdom went through two stages of law making for incentivizing the renewable energy. The first stage of the auction system was aiming at integrating renewable energy to the market and decreasing fossil fuels, However it wasn't until 1997 that real changes happened. This happened when the government was changed to a more pro-environment government. The auction system began in 1990 with the The Non-Fossil Fuel Obligation (NFFO) that ended in 1998 and was changed to renewable obligation. The system allowed renewable operators to enter the reserve market and compete for a wider share of electricity capacity to be sold. This auction was conducted 5 times in the UK twice with 8 years contract and 3 times with 15 years contracts. The advantage of that methodology was more for the operators than for the British end user. The operator winning the auction benefited from having a purchasing agreement for a short period of time and fixed price for generated power. The price was determined by the bidding process in the competitive market, and the extra benefit depending on the type of technology the renewable operator sold. That extra benefit came from the difference between the price decided in and the competitive value of conventional sources from taxation on fossil fuels (RICARDO MARQUES, 2007). The main disadvantage of this methodology was that it disincentive renewable operators from investing in reducing the cost of their production, since no extra income comes from the process. This system is still adapted in wales and Ireland, while France changed it in 2000.

In 2000 the change in government to a more pro clean energy resources and after the Kyoto protocol, the government implemented a new act. The act was called the "Utilities act", and from the name the act involves utilities in the process of increasing renewable energy penetration and having a cleaner environment. This time suppliers were obliged by law to have a certain quota of clean energy in their energy mix sold to end consumers. This quota was set to 3% in 2003 and increased to 10% in 2010. This quota is set to increase further as the country looks forward to decrease CO_2 emission. The New Electricity Trading Arrangements (NETA) as well as the renewable obligation (RO) created green certificates called Renewables Obligation Certificates (ROCs) for each MWh of electricity created. This certificate is given to

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[4]

[5] 20 years usually, 30 for small hydropower Plants (up to 5 MW) and 15 Years for Large Hydropower plants (up to 150 MW).

renewable energy generators to sell to suppliers in order for the latter to fulfill their required quotas. The renewable energy producer thus benefits from normal competitive market price and selling these green certificates. The price to end users was set by a price cap protected by law till 2027. Austria Denmark and Belgium are now using this system as well as 13 of the pro-renewables US states.

This system is also found in Australia in two different type; large scale certificates similar to the ones in the UK, and Small scale certificates applicable to end users that have their own solar panels. Consumers who produce solar energy and provide it to the grid not only benefit from selling Electricity to the grid, but also they can sell green certificates to retailers for every MW produced. The prices of the certificates are varying according to the location and the size of solar panels. This gives the market operator the tool to push for green energy in states with higher CO_2 emission rates and low renewable energy penetration by raising the certificate price thus making solar panels more competitive.

3. Subsidies to investment

Subsidies differ from traditional incentives in the fact that they are applied early on in the investment phase. The reduction in required capital costs results in potential increase in capacity established by operators. This is particularly useful for renewable power plants that usually has low capacity factors and require large capacity to meet the required demand. This subsidy is applied to end customer in the final price. Therefore choosing inappropriate level of subsidy or technology subsidized will harm the market. This methodology is most suitable in emerging and immature technologies requiring strong kick start, but it is not very efficient on the long term. Countries like Norway still use this methodology for PHS, while many developing countries use it for traditional power plants to fight inflation.

4. Tax benefits

The tax benefits works in a more dynamic way than other sources of incentives. The incentive comes in the form of exempting green operators from a portion of their income tax payed. This provides a more accurate and realistic methodology of accounting for the subsidy needed. This is done by deducting the depreciated value of the equipment's from the calculation of the income tax. This creates virtual income useful for future replacement of the equipment's, keeping renewable energy operators up to date in the market. This cost is therefore not included in the final price for customers. Instead it's considered part of the tax money allocated to developing the infrastructure of the government. This form of benefits is found extensively on customer level for solar panels purchasing. This is the most favourable technique for the continuation of an already developed technology.

2.1.3.2.5 Negative pricing

The concept of Negative Pricing is an emerging concept that has been allowed in Germany, Spain, the UK and other nations. The concept is made to help renewables maintain competitiveness even at low demand times. The central operator allows generators to offer their electricity at negative prices to insure selection in the producing units. The concept itself was thought as a solution to inflexible power plants that find it very expensive to shut down their plants and open it again over short period of time due to ramping costs. Renewables with zero variable costs could benefit from these prices by offering their electricity at negative prices to ensure selected in the biding process. They can then benefit from their feed in tariffs. Provided that the tariff covers the negative price offered

2.1.3.2.6 Emission Certificates

Created by the EU ETS, Carbon certificates works similar to green certificates mentioned as incentive for renewables. The basic concept works the same as the one mentioned in the quotas subsection, except that it is on a global scale. Currently the EU, which is the first and largest emission trading in the world, has signed a link with the Australian Emission trading system to be in effect in 2015 (Ellerman, A., Denny, 2007). The EU Commission stated that it *"hopes to link up the ETS with compatible systems around the world to form the backbone of a global carbon market"*[6]. The emission trading scheme deals with the certificates with the same economic matter of any product. The certificates are held at auctions and prices vary depending on supply and demand. The different ETS's have become stricter in the last years and auctions are being delayed to control the supply. These certificates in return have a very positive effect on renewable energy integration. The cost bared by thermal power plants that emit large percentages of CO_2 in compare with renewable one that doesn't emit makes the latter more competitive. Many of the academic paper discussed in the later chapters mention the implementation of CO_2 certificates, among other externalities and social costs as the main contributor for renewables economic viability.

2. Renewable Energy Sources:

The term renewable energy is often associated with any form of electricity generation with sources that are infinite; namely natural resources such as wind, water, sun, biomass or waves. The renewable energy has enjoyed historical projection over the last 10 years as illustrated in figure 1.4. Nowadays hydropower is no longer considered as a renewable energy. This is because even though water is infinite, rivers aren't. Countries like Brazil have already exploited most of the suitable spots for building dams to generate electricity. This is why this study focuses mainly on wind and solar energy (as they are the focus of most countries around the world). Most problems and solutions associated with renewable energy focus on wind and solar energy. In fact as mentioned above some protocols signed by countries specifically names wind and solar when discussing expanding renewable energy. Contribution from other sources remains important especially solid biofuels but is less complex and relevant to this research.

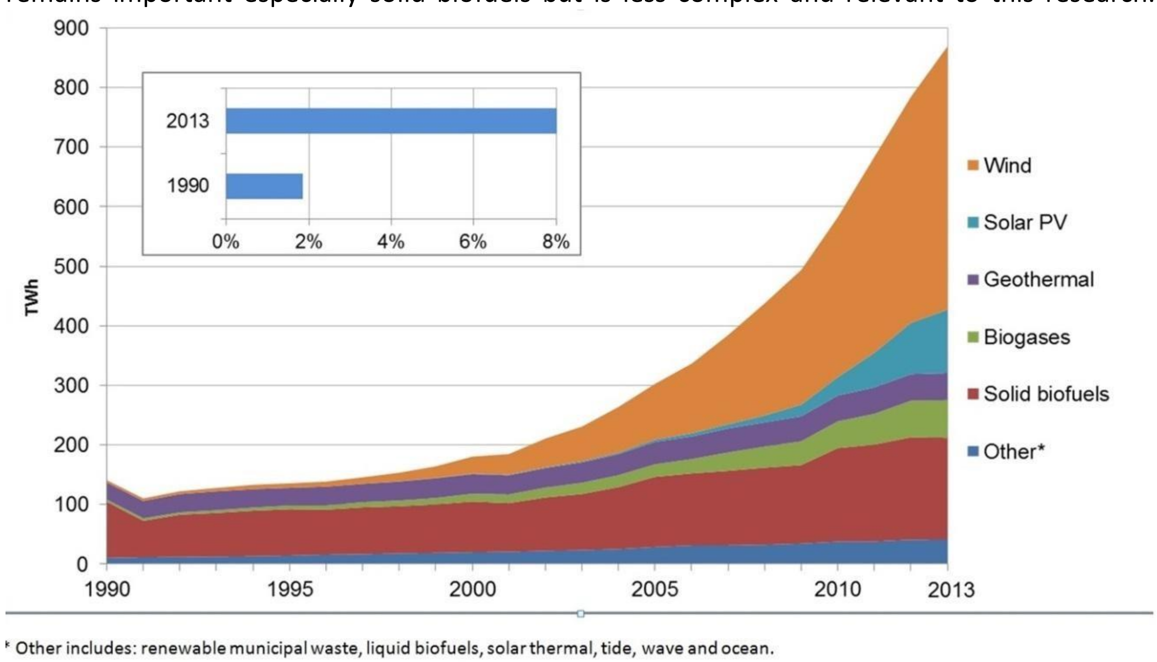


Figure 1.4 Non Hydro Renewable energy electricity generation in the OECD countries Source: IEA Energy outlook 2014

[6] http://ec.europa.eu/clima/policies/ets/index_en.htm

3.2.1 Wind energy

Wind energy has been one of mankind's first uses of nature resources. This use goes back to the pharaoh's times 5000 B.C [7] where they propelled boats by the Nile river, this evolved in China to pumping water, and vertical axis windmills were already grinding grains in china. By the 11th century the Middle Easter's were producing food using wind mills. The European merchants and crusaders took this invention back to Europe and The Dutch refined the windmill and adapted it for draining lakes and marshes in the Rhine River Delta.

By the End of the 19th century, wind energy was beginning to be used for producing electricity. This however was slowed down by the 1930's due to the introduction of coal as a thermal power plant.

Wind energy is becoming the highest growing energy supplier in the world. World capacity of wind tripled between 1999 and 2004 reaching 47,600 MW (WWEA, 2005).Wind energy is not only increasing its capacity factor but also decreasing the price. Figure 1.5 illustrates the historic drop in wind energy prices compared to solar energy in the US[8].

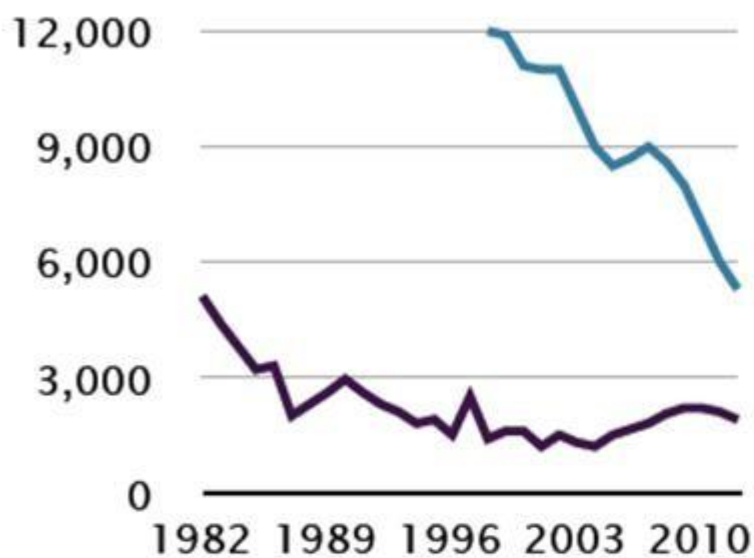


Figure 1.5 US installed cost of wind and solar power ($/KW). (Source Lawrence Berkley Lab)

As the EIA outlook 2013 expects capacity factor of wind to rise to almost 40% by 2035, wind remains the leading technology in renewable energies. It's expected to make the largest leap among all energy resources not just renewables. The industry is already diversifying and offshore wind plants are beginning to catch up with onshore plants which will solve some of the space problems that countries like Spain are beginning to face. Concerns about flying birds are even being met with new windmills that rotate horizontally in a curly shape rather than the traditional ones (this of course has less capacity factor). This technology has the advantage of intercepting wind coming from any direction unlike the traditional wind mills.

[7] U.S energy website http://energy.gov/eere/wind/history-wind-energy

[8] The US is chosen as a reference for changes in prices in other parts because it is a leader in the world monetary Market, as well as the most liberal market in terms of sensitivity of the prices of electricity.

3.2.2 Solar Energy

The sun is the source to all other energy types in the world where its primary energy is light and heat. The Sun irradiation power on the surface of the earth is about 175,000 TW. That is about 4 times larger than the total energy need in the world.

Over the last 10 years, solar PV generations expanded by over 50%. It reached 100 TWh of production in 2012 (International Energy outlook, 2013). In 2013 total installed capacity increased by 43% (29.3 GW) which is 15% of the total growth of global power generation capacity. This could be accredited to 6 countries in particular; Germany accounts with 25% of this Increase (7.6 W) due to the strong government support. Italy (3.6 GW), China (3.5 GW) the U.S (3.3 GW) Japan (2.0 GW) and India (1.1 GW).

In 2011, the International Energy Agency said that "the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits. It will increase countries' energy security through reliance on an indigenous, inexhaustible and mostly import-independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating climate change, and keep fossil fuel prices lower than otherwise. These advantages are global. Hence the additional costs of the incentives for early deployment should be considered learning investments; they must be wisely spent and need to be widely shared" (International Energy Agency, 2011)

3.2.2.1 Future of Solar Energy:

The price of solar PV dropped down by more than 40% between the years 2010 and 2012; this is due to the overcapacity in manufacturing and stepped up deployment. Now it's assumed that the learning cost and economy of scale will decrease the price by 20% for every time the capacity of solar energy doubles (Frauenhofer ISE, 2012).

3.2.3 Hydropower energy:

Hydropower is the fourth source of primary energy in the world and the first one among renewable energies (EA and CERT, 2011). It's expected to grow significantly in the next years due to its high level of efficiency and stability. Figure 1.6 highlights this projected increase which is expected to come mainly from non OECD Countries (around 82% according to the EIA). Hydropower is not discussed in this thesis extensively as it is a very stable energy source, and the problems of intermittency associated with wind and solar as well as high prices are not present in hydropower. However Hydropower is mainly mentioned as a solution for intermittency when mentioned with pumped storage.

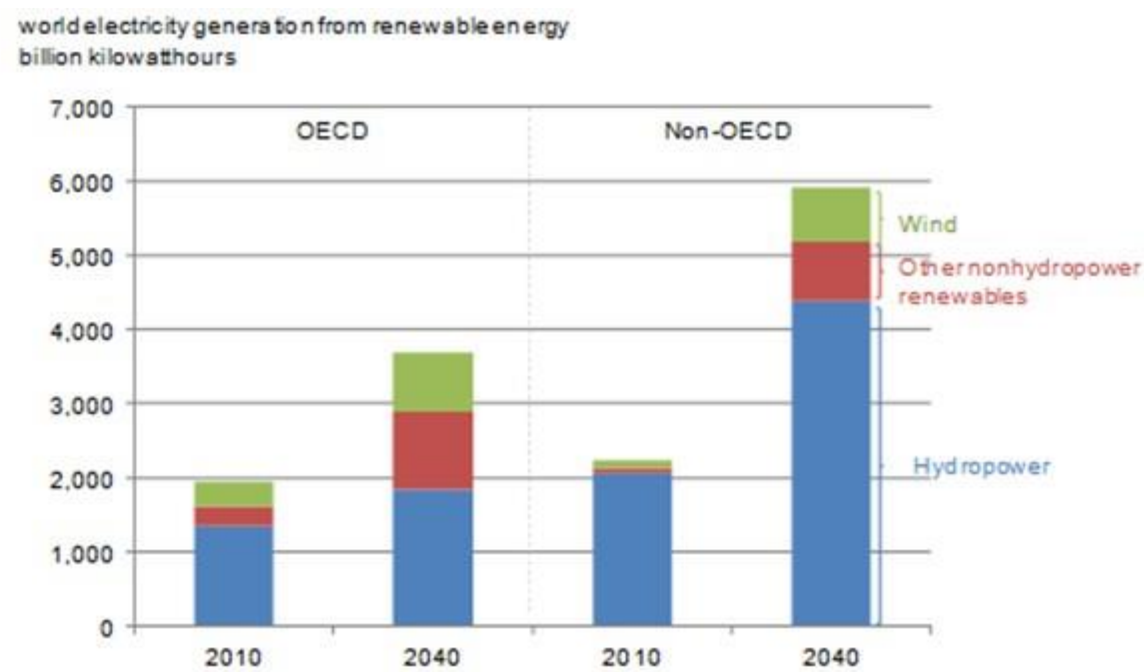


Figure 1.6 Source: The international Energy outlook 2013

3. Energy storage

Electricity in principle is a form of energy that cannot be stored nor destroyed or created. Electricity storage however is often mentioned as an option for increasing flexibility. The actual process however is not physical storage of capacity but rather conversion of electricity from one form or another. In the past, electricity storage was often the act of keeping the physical resources for generating electricity in large quantities to be used later. Resources such as gas, coal and oil could be stored for years without losing their efficiency. That is not the case when it comes to energy generated through renewable sources such as wind and sun. Wind and sun are natural resources that come with natural events. The sun irradiation or the wind blow is either to be used on the instant or it's missed. Thus modern day storage means that the electricity is generated through these resources but converted to other forms of energy such as chemical energy, kinetic energy or thermal energy. Sometimes storage comes in an even more different form such as generating electricity and using it to supply energy to something that has a flexible schedule. The used energy then would be saved from being used at other times were renewable energy is not present. An example of that is associating wind energy with pumped storage as explained later.

3.3.1 Flywheels:

Flywheels are transforming electrical energy to kinetic energy in the form of rotating wheels. The system is excited to rotate to up to 40,000 RPM through electrical energy for charging. Then when required to be used the flywheel provides its kinetic energy to the generator as illustrated in the figure. The concept is simple; however there are technicalities associated with keeping the flywheel at a stable position, and keeping high efficiency. Energy loss (usually through air friction with the wheel) is mitigated through putting the system in a vacuum. The super conducting coil shown in figure 1.7 creates a magnetic field that keeps the flywheel stable and spinning.

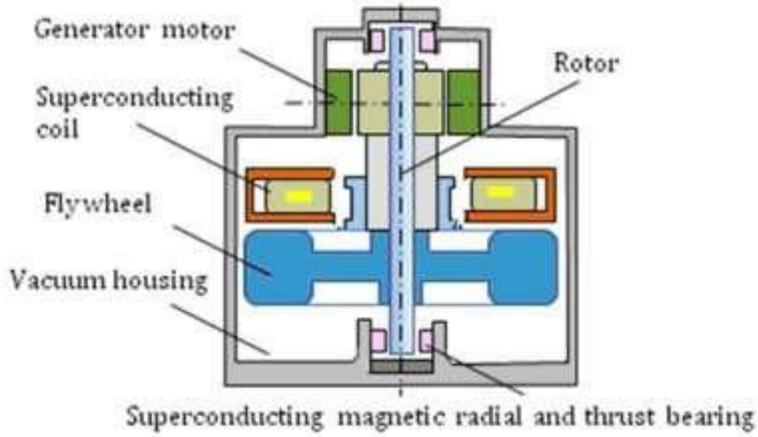


Figure 1.7 Principle and structure of flywheel Source: (IEA, 2009)

Flywheels have very low energy density as well as ramping up and ramping down speeds. The biggest facility, Beacon in the US, takes 6 mins to charge and 30s to discharge. This is with a storage capacity of 160 MW. The facility has a density of 50J/cm^3 for the flywheel, and 19J/cm^3 for the overall system. Thus the system has an equivalent energy density of 2000m filled PHS. The operated system Beacon has achieved between 2004-2005 more than 10,000 of roundtrip cycles and operated for more than 5000h.

The system is already present in commercial scale in Germany and the Netherlands with one facility each and the US with 5 facilities. The facility is also being used commercially in UPS systems nowadays. The cost of flywheel varies between $800-2700 /KW for capital costs, and varies between 2-22/KWh for running costs. A 10 MW flywheel costs between $36950-4315/ KW according to (EPRI, 2009). The future of the technology is limited to technological advancements. The system is limited by short term storage due to the windage and bearing losses according to (IEA, 2009). For the moment it’s very useful for fast response emergency storage as well as coupling with wind energy.

3.3.2 Compressed Air Energy Storage

CAES is not a traditional energy storage system such as batteries or even pumped hydro storage. CAES is a modification to conventional gas turbines. The CAES consumes less than 40% of the normal fuel used to produce electricity. Traditional gas turbines consume two-third of the input fuel when they want to compress air at production. CAES does this ahead of time at times with low electricity demand. The energy is used later with some gas as fuel to generate the electricity. The main disadvantage of such a system is that requires certain geographical conditions. In short it’s a process of storing electrical energy in the form of pressurized air Figure 1.8 illustrates the charging and discharging process

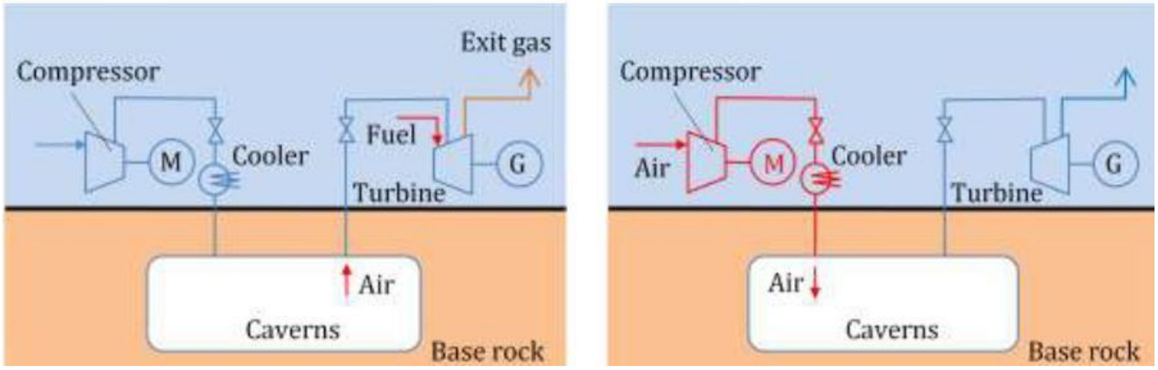


Figure 1.8 Principle of the CAES system, showing daytime discharge (left) and night time charge (right). Source (IEA, 2009)

Unlike traditional storage devices like PHS and batteries, CAES is only present in Germany and the US with one site in each country and another proposed in Canada:

- 290 MW built in 1978 in Huntorf Germany with energy efficiency of 42%
- 110 MW built in 1991 in Alabama The US with energy efficiency of 54%
- 2700 MW proposed in Ohio Canada

The storage device there uses natural Gas as fuel. The cavern provides capacity to store the compressed air to increase efficiency of gas turbines. It's more economically viable to make caverns through solution mining of the salt deposits rather than traditional mining. This restricts the number of areas CAES could be present depending on their geology. Areas of salt geology and disused mines are the most recommended. Research is being conducted to implement the thermodynamics theory of adiabatic transfer[9] on CAES. The concept will allow heat from compression to be stored for later use in the expansion process to save on energy.

Capital cost of the technology vary between $600-700/KW for large capacity (100-300 MW), and $1500-1800/KW for smaller capacities (10-20 MW) (EPRI, 2009). While research continuous the technology still lakes a learning curve. Furthermore the estimated costs for above the ground storage are considered to be 5 times as much as the normal underground.

2.3.3 Pumped Hydro Storage:

Pumped Hydro Storage (PHS) is the main established technology for large scale electricity storage. The first pumped hydro storage systems were built between 1910 and 1927 (Kuan T., 1989).Over 95% of deployed energy storage comes in the form of pumped hydrogen storage (John Farell, 2014). This amounts to over 100 GW of storage capacity. Hydrogen storage in the simplest form is 2 water reservoirs at different heights connected by a penstock. The water used to generate electricity passing through the first reservoirs and down through the turbines goes a second reservoir. This reservoir pumps the water up again at certain efficiency given that this process consumes energy. The process is illustrated in figure 1.9:

[9] http://en.wikipedia.org/wiki/Adiabatic_process

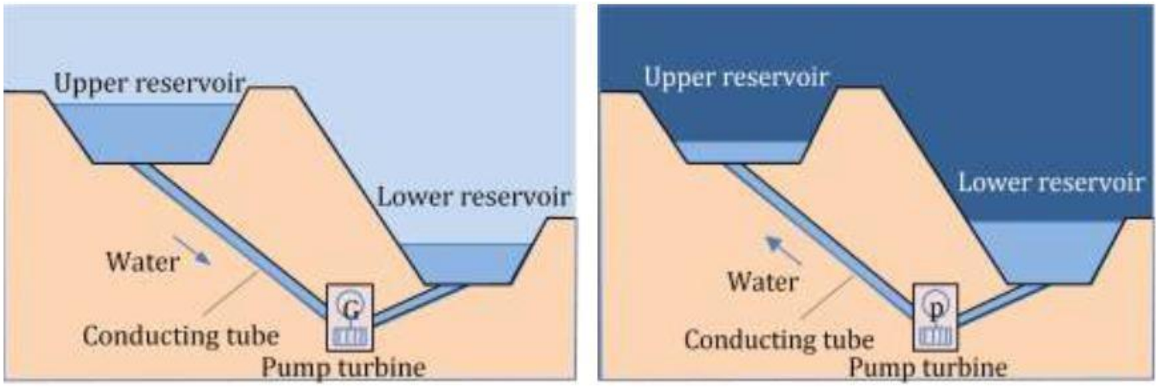


Figure 1.9 Principle of pumped hydro storage systems, showing discharge during the day (left) and charge during the night (right). Source (IEA, 2009)

Hydrogen Pumped storage is capable of increasing the available capacity for Germany by 60% (Bjarne Steffen,2012). At the current moment 4.9% (7.6 GW) of the countries capacity comes from Hydrogen storage. Figure 1.10 shows the development of the PHS capacity in Germany over the years.

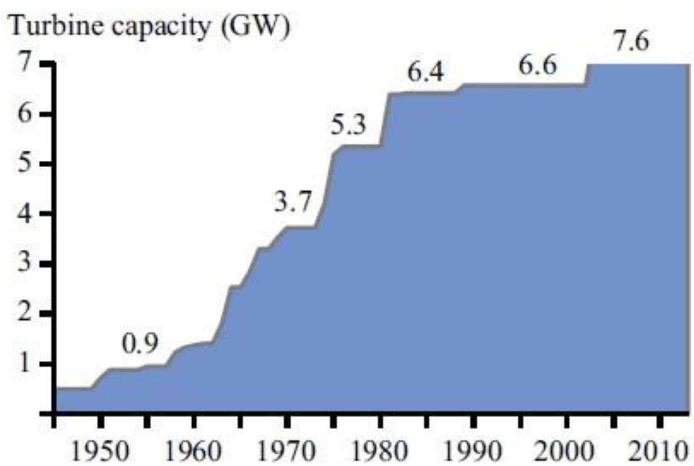


Figure 1.10 Development of PHS capacity in Germany source: (B.steffen,2012)

Hydrogen storage is a saturated technology with limits for further efficiency increase and is limited with the presence of space for building water dams. PHS as introduced in this section is not storing electricity in any form of another energy but rather using whatever resources that needs to be used instantaneously to generate electricity , to allow further generation of electricity at any required time increasing flexibility. This of course is limited by the size of reservoir in which water is pumped. In cases where continuous rain sessions happen, the process may not be very useful, as the operator may be forced to discharge the water to avoid over flooding the dam.

3.3.4 Batteries:

Using batteries as storage technique is an old invention that eased the life of millions around the world. Now batteries could and is being used as storage for providing electricity for the entire house and not just one device. The question of battery type is not a matter of just price. Batteries have tradeoff between prices, flexibility, storage capacity, and number of charge and discharge cycles. The lead-acid battery that is being used for cars for years is the most favorable solution for large scale storage. Those batteries although cheap and reliable they remain uncompetitive with low energy density (Amount of KW available for storage / m^3 of volume). Led acid also has a low charging discharging lifecycle.

Sodium-sulphur (NaS) batteries are rising as a good alternative with thousands of charging-discharging lifecycles and high energy density. The process works by chemically dissolving polysulphide into sodium and sulphur. Breaking the chemical bond releases the energy previously stored through the bonds. The battery requires the molten solution to be in two seprate tanks (Sulphur and sodium) at 300C each. Moreover the battery cannot be allowed to discharge completely as this cause irreparable damage. The advanced technical requirements of the battery makes it very expensive source of storage.

3.3.4.1 *Capabilities of EV batteries*:

An important issue introduction of batteries including EV batteries as an alternative means of providing electricity is the capability of the battery. While providing households with electricity is not the main function of EVs, it could be useful backup in case of emergency as well as help expand renewable energy capabilities as discussed in the further chapters.

An EV battery has energy storage ranging between 20 and 60 KWh as illustrated in the table 1.1; taking an average priced EV battery (22 KWh) the EV battery could provide electricity to keep a refrigerator (1.4 KWh/day) running for 15 days

Name	Battery Capacity (KWh)	Advertised range
Ford Focus	23 KWh	76 miles
Nissan Leaf	24KWh	73 Miles
Chevy Spark	21KWh	82 Miles
Honda Fit	20KWh	82 Miles
Tesla Model S	60KWh	194 Miles

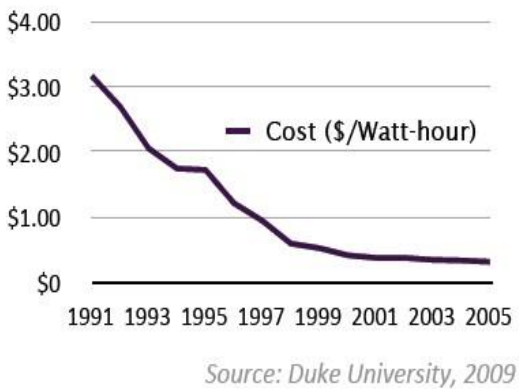
Table 1.1 EV batteries by capacity and driving distance source: the companies website

3.3.4.2 Price evolvement of batteries:

The main reason for the rise of discussions and papers about batteries as the future mean of storage is not only its size and flexibility but the decrease in price. Till this moment the most effective battery (sodium-sulphur) is 3 times more expensive per KW than gas power plants ($3000/KW Compared with just $1000/KW). However, batteries were historically part of the evolvement of technologies and have been used in cellular phones and laptops among many other devices, thus the increase in capacity and decrease in price was eventual to allow these devices to penetrate more into our lives. Price history of laptop from the famous online buying website amazon.com shows a 67% decrease over the last 3.5 years[10]. For bulk buyers the last five years witnessed further decrease in price of around 75% (Jaffe Sam, 2013).

Figure 1.11 illustrates the decrease in price of lithium-ion batteries as well as laptop batteries by brand:

[10] hjp://bnyurl.com/n6vql3u



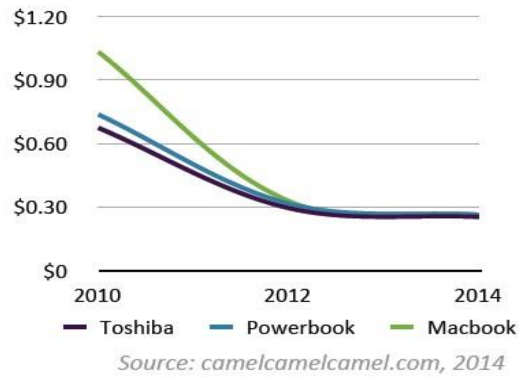


Figure 1.11 Pricing History for selected Laptop Batteries ($/Wh) **Figure 2 Price of lithium-Ion Battery in manufacturing**

The drop in price in batteries is not exclusive to user batteries but large format as well. Without drop in prices of these prices discussion about energy storage for renewable energy is useless. According to a report Bloomberg there would be a 57% drop in cost of energy per KWh of storage by 2020 (Brian Domain, 2013). Another report by the Navigant research centre there has been 60% decrease in the last 5 years in large format batteries. A much steeper decrease is expected by the end of 2015 by another 40%, and a total 60% increase from today's price by the end of 2020 (Sam Jaffe, 2013). The later report suggests that by 2020 "EV's will carry only a small premium over gasoline and battery based energy storage will be almost inexpensive as natural gas generation in a peaker plant".

3.3.5 The Tradeoff

The choice between the mentioned technologies in terms of difference in cost of capacity and efficiency and life time, adds to the problem of intermittency itself. Table 1.2 presents a Summary of the difference of 4 main storage devices. Several points are deduced from the table. First the cycle here is defined on an 80% discharge, higher level to complete discharging decreases the lifetime of the device significantly. Secondly the need of a calibration method to monitor this discharging level may change prices of each device. Thirdly the price of Hydrogen storage depends on the location although it remains competitive with $8/KWh. Forth Li-Ion has the lowest power cost but its ratio between power capacity and energy capacity is constant at 0.45h. Therefore it becomes very uncompetitive if offered as large storage device as presented in figure 1.12.

Property	Li-Ion	Flow batteries	CAES	Hydrogen storage	unit
Energy cost	500	70	25	4-8	$/KWh
Power Cost	225	600	550	1200	$/ KW
Efficiency	90	75	72	35	%
Lifetime	600	1500	6000	1800	Cycles

Table 1.2 Storage property assumptions for selected technologies. Based on Amos (1998), Cavallo (2001), Eckroad (2002), Townsend (2009), Schoenung (2008), Haubrich (2006), and Electricity Storage Association (ESA) (2010).

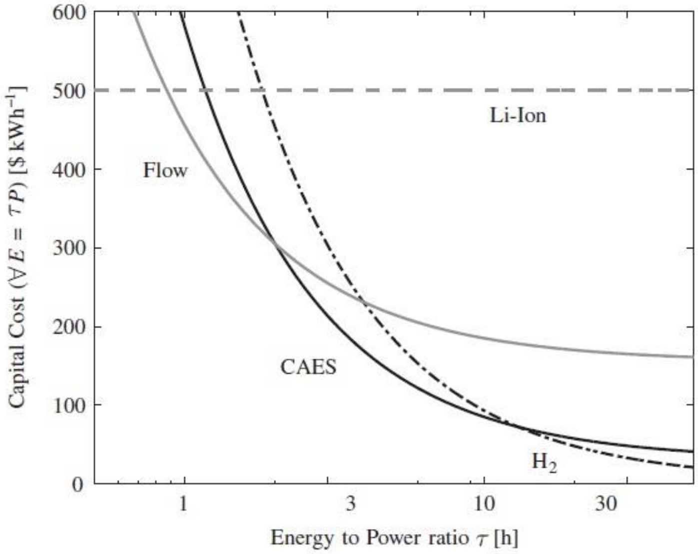


Figure 1.12 Capital cost of power storage technologies for a given storage duration, i.e. energy to power ratio (t). Source: (P. Gr¨unewald etal, 2011)

4. Complications facing the proposed future

The basis of finding good solutions is always identifying the right problem. This chapter takes a look at the main problems facing the integration of renewable energy. People often fall into the unrealistic belief that the near to zero marginal cost of renewable energy and the infinite availability of its sources makes it possible to integrate renewables indefinitely. The high investment cost, the volatility, the structure of the existent market with the existent power plants and the low capacity factor makes renewable energy integration not a very easy matter. The chapter highlights the beginning of the problem due to the need for energy security. The problem of intermittency is represented numerically with examples, as well as the direct and indirect costs incurred because of it. The chapter looks at the costs incurred due to the increased share of renewables on the long term as well. Storage which is often coupled with renewable energy as a solution for intermittency is examined in terms of possible complications as well. Special attention is given to the problems associated with Hydropower alongside with PHS. This is important to explain the need to rely on other less effective renewable energy and storage techniques. The last section refutes claims for increasing share of renewable energy to full reliance in the future.

1. The Question of Energy security

In 1973, Egypt and Syria went into war with Israel to restore their lands lost in 1967. As an act of support, the Middle Eastern countries (members of Organization of Arab Petroleum Exporting Countries or the OAPEC (consisting of the Arab members of OPEC, plus Egypt, Syria and Tunisia)) decided to limit their oil exports to just Egypt and Syria. They thus proposed an oil embargo on countries supporting Israel. This event created what was known as the Oil Shock Crises of 1973. The European industry was put on halt and cars had to wait in lines for hours to fill their tanks. This created a great economic impact on the market in Europe and drove the decision maker's focus more on means to ensure more stable energy supply for power generation and transportation. The price of oil barrels rose from 3 US$ to 12 US$ by 1974. More about the crises could be found in (Oyedepo SO, 2012).

In the 11th of March 2011 the Fukushima accident happened in which Daiichi nuclear station was subject to extreme melting as a result of the earthquake and tsunami. The accident created a major shift in Japan's viewpoint on energy security. This led to Japan's closure of all nuclear reactors and Germany moving to do the same. Several other countries have stopped their plans of expanding nuclear energy and some more decided to terminate the existing ones. The crises and the policy decisions are discussed in details in Hayashi and Hughes (2012). That incident affected global prices of uranium and electricity wholesale price. Japan's increased demand for LNG created sharp escalation in the price as well (Hayashi and Hughes, 2012). Japan's policy makers began implementing serious measures to limit energy consumption and reduce unnecessary use of electricity including limiting the use of air conditioning. The public radical shift against nuclear reactors has caused more and more pressure in favour of relying on renewable energy resources.

The matter of energy security has become of very large importance to the decision makers and one main way to do so is by diversifying the energy mix. Many countries are pushing their governments to increase their reliance on energy resources that are available sustainably at their own land. This particularly means more reliance on renewable energy. Renewable energy however is known to have an intermittent nature and although it is available at infinite capacity and free it is however not constantly available throughout the day/year. This chapter discusses the complications of introducing renewable energy and the price consumers have to pay for it.

Moreover in order to address the matter of energy security we need to discuss the concept of storage as well. In 2006 the EU Chamber drafter the EU Directive 2006/67/EC (EU, 2007), which legislates that ''Member States are required to build up and constantly maintain minimum stocks of petroleum products equal to at least 90 days of the average daily internal consumption during the previous calendar year''. In this chapter the storage is discussed from a different point of view that is the unconventional storage devices such as hydro-pumped and batteries and compressed air, and all complications with introducing them as a solution to renewable energy intermittency is looked at.

2. Renewable Energy Volatility

Renewable energy intermittency is a huge problem that energy markets are facing nowadays. The nature of the liberalized market creates problems for renewable energy power plants. These markets includes one hour ahead and real time trade which does not comply with the nature of the intermittency of the renewables. Solar PV panels could be blocked from production by an unpredicted cloud within minutes. Not only has that but the level of irradiation itself had a huge impact on the production level. Just having a “sunny day” does not guarantee of production. Intermittent irradiation on a partially cloudy day can be misread as continuous sunshine, over- estimating irradiance by up to 20%. On the other hand, diffuse sunlight that is not recorded, may still lead to PV output. Prediction of expected rain levels determines to a large extends the level of energy produced by hydro power plants. Wind speed determines the power generated, creating what is known as the intermittency management cost.

Within the different renewable energy sources wind remains the most uncertain source of energy (Ehsan Rahimi et. al, 2013). Although wind energy has higher overall capacity factor than solar energy, wind is much more volatile in terms of wind speed, frequency of occurrence and duration of occurrence. In other words, if special preparation such as stochastic approaches is made, progress would be seen in covering the uncertainty problem caused by introducing wind energy in the production mix.

One main issue is that there are always discussions about technological progress in wind turbines or renewable power plants in general. However, there is not much discussion about progress in the accuracy of tools analyzing the volatile nature of wind generation in planning and operation of power station. This is also very important when discussing expanding renewable energy production to countries in the southern hemisphere. These countries although very rich in sun, wind and rain falls, they do not have the technological capability of forecasting the expected levels of these resources to efficiently manage their energy mix. This means that they will have high level of energy insecurity and reliance on conventional power plants as peak load generation unit which is more expensive and more polluting and inefficient.

According to IEEE (2007), the reliance on forecast for wind level 4 hours ahead is less accurate than doing so 1 hour ahead. This means that planning ahead for these power plants is not possible or less reliable. According to another report written about forecast uncertainty (IEEE, 2005), the current information collected for wind forecasting comes from a limited amount of metrological weather stations. In fact most researchers are still missing efficient tools to predict wind power with acceptable degree of accuracy. This however is not a general consent among all scientists. Papers like Giebel et al. (2003) believe that significant effort has been done to improve accuracy of forecasting techniques. Others believe that there has been improvement in providing information about uncertainty to end users (Tsikalakis et al., 2009a).

It is also worth mentioning that 100% accuracy in forecasting rain level, solar irradiations or wind speed does not remove the intermittency, just improve the predictability and planning level. Solving the problem is not just in knowing the intermittency but dealing with it. The policy makers for the energy market need to understand and weight off the economical and environmental benefits of introducing the renewable energy in the energy market with a large percentage. Storage techniques need to be integrated to normalize this intermittency in order to produce a stable output.

Moreover the climate change happening around the globe is suggesting future change in wind speed, sun irradiation level and concentration of rain droplets. Although the effect is expected to be seen over the next 100 years, it raises the question of sustainability of renewable energy as a whole.

1. Examples of wrong forecast of water/wind/solar levels

The main problem as mentioned of renewable energy is the fact that the power plants are under the control of the nature. Taking a look at a few studies conducted we realize how intermittency could block the prospect of renewable energy becoming the main supplier of electricity.

- During 2005 the UK suffered 14 days in which demand was peaking while wind and solar where minimal according to Oswald et al. (2008). Same was witnessed in 2006 according to MacKay (2008, p. 187).
- In October 2007 for 11 days straight, 90% of the U.K wind system had wind speed registered under 4m/s at 10m height (Jefferson (2008)). This is a very low compared to the average of 6-7 m/s in the south, and the 8-10 m/s for the north according to the British database for wind speeds NOAB L. Another study (Oswaldet al...2008) shows that for the first six days of February 2006 wind energy between Ireland and Germany was almost 0 and negligible solar energy were also shown in the UK at the same time.
- In February 2008, during a sudden cold snap, the normally relentless winds of west Texas fell silent and the thousands of wind turbines that dot that part of the state slowed to a halt. Local utility operators, unable to make up the shortfall with power from elsewhere in the grid, were forced to cut service to some users for up to an hour and a half before the winds picked up again.(Macmillan Publishers Limited.,2010).

Most of these studies were presented as a response to other studies assuming possible reliance on renewable energy alone. Many of these studies discuss the issue with relation to storage as a possibility to deal with intermittency. This is discussed in a section later in this chapter.

3. Renewable Energy costs challenges

From an economic perspective arguments about renewable energy cheap cost is very controversial. Variable costs for water, wind or solar is almost non-existent, unless we consider opportunity costs for using water for other options. However, investment cost and to a smaller extent operating and maintenance cost remains expensive and unable to compete with traditional energy sources that already gained market share and experienced a learning curve. This forced governments to subsidize renewable energy to reach total of $101 billion in 2012, and expected to rise to $220 Billion in 2035 (IEA world Energy outlook, 2013). One example for those subsidies is feed-in tariffs. The subsidy added to encourage investors to invest in renewable energy and mitigate the risk. Many researchers, however, argue that the price lowering due to low marginal costs of renewables (in Spain for example) compensates for the money paid in subsidy resulting in net welfare for the Spaniards. (Energy Policy 2008).

One advantage for renewable energies is decreasing CO_2 emission costs which contribute significantly to lift the burden on the government or the producing plants. On the other hand it's

Complications facing the proposed future

a double edged sword; CO_2 emission licenses are priced depending on the demand and supply curve, which means lower demand for certificates due to more dependence on clean capacity,

means lower cost for the certificates. The lower cost for these certificates puts thermal power plants in an advantage in terms of energy prices.
The consulting firm Wood Mackenzie reported in 2006, that an estimate of $240 billion of feed in tariffs is needed in the EU to meet the then 15% (now 20%) hoped market share for renewables. The report claims that the estimated construction costs incurred by investors to be just $134 billion. This leaves the potential investors (the wholesale companies) in wind and solar farms with a net profit of $106 billion. This money falls on the burden of the federal government giving the feed in tariff. Which are primarily the people's paid taxes Thus what's being saved in electricity prices is being deducted double from people's pocket through tax money.
Another Hidden costs worth mentioning is transmission and distribution costs due to increasing renewable energy capacity. The location of wind farms and solar PV as well as of course hydro dams depends on many constrains meaning that investment in new transmission lines is necessary, depending on the distance covered, status of development of the grid and the capacity installed of renewable. According to the EIA outlook for world energy in 2013, the cost varies between; $100-$250 per KW of installed capacity of renewable (Dena, 2010; EnerNex, 2011; NREL, 2010). Considering the expected increase in renewable capacity, a total of $170 billion of investments in transmission and distribution will be necessary over the course of the next years to reach the proposed growth in all OECD countries until 2035.
On the other hand, many wind power (Mid-voltage) and solar power (low-voltage) due to the modularity of variable renewable have their power connected directly to the distribution grid. At low level of generation, the produced electricity is often consumed near the production site. This means that increase in the capacity of the distribution grid and the integration of voltage transformers is needed. Cost of applying these changes vary from $100-$300 for each KW of additional renewable energy capacity (Lodl, et al, 2010; Dena, 2012; CRE, 2012).
Wind energy also is a source of negative contribution, i.e. wind farms consuming energy rather than producing. This is the case according to Mardon (2010) in the state of Victoria in Australia. The report discusses that sometimes the wind turbine draws power from the grid to maintain generator fields during times of low wind flow.

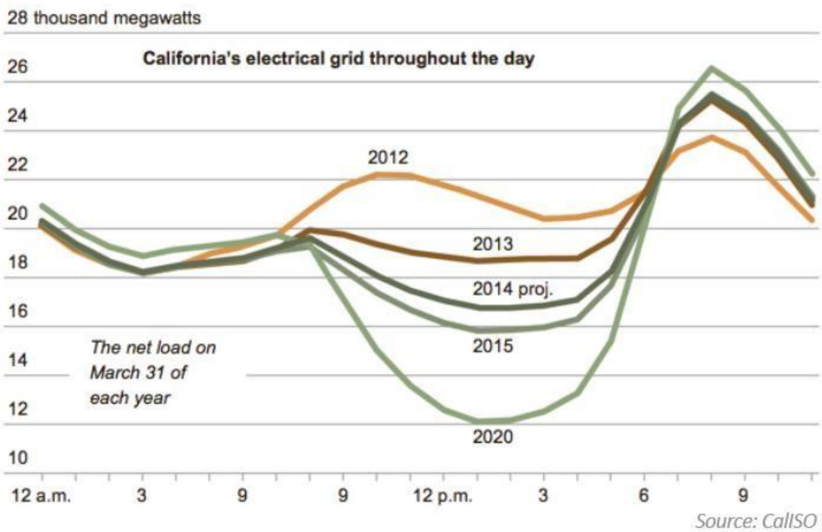
1. Change of wholesale price due to renewables

The economic theory of the demand and supply curve explains the limit to the theory that; future hope for higher share of renewable energy and wind specifically will lead to reduction in price. In principle countries need to decrease their wholesale price through renewables at least to accommodate the increase in retail price through subsidies given to these renewables.
The supply demand curve of electricity is based on merit system. Wholesale electricity price is decided through the most expensive unit (fossil fuel) dispatched which is also the last dispatched unit. The common assumption is the increase in the share of low marginal cost of renewable energy will drive thermal power plants outside the market according to the merit order scheme. This results in shifting the supply curve to the right lowering wholesale price. But that does not necessarily decrease the final retail price which will include subsidies provided to renewable energy. Shifting the curve would keep the price constant if the demand was totally elastic, which is not the case. On the contrast, necessary commodities like electricity have inelastic response to changes. Therefore for wholesale electricity price to reduce the slope of the supply curve needs to be very steep or the market share of renewables need to be very high. Furthermore, marginal cost of thermal power plants needs to be very high to reach that conclusion. This is because in that case the higher the thermal power plant share the higher the price of the last unit dispatched, which means that the more renewables penetrate the grid the more expensive units of thermal plant are kicked out. Therefore; the greater the share of

thermal units, the higher the chance is of reducing wholesale price. However, in countries with large share of low marginal cost units that are not wind and solar such as Hydropower and Nuclear Power, the change in the mix might not reduce prices at all.
The existing point of each country decides how far each country can penetrate its market share with renewables, while keeping prices at a low rate. Countries like Norway already rely fully on renewable energy; others still struggle to introduce any share of renewables. Empirical studies conclude that there is a minimum threshold of the share renewables could have for affecting wholesale price (Ahlgren, 2005). Thus the lower the share and percentage increase of renewables the lower the probability of decrease in wholesale price. In Spain for example wind generation happens to be in times of already low demand. Therefore increasing share of wind energy does not in fact decrease wholesale price at the moment.

2. Costs related to changes in thermal power plants

Renewable energy is very volatile when it comes to available resources for production. That means that there will be times where wind or solar are expected to produce but fail. This yields costs that arise from the substitution that has to be made. In the following chapters we discuss how this intermittency is met by storage, however realistic real-time solutions involves changes in traditional grids. In fact, many of thermal power plants are suffering and are expected to suffer from renewable energy. In real electricity markets, systems with lowest short-run marginal cost are dispatched first, maximizing capacity factors for those systems while diminishing capacity factors and raising the total cost of high-marginal cost. Subsidies provided to make renewable energy competitive results in either short term or long term incapability of thermal plants to remain in the grid. This was noticed in Germany for example (Mat Hope, 2014).
Renewable energy integration changes the mix of production removing some electricity production units from being base load supply to allow for renewables to be produced. This results in inefficiency and losses to traditional energy generators. On the other hand decreasing demand for oil and coal as a result of that will decrease their prices. A more complicated cost however arises when these units are then again needed to renewable energy failure to meet.
In periods accompanied by an unfavourable rainy season, the additional dispatch from thermal power plants could be very costly. For instance, the additional cost for thermal power plants for security reasons in an unfavourable year in Brazil (like 2012 or forecast for 2013) is approximately $2 billion/year (Canal Energia, 2013).
On the long run, provision for additional dispatch needs to be added, with the need for fast and short substitution of renewable energy, natural gas is expected to replace other capital intensive power plants. Naturally, natural gas has higher variable cost than conventional base load power plants. Additional gas turbines are expected cost between; $3-$5 for each MW hour of additional generation from variable renewable (IEA, 2011).
In general renewable energy tends to be more costly the more share it gets in the production mix. It is estimated that contributions of above 20% from non-dispatch able renewable energy will require much greater balancing and system reserve requirements than contributions below 20% (Gross et al., 2006). The following figure shows the expected electricity demand/supply curve for the state of California for one specific day in the years 2012-2020.



The curve show that absolute peak demand increases significantly between 2012 and 2020 by more than 4GW however for the period between 9 am and 6 pm demand for electricity from the central grid decreases to up to 10 GW at 1:30 PM. This is due to the expected increase on reliance on solar panels through Micro Grids. This may be good news for consumers who will enjoy "free" electricity for 37.5% of the day especially at peak demand times; it is however, bad news for power plants. The need for ramping up and down of power plants to work with the new demand/supply curve will impose extra costs on the grid. This means that the operators of base load power plants will lose money, as well as operators of peaking power plants. The later will still enjoy peak load demand but for shorter periods

The decentralization of the electricity grid is creating significant problems as well for traditional power plants who are trying to block the initiatives to expand reliance on micro grids politically. Some users have already eliminated their reliance on the central grid; others are providing excess power to the grid and receiving money. In the U.S, it seems that the federal and state governments are supporting the energy storage against conventional power plants in many states like California. The federal energy regulatory commission ordered on July 2013 transmission markets to compensate accurately for the services provided by energy storage. California passed an energy storage mandate dividing the 1.3 GW target between transmission distribution and customer sited storage (Darren Quick, 2014).

4. Energy storage challenges

When renewable energy is mentioned it's often coupled with storage. Most solar PVs nowadays are sold with batteries and many wind farms are considering introducing Flywheels or CAES as a regulator for intermittency. Energy storage is not very different however from renewable energy. In the sense that it's a relatively new technology, its very expensive, very limited in size and most importantly is a substitute and a threat to traditional fast ramping power plants that serve as a backup.

1. Capacity capability

One of the main problems of energy storage with their different types is that they are not capable of providing storage for very long periods. One example in Trainer (2013b) mentions that in order for the present heat storage system that is capable to maintain output for 6h, to maintain supply through one day of negligible direct normal irradiation (DNI) following a good day would need more than 5 times the storage capacity. To do so for 2 consecutive days 9 times the storage capacity would be needed.

Energy storage has gained great growth at the past 5 years and is continuing to do so. However, the rate of increase in generation capacity especially intermittent is much higher. The increase in capacity has been compensated with other cheaper and more favorable methods such as; increasing the network size to integrate local networks into regional and national and continental even in the case of Europe. This has in return for pooling response and reserve plants to provide the balancing and ancillary services that would regulate frequency and voltage.

Introduction of batteries not only increases electricity production costs (weather allocated to the end user or to the operator), it also increases secondary costs for increasing the generator's capacity. According to Love et al. (2003), the storage system impose energy penalty during the charging and discharging process. A typical battery has roundtrip efficiency of about 80% and fuel cells have even lower efficiency of 35-40%. This means that a fraction of the energy produced by wind or solar is wasted. To maintain the production levels intended means that additional capacity needs to be installed beyond the extra capacity already installed to account for intermittency and low load factor.

2. Allocating the costs

Allocating the cost of storage is a main obstacle towards its integration. Storage normally costs a lot of money. For example Sodium Sulphur (NaS) batteries cost around $3000/KW of capacity which costs 3 times the price natural gas power plants (Macmillan Publishers Limited, 2010). Another study done by Greenblatt et al. (2006) has attempted to model the cost of producing base load wind energy and its competition with fossil base load energy. Under base case assumptions with fixed 90% capacity factors for all the options, wind energy does not begin to compete with CC gas in terms of total cost of energy (COE) until effective fuel costs exceed $7/GJ. It becomes even harder for wind to compete with combined cycle gas if it's coupled with Compressed Air Energy storage, as competition then only starts at fuel prices of $9/GJ.

Taking a look at Hydrogen pumped storage in Germany for example, we notice the problem with grid and water fees imposing additional costs on hydro power water generation. As of 2009, the German higher court has approved regulatory decision to allocate costs for transmission of pumping electricity to operators (BGH, 2009). Pumped Hydrogen Storage operators argue that this a discriminative decision resulting in welfare losses when compared to other generation technologies (Krebs and Ermlich, 2008). An estimated mark up on generation costs is between 2.5 and 2.8 Ct/KWh according to (Dena, 2008). The former reference highlights that the operation of PHS plants is very elastic with respect to grid fees or costs in general, not the same could be said for end customer who considers electricity as a necessity i.e. has an inelastic response to rise in electricity prices. The paper thus concludes that it is better to allocate these costs to the end user to maintain the efficiency and competitiveness of PHS operators. Water fees also cause potential obstacle towards the expansion of PHS in the energy mix. According to Bergedorfer (2011), the only PHS plant with significant water fees in the Schleswig-Holstein area in Germany was rarely used. This is due to the increase in costs of production from water fees that makes the production units not competitive enough.

Thus the decision of allocating the costs to the end customer or the energy provider is a very controversial one. Allocating the cost on power plant companies or energy generators in general will repel investors from investing in storage techniques as the costs become too high for them to be encouraged to invest. This will negatively affect the learning curve and the efforts to decrease storage price. On the other hand, allocating it to the customer increases the overall energy price cancelling the positive effect of integrating renewable energy as a cheap alternative.

3. Spatial concerns

One of the main problems that come with storage especially hydro-pumped storage is the spatial concerns. This is also a problem associated with batteries. The concerns here are with the size of the reservoirs and the batteries as well as the location. Flexibility is a problem when it comes to using storage techniques with large sizes or the lack of space for them. Quoting. (David Lindley, 2010) "Pumped storage hydroelectricity requires mountains, so opportunities are limited by geography. Building such storage also tends to be expensive and environmentally destructive, and installing high-voltage transmission lines to connect remote storage sites to grids often triggers opposition on environmental grounds. If the capacity of pumped storage hydroelectricity is to grow significantly, it will have to leave the mountains".

In a paper discussing the number of planned Pumped Hydrogen storage in Europe (Deane et al. (2010), we notice the spatial problem for Germany. While many new sites and extensions are planned in neighboring countries Switzerland and Australia, the paper list only one project in Germany (the 1.4 GW Atdorf plant). This is an indication that the potential for PHS plants in Germany is largely exhausted due to the topographic conditions (VDE, 2009; SRU, 2011).

5. Hydropower Challenges

Hydropower as mentioned before is the strongest resource for renewable energy, with 80% representation in the electricity mix in Brazil and nearly 97% in Norway. Not only that but the world largest power plant in terms of capacity is the 3 Georges water dam in China, and in terms of production it's the Itaipú water dam in Brazil. Hydropower also provides a substantial advantage since it allows for large scale storage through the hydro-pump storage system. Therefore the combination of hydropower and pump storages provides the most idealistic scenario for renewable energy integration with low levels of intermittency, provided that storage is used wisely.

However water dams are facing increasing public resistance as a source of environmental damage as well as social implications resulting from re-allocating citizens living nearby rivers in which water dams are proposed to build on it. In spite of its renewable nature, several investigations indicate that hydroelectric plants can yield undesirable effects on river ecosystems (Trussart et al., 2002). Already Belo Monte water dam proposed on the Amazonia Region is being experiencing strong resistance from being built and operated due to public resistance and court ruling. This is the reason why many countries have developed specific policies to reduce environmental impacts caused by this power generation technology (ESHA, 2011).

Hydro pumped storage has also triggered one of the strongest opposition compared to any storage technique so far. Opposition accuse building reservoirs a potential for mosquito plagues, danger of bursting dams, bed smells and increased risk for earthquakes according to (Bjarne Steffen, 2012). Permanent environmental impact might also originate from the presence of artificial pools, infrastructure like power lines and change in water flow patterns (Egre and Milewski, 2002). Such plants are often built in area which could potentially be nature conservations. The Habitats Directive (EEC, 1992), defines area called "Natura 2000"; in which construction affecting this area is prohibited unless no alternative project sites exit, and there is a public benefit from the project. The assessment of these sites and the project often puts the potential of building PHS plants at risk. This undermines the credibility of studies of future energy capacity that relies on proposed PHS plants to be built.

1. Impact of Environmental constraints one Hydropower energy

The topic of the environmental negative effect of hydropower is very controversial since hydropower is the most mature source of renewable energy and is a good source for integrating other renewable energies such as wind energy (discussed in a later chapter).. It does also in fact help in decreasing GHG effect by substituting other fossil fuel power plants. It also helps meeting the EU directive of 2009/08/CE of mitigating the climate change and increasing renewable energy penetration in the energy market. However the negative impact on the river ecosystem could cancel these effects.

In this subsection however we discuss the results of the increasingly restrictive environmental constraints imposed on the hydropower industry. A methodology to assess the annual production and economic impact of fulfilling the minimum environmental flow and the maximum ramping rate (Maximum rate of change of flows) is discussed. The main resources are gathered from several papers such as (Ignacio Guisandez et.al, 2013) and other papers referred to later. The technical constraints set for hydropower plants are such as maximum and minimum unit's power capacity and discharge, operational restrictions are such as existence of priority for other uses in the reservoir (Nagesh and Baliarsingh, 2003).

From the paper mentioned earlier other results from academic researchers are presented through their linear programming, mixed integer liner programming, nonlinear programming, stochastic control approach and finally network flow models. The papers discusses the effect of controlling the minimum water flow as a percentage of the maximum flow, as well as the average of the numbers of hours for the plant to go from zero to maximum and vice versa. It also discusses the effects of the influence on power production of the water level in the reservoir and the hourly water inflow variation and energy price variations. The results were as such.

- (Harpman, 1990) estimates annual revenue losses for hydro power plants of 8.8% in cases of increasing the minimum environmental flow from 5 to 20.63% and setting the ramping limit to 94.74h.
- (Alfieri et al., 2006) increases the minimum environmental flow between 6-16% and notices a 1% decrease in energy production for each 5% increase in the minimum environmental flow.
- (Chen and Forsyth, 2008) expects weekly losses to quadruple as the ramping rate increase from 0 to 25h with minimum environmental flow = 26.67% and zero.
- (Olivares, 2008) also comes to the result of linear daily losses in the increase in minimum environmental flow and quadruple for the increase in the ramping rate.
- (Niu and Insley, 2010) and (Perez-Diaz and Wilhelmy, 2010) arrive to similar results.

The above mentioned papers are good resources about the high sensitivity of hydropower plants. Ignacio Guisandez et.al. (2013) concludes similar results to the ones presented above and adds that the smaller the rainfall of a year the bigger the annual revenue losses due to reduction in production.

2. Concerns about Hydro-pumped storage

Hydro-pumped storage faces many obstacles in its prospected future. Hydro-pump in definition is associated with Hydropower generators which mean the capacity of the generators. The flow of the river water and location of the dam determines to a great extend the viability of such storage technique. In Brazil for example the Itaipu dam which is the world largest power plant in terms of electricity production, produces 98,630,035 MWh/year[11]. This means that the dam has a capacity factor of 80%. The remaining 20% would be more linked to maintenance time and mismatch between demand and supply of the Brazilian and Paraguayan market than lack of water supply. Thus the idea of introducing a Hydro-pump is t unlikely in that case.

In a paper that discusses energy storage in the UK (Ian Wilson, Energy Policy, 2010), it is presented that there is no comparison between storage in conventional and renewable storage. The total storage capacity for gas and coal for England is 36930 GWh compared to 27.6 GWh for Hydro-pumped storage. Thus to replace the conventional storage with renewable one England would need 3700 Hydro-pumped storage units the size of Dinorwig (England's biggest hydro-pumped storage). This represents an economic and environmental challenge to achieve.

Such problems could be referred back to the way the legal and political system of the Energy management framework was set back in the past. The Central Electricity Generation Board (CEGB) has vertically integrated its planning in this way in the times before the liberalization of the energy market. It remains to this date of the regulated market in the same manner.

6. *Overly optimistic future plans*

In a paper by Ted Trainer (2013), a discussion is made about if it is feasible to hope for a 100% reliance on renewable energy in 2050. The paper refers to the current energy demand in Europe as an example. The paper neglects the 2050 proposed increase in demand which would strengthen even further the hypothesis that this is an unrealistic goal. The total demand for electricity in 2010 in power terms was 380 GW. The calculation of the contribution of Hydropower is possibly easy to calculate. According to the European Union (2013), hydropower could contribute between 10-17% of electricity consumption thus the rest of the renewable energy sources are left with 323 GW to supply.

Looking at the prospect of supplying this remaining demand partly from wind the maximum percentage would be between 20-25% according to (Lenzen, 2009, p. 19). This means that wind energy in Europe is expected to produce at around 81 GW. Wind turbines has an average capacity factor between 38% in the winter and 15% in the summer, this means that to produce 80 GW Capacity of wind farms need to be between 213 GW and 540 GW. To calculate the costs of building and maintaining these wind farms we refer to a study by AETA (2012) that estimates offshore wind farms to cost around \$2000/KW. This is results in around \$426 billion.

The study also discusses photovoltaic panels and solar thermal power as primary sources of electricity. The problem in solar energy is not limited to costs but also technical capability. PV panels could only provide electricity during the day (around 8h or 1/3 of the day). This also limits the production from thermal power as well as wind energy and hydropower that would have to shut down during periods where PV is providing the maximum capacity. According to (Denholm and Margolis (2007), PV cannot exceed 25% of demand. Some other reports Palmer (2013) limit it to only 10-20%. Assuming the optimistic figures 25% x 323 GW x 24h = 1938 GWh/per day. This can only be covered over 7h/day (Storage would be needed to stretch this over the entire day). Therefore the 1938 GWh/7h means the EU would need more than 277 GW of capacity to meet 25% of the demand by PV.

To take a look how big in size is the area required to cover such expansion in capacity the rate of radiation is examined which 1 KWh/m^2/d in Europe and 6+ KWh/m^2/d in North Africa (the EU is

Complications facing the proposed future

[11] Source the website of the Dam http://www.itaipu.gov.br/en

proposing a project to expand in the sub-Saharan and provide transmission cables between there and Europe) with capacity factor of 15%. This means that the required area would be 1938 GWh divided by the irradiance of 0.9-6 $KWh/m^2/d$ = 323-2153 million square meter of collection area. This makes solar energy the lowest electricity density power plant.

The costs of PV plants are expected to decrease significantly but not as optimistic as sum assumes. The Chinese over production is perhaps the main contribution to the continuous decrease in price. According to Lenzen (2009) the price is around $7/peak Watt, with the assumption of this price decreasing to $3 /peak Watt with a square meter of production having peak rating of around 200 peak Watts. Thus one square meter costs $600 which means the 2153 million square meters would cost around $1.292 Trillion.

This leaves around 3876 GWh /day of Energy to provide by solar thermal power. According to (NREL, 2011), the best site in the US (Blythe Riverside), receives around 358 million KWh a year from a 100 MW central receiver. That costs around $658 million. This means that the daily output is around 1 million KWh which means that 3876 of this unit is needed to cover the demand assigned to thermal solar power. Putting into assumption that the northern African region has a better radiation rate (6 $KW\ h/m^2/day$ instead of 5.2 in Blythe Riverside) then 3372 units is needed instead. The total cost becomes around $1.1 Trillion.

In a paper by Hart and Jacabson (2011)) assumption is made that California (69,882 Million KWh of production in 2011)12 could switch their 33% goal of 2020 to 100% reliance on renewable. However this is refuted in Trainer (2013b) where the author argues it is not possible to present such assumption without long term weather patterns for the region. The author argues that meeting the 66 GW demand requires at least a capacity of 81 GW including 75 GW of gas to be used 2.5% of the time contributing 5% of annual demand. This leaves 75 power stations idle most of the time just to deal with the problem of intermittency. The same paper claims that the proposal of reliance on solely renewable energy means 3-8 times the cost of capital cost to deal with the mentioned problems.

According to (Colin Robinson, 2006), "because of the variability and unpredictable nature of -wind energy´s- availability, additional standby generating capacity is required. Estimates of the extend of this additional capacity range from 65% to 100% -of installed wind capacity-. At low levels of wind penetration the cost of this standby capacity is small, but when wind power is approaching 20% of the natural power supply the costs become prohibitive".

Thus governments need to develop a scenario that wind power increases enough for having a clean matrix, but remain within the boundaries of not harming the operator when I come to reliability of supply. Therefore countries like Brazil for example are assuming that no more than 7% of its energy mix will involve Wind energy.

[12] http://apps1.eere.energy.gov/states/renewable_energy.cfm/state=CA

5. Proposed solutions

In the previous chapters we discussed the rising demand for energy, as well as the need for diversification in the energy mix to meet the new constraints. Later we highlighted the need for renewable energy specifically to ensure security and sustainability of future energy supply. However the previous chapter discussed also the implication of integrating renewable energy in the mix with large quantities. The problem of intermittency and the need for more robust techniques to arrange the economic problem was discussed. In this chapter we discuss some of the proposed solutions to intermittency and wrong forecasting. We also discuss the integration of storage technology in the production process and the benefits of including it.

1. Renewable energy integration with storage:

In this section we analyse how renewable energy could be integrated with storage devices and the economics as well as the implication on capacity of doing so. This section relies mainly on proposed solutions in academic articles, since the previous chapter discuses already successful implementation in different countries. Most of the articles discuss theoretical models and simulated ones proposing wider range of storage integration with renewable to deal with intermittency, loss of load and the need for conventional generation units as peak load units.
According to (IEA, 2008) disparity in net variability for renewable energy (wind speeds and solar irradiation) for Western Europe over 10-15 mins is at maximum between 6-12%. The average is even 20-30% of these levels. Analysis shows that at 5% variation, storage would not be a necessity by 2050, even with high shares of renewables. However this is not the case for the rest of the world. The actual variations to some parts of Europe extend to 30%. This (according to the reference) results in required storage capacity between 0-90 GW, based on the estimated renewable energy share by then. The study estimates the average variation worldwide to be 15-30% meaning that the net storage needed by 2050 to accommodate the rise in renewable will be between 189-305 GW.
The main advantage of coupling energy storage with renewable energy is its ability to quickly and effectively respond to variation in renewable energy to meet, maintain the required demand and allowing for higher penetration of wind and solar energy. Energy storage is expected to grow for many reasons, (as referred to by numerous scientists); it is the technology of the next decade. The falling costs and the increase of reliance on renewable will push storage technology further increasing the learning curve and allowing even further penetration renewable energy which will create a loop of storage and renewable energy benefiting from the growth of one another. The rising prices of fossil fuels will increase EV's and increase storage capacity. Finally the threat of surge of distributed micro grids through storage will move central power plant owners to increase their storage capacity to maintain their share of the electricity market thus increasing the scale of storage technologies.
This section discusses examples of extending specific renewable energy with a specific storage technology such as wind with PHS or solar with batteries. This is to refute the notion that renewable energy in general could be coupled with storage in general. But rather, specific renewable energy technology could be coupled by a specific storage technique depending on the characteristics of each and their match together.

1. Wind and Hydro storage integration:

One of the proposed methods of integrating renewable energy with storage is wind energy with hydropower storage systems. PHS by definition is intended to serve hydropower plants, however with it being the largest storage system in the world with more than 75 GW of capacity around the world, PHS could be deployed with much more renewable energy sources. The main concept of integrating both technologies is that PHS uses energy to pump water up the hill and

back to the initial water reservoir for generating electricity. Wind energy could be used to provide their excess electricity to pump water back to the first reservoir. In concept this is a form of storage of energy since electrical energy from wind was transformed to potential energy waiting to be transformed back to electrical energy again through the water dam's generators.
The main advantage of the technology is not only eliminating the intermittency of wind but also raising the flexibility of its production. Although the overall intermittency of the production of wind is the same with or without PHS the choices for using the generated electricity is now wider. The operator now has the option of not supplying the grid with the produced electricity from wind at times where prices are low and instead use it to pump water from the second reservoir to the first. The user can then generate electricity at times of high prices of electricity through the hydropower plant using the pumped water. A paper by Wolf Heinrich Reuter et al. (2012) identifies the return on investment for such an option and states the economic constraints for such a combination to be profitable. The paper defines the price premium as the extra profit the operator of a joint wind farm and PHS makes from the ability to decide on the times to supply the grid. This premium has to be more than the costs associated with adding the PHS such as investment costs for the hydro plant, variable costs (operation and maintenance) for the plant, as well as the losses associated with storing the water.

The mentioned paper identifies a model that analyzes data from Germany and Norway as one of the largest hydropower suppliers in Europe. The paper looks at the number of plants combining both technologies, which could come into reality depending on the previously identified price premium, as well as proposed subsidies by the governments. Both countries enjoy a very progressive policy towards both wind energy and PHS and have optimistic plans for the future share of renewables in their energy grid.
The model puts a constraint of a limit of 1 project per year and a maximum of 4 projects throughout the simulation. The main motivation of these constraints is that the model remains realistic and keeps an accurate estimation of the prices of electricity. Norway at the moment has 97% reliance on hydropower, further increase in capacity has a threshold, especially since the increase in capacity/supply decreases electricity prices and thus profitability. The model considers not only volatility of wind energy production but price elasticity and variation as well. The latter is one of the big mistakes academic researchers and policy makers ignore when discussing the possibility of further deployment of capacity relying on renewable energy.

The model results suggest that price premium would have to be at least 75% for Norway and 70% for Germany for at least one project to be planned and operated. For further inclusion of such projects (the maximum of 4), the premium needs to be around 115% for Germany and 150% for Norway. However, this is not a realistic number according to Castronuovo and Lopez (2004). The reference calculates the increase in profit between only wind energy and wind energy combined with PHS to be 20.12%. Thus the study explores the need for government subsidies to come with the price premium.

Figure 4.1 shows the results obtained by Wolf Heinrich Reuter et al. (2012) of the combination of subsidies and price premium needed for Wind+ PHS to break even. The results show that price premium between 10%-30% means that subsidies have to be between 35% and 50%. These subsidies are given in the case of Norway on investment costs before the start of the project not like the German Feed in tariff. The subsidy increases to 70% in Germany and 90% in Norway in case more projects are to be executed.

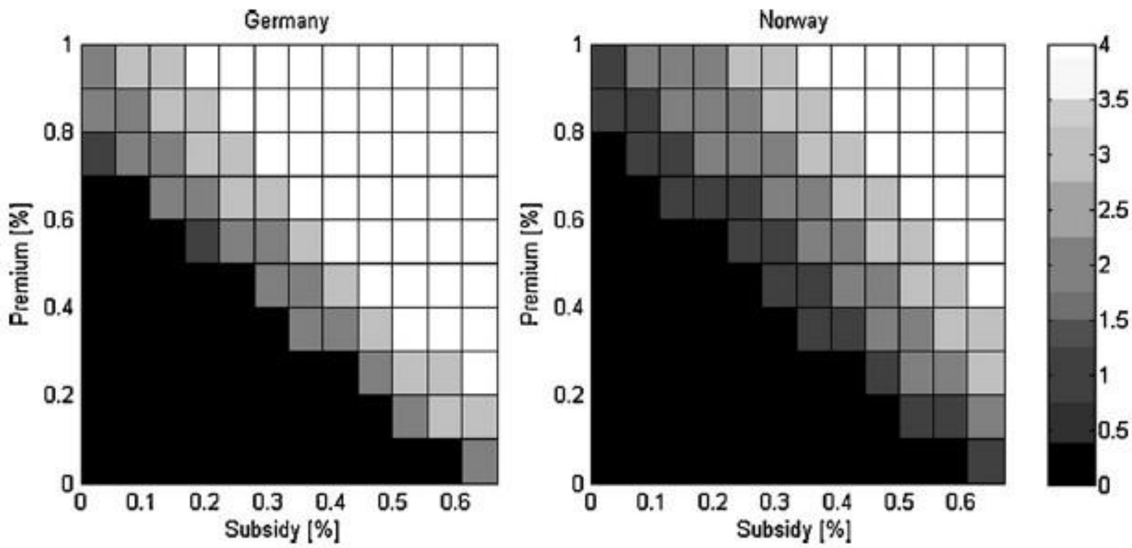


Figure 4.4: Average investments into wind–hydro at the end of the planning period for different levels of capital cost subsidies.

The paper concludes by suggesting that the subsidies provided by the governments should be better reallocated to R&D to enhance the overall efficiency of the system and decrease costs. The pumping process for example has an efficiency of 89% leaving room for further improvement. The paper suggests further investigation of the possibility of using Denmark's wind power (almost 50% of the country's production) with Norway's Hydropower (97% of the country's production). This is instead of either building wind farms in Norway or PHS in Denmark. The proposed model also could increase trading between Norway and Nordic countries as more stable capacity become available.

The proposed merger of wind and PHS is not exclusive to the mentioned paper nor Germany and Norway; many countries have already proposed and implemented the technique. The wide area provided by hydro dams creates possibility for wind farms. Furthermore countries that build dams relying on high level of rainfalls usually enjoy high levels of wind as well. This makes the merger of technologies more suitable. The proposed technology could also add to ancillary services as well be mentioned in the next sections. However as mentioned in the third chapter the technique has obstacles to overcome, the Itaipú dam for example does not have PHS due to the high capacity factor which means that storage could not increase production.

The increase in flexibility which will benefit the generators will have negative effects on the customers. One of the main reasons governments pushed for renewable energy was its goal or decreasing electricity price. However the operation of the system based on producing electricity at high prices will raise the overall cost of electricity, besides the already increased costs due to subsidies proposed by the governments. Moreover intermittency is not completely eliminated as mentioned before, in fact without extensive scheduling the whole system might not work at all. Both hydropower and wind energy rely on intermittent resources, thus the water level at both the first and second reservoirs are subject to variations just like wind farms. Without proper management of the variability in wind and water levels in the reservoirs, it could be the case that wind energy could not be used to pump water to the top reservoir because; either the second reservoir is empty or the first reservoir is full.

2. Wind with flywheel

In 2007 Fuji electric used wind power to operate flywheel as storage system. The operator used a 250 KWh Beacon Power flywheel to store and release electric energy produced through wind. Figure 4.2 shows a graph of normal wind power production in KW over time and another with optional storage through flywheel. The device was useful for mitigating variation for wind energy. However, Beacon power stated that this regulation of wind energy could be done at a higher level if the flywheels used and the wind farm were in the order of MWs.

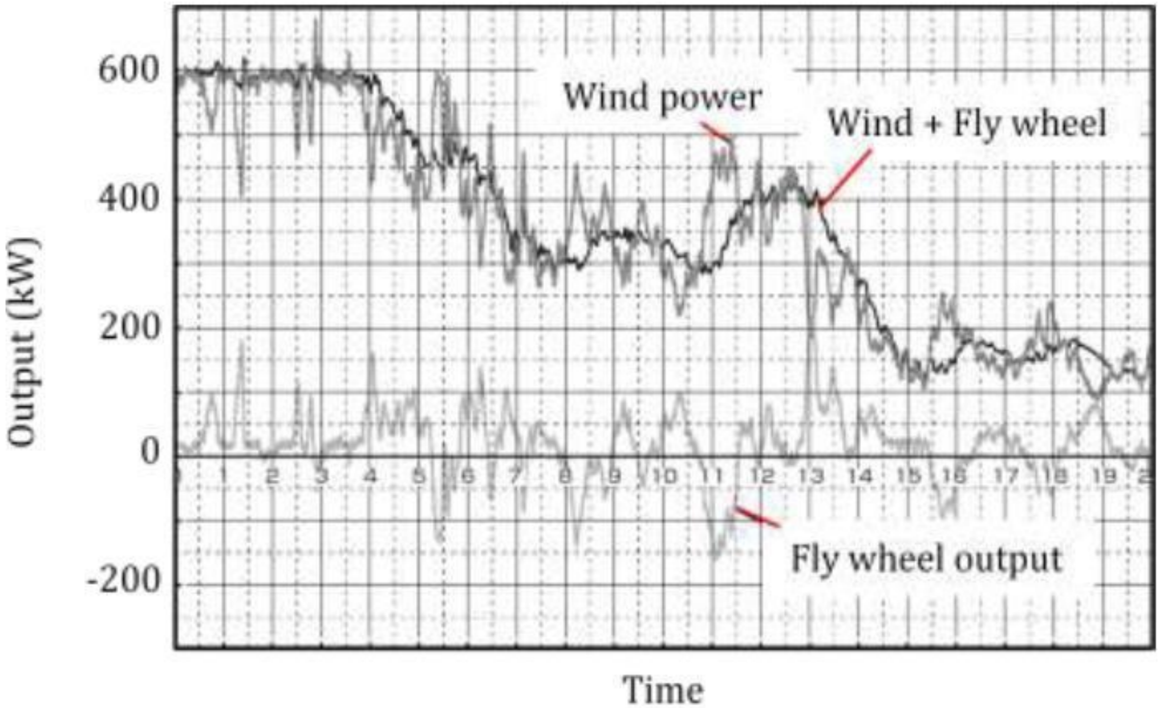


Figure 4.5 Operational results of wind power with flywheel Source: Fuji Electric, 2007.

3. Integrating Normal batteries with solar energy:

Integrating solar energy with batteries is the most efficient and implemented method of adding storage with intermittent renewable energy. The previously discussed problem of the duck projected to hit grids with high percentage of solar PVs, could be solved by storage. The problem as elaborated is that solar energy hits its peak production during times of low demand, and has almost non- supply levels during the evening where demand peaks. The price for this is paid by generators that have to ramp up at times by an estimate of 13 GWs in 2020 in California, in order to meet demand. What batteries of similar capacity as solar can offer is shifting the excess solar supply from midday to evening eliminating peak load demand. Examples of this are given in the case study chapter in the Kuai'I island of Hawaii.

4. Integrating E.V Batteries with Solar energy and wind plants:

Electric Vehicles is now becoming one of the most popular options for pro-environment customers. This could be well used on the customer level to support the grid. The idea is to target the right audience and create methods for them to be part of the solution. Vehicle to grid is a new concept of a system in which the flexibility of electrical vehicles is used to connect to the power grid and provide demand response services. This could be done by either;

Proposed solutions

1. Changing charge rates and sessions (time of high presence of renewable energies or low demand).
2. Or by actually selling the grid electricity not needed at certain times when demand is high (peak shaving)

The Science Daily in an issue in 2007 estimated that utilities could save up to $4000 per car per year if the electric cars are connected to the grid while parked.

According to a study in the US By (Pacific Northwest National Laboratories, 2011); Large scale
deployment of EVs in the seven states of the Northwest Power pool may result in doubling the wind power contribution to the US grid system. The study explains that 10 GW could be added through absorbing the excess wind power production of times of low demand. This is however subject to a constraint of the need for high penetration of EV's, the study by John Farell (2011) suggests this percentage to be 1 in every 8 car driven is EV. Another study by the same author (John Farell, 2010), presents similar results reached by Denmark. EVs are considered to become more economically and environmentally beneficial in the future compared with fossil fuels, But also proposes a method of storing grid electricity and increases the flexibility of the grid with rising contribution of intermittent energy resources.

One of the widely discussed options for the community of renewable energy supporters is the reliance on electricity from Solar panels to fuel EVs. Figure 4.3 shows that more than 56% of EV owners are planning to rely on solar panels for running their Electrical Vehicles.

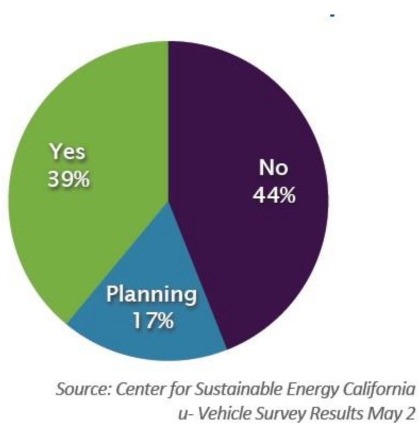


Figure 4.6 Users response on whether they fuel their EVs with Solar PVs

5. Other benefits of Energy storage

The integration of energy storage has multiple benefits aside from responding to renewable energy intermittency; in this section we discuss these benefits as a strength point for integrating storage technology in the electricity grid. Energy storage through batteries comes in 3 forms:

- Connected to the transmission system
- Connected to the low voltage distribution system
- Connected to the end user customer (behind the meter)

The benefits of energy storage depending on its location were highlighted by the California Public Utilities Commission (CPUC) in the following table(4.1):

Storage Grid Domains (Grid Interconnection Point)	Regulatory Function	Use---Case Examples
Transmission---Connected	Generation/ Market	(Co---Located Energy Storage) Concentrated Solar Power, Wind+ Solar Storage, Gas Fired Generation + Thermal Energy Storage
		Stand Alone Energy Storage, Ancillary Services, Peaker, Load Following
	Transmission Reliability (FERC)	Voltage Support
Distribution--- Connected	Distribution	Substation Energy Storage (Deferral)

	Reliability	
	Generation/ Market	Distributed Generation+ Energy Storage
	Dual---Use (Reliability &Market)	Distribution Peaker
Behind---the---Meter	Dual---Use (Reliability & Market)	Distributed Peaker
	Customer---Sited Storage	Bill Management/ Permanent Load Shifting, Electric Vehicle Charging

Table 4.1 Potential function of Energy storage (Source: California public utilities commission)

1. Providing ancillary services

According the United States Federal Energy Regulatory Commission (FERC), ancillary services are defined as *"those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system"*. Examples of these services are scheduling and dispatching, reactive power and voltage control, loss compensation, load following, frequency control, system protection and energy imbalance. These services usually impose extra costs on the system and delays electricity production. However, the nature of energy storage provides some aid to lift of this burden and provide these services instantaneously and without extra costs.

Energy storage has the advantage of fast response compared to most existing technologies to maintain the voltage and frequency of the electric system to avoid power outage and damage of connected motors and electronics. This is very important to deal with supply and demand balance.

Maintaining voltage and frequency at the specified voltage defined by the country, is one of the ancillary services storage devices provides really well. Supporting the voltage is more efficient the nearer the electricity is produced to the consumer. Traditional power plants usually is noisy and dirty and therefore located far away from the consumers. Backyard storage such as traditional batteries or EV batteries can be a good source of energy right where it's being consumed. The same thing goes for frequency control; flywheels and fast battery technology are designed to follow variations in frequency more accurately and quicker than traditional generators. This increases the overall efficiency of the electricity production and consumption process.

Maintaining voltage or frequency sometimes is done through avoiding excess power supply to the grid. The issue of excess supply of power to the grid is an increasing matter since the integration of renewable energy. As the integration of renewable energy causes the risk of not meeting the expected demand, it also risks providing more power than needed. Thus by absorbing excess power storage devices help balance the grid energy and support power quality. This service also saves some costs incurred by the operator that would be normally added to the final price of electricity. These costs are the cost imposed by the market for absorbing energy from the grid (in case of excess power) even if it's done as means of regulation.

2. Increasing decentralization of the grid

As it will be discussed in the following section, micro grids or decentralization of the energy supply is a very useful alternative when dealing with the issue of meeting rising electricity demand. This however is not possible without the availability of storage capacity at each decentralized household providing their own electricity through Solar panels for example. Storage technology alongside with smart metering and micro grid distribution provides users the flexibility of controlling their consumption. Storage technology may not have the current capacity to always provide users with electricity at times where they are not using their solar panels directly; it however, allows users to choose between using the central grid or their own storage devices. At times of high demand with electricity prices are expensive stored energy could be used instead of central grid energy. This results in decreasing the overall electricity bill of households.

According to a report by Rocky Mountain Institute (2014), the flexibility storage technology will provide for users a bargaining position against centralized grid owners. The risk of leaving the grid and replacing their reliance on cost effective energy storage will force power plant owners to decrease their prices and invest in more cost effective techniques giving leverage for users and control over their energy future.

Power lines and transformers as well as other grid infrastructure will benefit more from energy storage if it succeeds to decrease peak demand capacity. These equipments tend to wear significantly when operating at peak capacity, and easing stress on such expensive equipment will be beneficial (John Farrell, 2014).

2. Enhancing forecast for renewable

Wind power is an intermittent resource and policy makers are aware of this problem especially at large scale integration. Intermittency will result in undermining the potential for reliable generation. The difference between countries with prepared forecasts about wind and solar could be noticed in their level of integration of renewables. This shown in the later chapter about case studies in the case of Brazil compared to countries like Germany and Australia in the fields of solar energy for example. This puts emphasis on the need for stochastic studies and strategic generation and creates an infrastructure to optimize the availability of power with wind power integrated.

Historically information has been gathered from meteorological towers or airport data. This information was gathered at different heights and different schemes, and wind speed was extrapolated to the wind turbine hub heights. Some studies were found to have worked extensively on realizing the needed information. Kiss (2008) uses the ECMWF's ERA-40 (European Centre for Medium-Range Weather Forecasts' 44-year reanalysis) northward and eastward over a time period of 44 years and height of 10m, in order to study wind field statistics over Europe. Larsen (2009) also used reanalysis data from NCEP/NCAR (National Center for Environmental Prediction/National Center for Atmospheric Research) to estimate the geotropic wind and extrapolated the geotropic wind to 10 m height. Archer (2007) used upper air measurements from balloons and raw insides at the nearest meteorological stations to extrapolate wind speeds at 10 m to the hub height at 50 m or 80 m.

Similarly, many researchers used a power or logarithmic law assuming roughness length and friction velocity in the boundary layer that did not vary with seasons, terrain and stability of the atmosphere. It is also possible to widen the scope of knowledge through using information about wind speed at certain heights to estimate wind speed at different heights. This is using simple formulas such as $U_i=U_J*(—)^p$. The p here represents the surface roughness and is around 0.1429 (Best et al., 2008). The letters i and j represents indices for different wind speed, where i is the wind speed in question and j is the given one. U and h represents the speed and height respectively. The main difference between Metrological models and statistical analysis is that the latter is suitable only for six hours ahead forecasts while meteorological models usually are useful for models with long-term forecasting (Lange and Focken, 2008).

In the UK, the department of Trade and Industry created a database for wind speeds named NOABL for every 1 km^2 in the country. This opens the room for investors around the world to obtain the necessary information to estimate their NPV in case they want to invest in wind farms in the country. It also allows research institutes and students to have an insight on how to improve the integration of renewable energy. The database still needs improvement as it only takes estimates and not accurate measures and does not take into account barriers such as wall in the scale smaller than the 1 km.

3. Demand side management:

The concept of Demand side management is discussed in several parts of the thesis in the case studies and this chapter highlighting possible solutions. The EIA energy outlook 2013 highlights energy efficiency among the main factors of the energy production in the future alongside oil among others. The reduction of demand and switching away from peak times is the future for a more sustainable energy system. Ideas such as smart metering and relying on local storage and roof top solar panels among others are important for the effort of integrating intermittent renewable energy.

1. Micro Grids

Micro grids are a very viable solution as will be mentioned in the next chapter in the US case study. A single button allows universities, hospitals research centers and theoretically any user to disconnect from the grid. When dealing with rural areas, transportation, distribution and retailing costs are usually very high due to the hard nature and scarcity of consumers. Micro grids are a form of demand side management, except it is not just a response to instantaneous demand/supply curve but a long term solution.

The central grid operators have for long fought back against the idea of distributed renewable energy in the form of micro grids. However recent research has come to the conclusion that micro grid could in fact be of use to central users (operators?). Micro grid have better chance at managing renewable energy and with the introduction of storage, MG's could provide supply to the grid in return of feed in reimbursements for the operators of the MG. This could decrease peak load demand which is very costly to central power plants. The costs of losing some users to Micro grids could be compensated by the decrease in peak load demand that involve costs of failure to deliver by central power plants.

2. Smart grid/metering

The concept of smart metering is wider than to be considered by single company programming software. The concept comes from the need to give customers the control that allows them to keep their electricity demand but decrease the size of the bill. Operating at peak load times is not beneficial for operating companies. Failure to deliver involves often penalties and losses to the operators. It is thus in the best interest to be able to control utilities of less importance at times of peak demand to avoid failure. In 2010 the US policy makers issued a stimulus bill allocating $4.3 Billion to research on renewables. This included for the first time a large share to smart grids (Macmillan, 2010). The case study mentioned in the earlier chapter discusses how micro grids that have smart grids built in mitigated power outage through decreasing usage of unnecessary items. This could be very useful if integrated with storage in which times of peak load demand could be served automatically with storage, instead of just decreasing demand. This will help decrease the overall prices of electricity bills for households. Some of the Protocols offered by smart grids at the moment are presented in table 4.2.

Protocol	Use
Time of use	It is a service providing information about electricity prices at different time intervals. These rates are usually average cost of energy production and delivery during those intervals (+/- one hour).
The Real Time Pricing (RTP)	It is an information base for changing wholesale prices; This is done by fluctuating hourly or retail prices. It is thought of as the most Efficient and directs Demand response protocol in competitive markets.
Peak Time Rebate (extreme day pricing)	This service allows customers remuneration in return for lowering their consumption below the threshold at period of time where there demand is critically peaking (usually capped for a calendar year). This is usually a reliability measure to handle fear of high supply prices.
Dynamic Demand Control (DDC)	also aims to provide economic frequency stabilization and peak shaving through the individual control of many smaller and highly distributed loads e.g. domestic fridges and freezers, and although a very promising addition to network stability, DDC has not been utilized on a significant scale so far (Short et al., 2007).
Critical peak pricing (CPP)	The program gathers high electricity prices at certain days and hours in case of high wholesale prices, in an attempt to shift users away from those highly priced time intervals.

Table 4.2 Protocols available for smart grid users

3. Net metering

Demand side management could not prove useful without some regulation of the electricity fed
in and out from users with micro grids or smart meters or in general supply the central grid with electricity. Net metering is the idea of rewarding demand side producers of electricity for the supply they provide. The billing technique is currently dominated by but not limited to solar energy producers. At times of excess solar irradiation, consumers could choose to supply the grid with electricity or store the excess if the system has a battery. Typically users will supply the market at peak demand times due to the high electricity price, this will in return help solve the problem over the long term. In the end of the month the consumer pays for the net energy used which is drawn energy minus added. This kind of incentives not only helps demand side management but increase renewable energy share further as more users are encouraged to buy rooftop solar PVs. Net metering has one disadvantage that it cannot with the current technology distinguish between different types of electricity fed to the grid. This means that users could store electricity from the central grid in their batteries at times of low prices, and feed it into the system at times of high price. This is not the purpose of net metering designed to encourage solar PVs.

4. Improving grid connections

Expanding the grid has not only been a rising public demand to accommodate people's need of connectivity to the grid. It has also become a solution to meet renewable energy intermittency. In short, connecting countries and continents open the market for larger supply and larger demand. This raises the flexibility of the operator to meet short term excess/deficiency of supply. This is particularly useful for countries with large share of intermittent sources of power electricity. The concept is simple as illustrated by Figure 4.4. Times of surplice supply of wind the grid exports electricity to areas with high fast dispatching thermal units. These units then decrease their production. The process works in reverse when the wind power is below demand level.

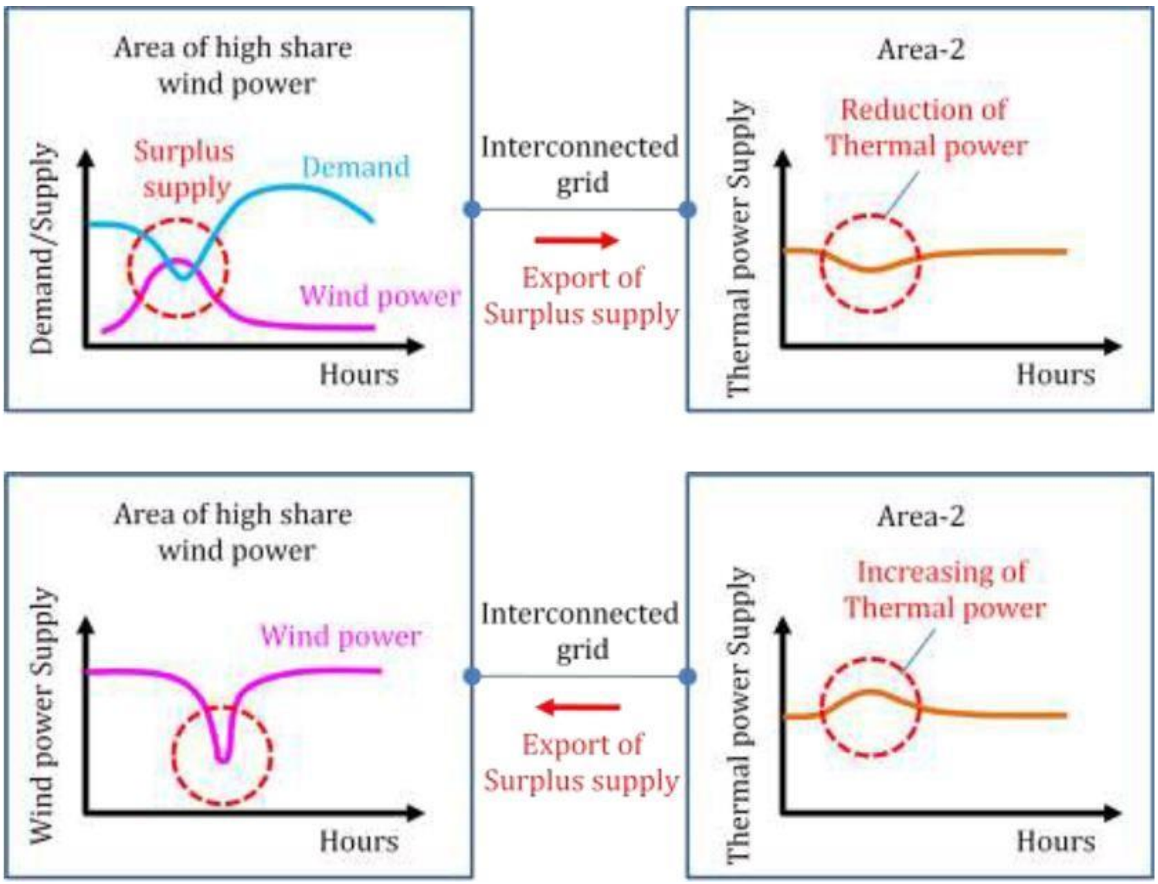


Figure 4.7 Balancing demand and supply through the interconnected grid. In the top figure, Surplus wind power supply is exported through the grid, while in the bottom figure power is imported source: (IEA, 2009).

Figure 4.5 presents the wind energy produced in west Denmark 2008 compared with the net trade of the region. The figure shows a clear correlation between spikes in wind power and increases in exported electricity. The figure suggests that excess wind does not go to waste but is rather exported to neighboring Scandinavian countries.

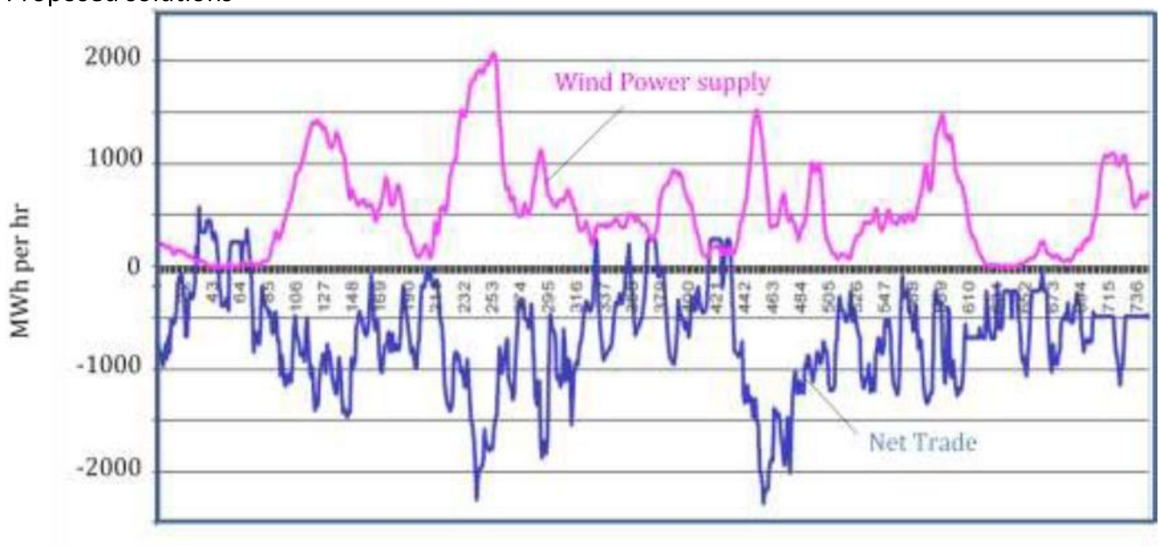


Figure 4.8 Comparison of the wind power supply and net trade in western Denmark at 2006 source: H. Sharman, 2007.

4. Reforming the energy market:

The energy market has been witnessing historic shift in the last decades. The changes in the features and motivation of the countries have encouraged the governments to constantly change their rules and regulations to push towards more pro-Renewables energy and pro-storage energy mix. Many countries around the world still face legal barriers preventing them from encouraging renewable energy deployment. Most subsidies around the world still go to conventional thermal power plants especially in oil rich countries. A country like Brazil with high potential for renewable energy is struggling to keep steady energy supply. This due to its lack of control on its hydro reservoirs. Already in middle of May 2014, Brazil finished its water reserves for hydropower generation till the end of the year. This is noticed in the UK as well, according to (Black and Strbac, 2007) PHS in the areas of Dinorwig and Ffstiniog have substantial capability of storage, but it's being used to trade actively as a generator in the market because of their fast response feature. Moreover, Brazil has no clear policy on CO_2 emission prices. This stands as an obstacle for making renewable energy competitive, since these certificates raises the prices of thermal units in favor of renewables.

In the third chapter the allocation of costs of the storage techniques was discussed as an obstacle towards solving the problem of intermittency of renewable energy. Emphasis was given on grid costs allocated to hydro-pumping storage operators in Germany. However according to (EnWG, 2009) new PHS plants were exempted from these costs for 10 years and according to (GNeV, 2011) the period was extended to 20 years. This comes from the motivation inside the legislative bodies towards incentivizing further PHS projects. Furthermore no or limited water fees (that has also been a burden in front of PHS operators) was charged for the power plants as seen in the figure 4.6. Areas like Schleswig-Holstein (with the Geesthacht power plant) which previously imposed such costs in 2001, decided in 2011 to reduce the costs (OWAG, 2011) to help the plant retain operation. This also comes from EU flexible policy attitude. Although the European water framework directive requires adequate pricing of water usage, they allow exceptions for social or economic reasons (EC, 2000, Art.9).

Water fees in German states (excl. city states) as of 10/2011.

State[a]	Surface water usage fees
BB	0.005–0.02 €/m[3b] (BbgWG, 2004)
BW	0.010–0.051 €/m³; for hydro power individual fee based on capacity (WG-BW, 2010, § 17)
BY	No fees
HE	No fees
MV	0.020 €/m³; omitted for hydro power uses (WaEntgVO M-V, 1996, § 1 Section 1b No. 4)
NI	0.01023–0.05113 €/m³; omitted for hydro power uses (NWG, 2010, § 21 Section 2 No. 7)
NW	0.0035–0.045 €/m³; omitted for hydro power uses (WasEG, 2004, § 1 Section 2 No. 6)
RP	No fees
SH	0.0077 €/m³; for hydro power uses reduced to 0.00077 €/m³ (OWAG, 2000, 2011)
SL	No fees
SN	0.005–0.020 €/m³; omitted for hydro power uses (SächsWG, 2004, § 21 Section 4 No. 3)
ST	No fees
TH	No fees

[a] BB, Brandenburg; BW, Baden-Wuerttemberg; BY, Bavaria; HE, Hesse; MV, Mecklenburg-Western Pomerania; NI, Lower Saxony; NW, North Rhine-Westphalia; RP, Rhineland-Palatinate; SH, Schleswig-Holstein; SL, Saarland; SN, Saxony; ST, Saxony-Anhalt; TH, Thuringia.

[b] No PHS existent or planned in this state.

Figure 4.6 Sources (Bijarne Steffen, 2012)

One of the main complications of the intermittency nature of renewable energy is that the methods of dispatching are no longer working. As mentioned before the longer the distance between the time of forecast and actual dispatch the higher the inaccuracy level. Moreover in an attempt to encourage renewable energy penetration, governments have decided to bear the costs of balancing the difference between forecasted and actual production level. This of course in turn goes to the final consumer in form of increase in price. The argument about if this increase is compensated by the social costs such as $C0_2$ emission costs or not is discussed in the previous chapter.

From a theoretical perspective if the information day ahead planning and the treading and real time operation are identical no need for adjustment is needed. This is however never the case according to Weber (2009). Normally the adjustments are carried in the intraday market or the balancing markets which involve increasing costs as mentioned before. The information update occurs normally with conventional energy sources due to unexpected plant outages or load forecast deviation. The same goes for wind energy where updated forecasts happens by the hour. This comes from meteorological models or on statistical analysis and extrapolation of the current wind power feed in as compared to the forecasts (Weber ,2009).

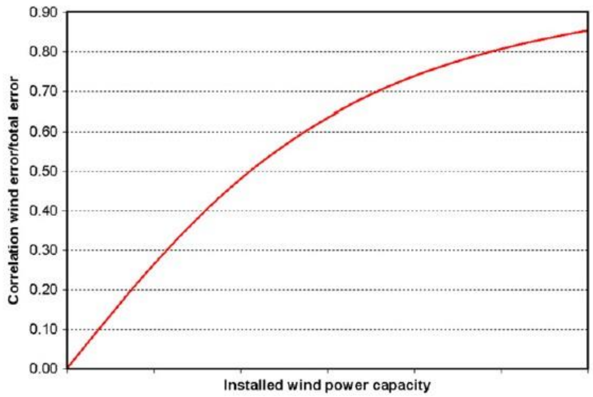


Fig. 3. Correlation between wind and total error as a function of installed wind power capacity.

Figure 4.7 Source (Christoph Weber, 2009)

As shown in figure 4.7 increasing the penetration of wind energy means there is increase in total error in of predicted energy production ahead of time. The paper reaches a numerical result that the adjustments costs mentioned earlier are a linear function of the absolute variance of the wind forecast error. This means that the relative wind forecast error must change inversely proportional with the increase in wind capacity otherwise the increase in wind capacity will result in quadratic increase in adjustment costs. Doing so is possible as mentioned before in the chapter through enhancement of forecasting techniques as well as paying attention to academic research done in the field.

Two strong contradicting points arise in reference to the increase of wind energy penetration. The first is increasing wind capacity in turn means increasing the geographical dispersion of wind farms; this means that the forecast error is likely to decrease with wider area covered. Which contradicts the earlier conclusion; this is mainly because countries such as Germany and Spain and Denmark have already exploited most of the good areas to be covered for wind energy. Furthermore wind farms divided to smaller plants with less than 30 MW are less efficient. This is particularly a case noticed in Spain extensively since companies benefit from incentives provided by the government for wind farms of this size. This opens the discussion for the need to reform the regulations for the energy market. So to be more specific dispersing the wind farms over large areas will overcome the forecasting problem but decrease efficiency.

Moreover the market requires an increase in its liquidity in general to increase the flexibility and enhance the chance of more reliable electricity production and delivery. According to (Amihud, 2002) the lower the liquidity; the higher the slope of the price function increase.

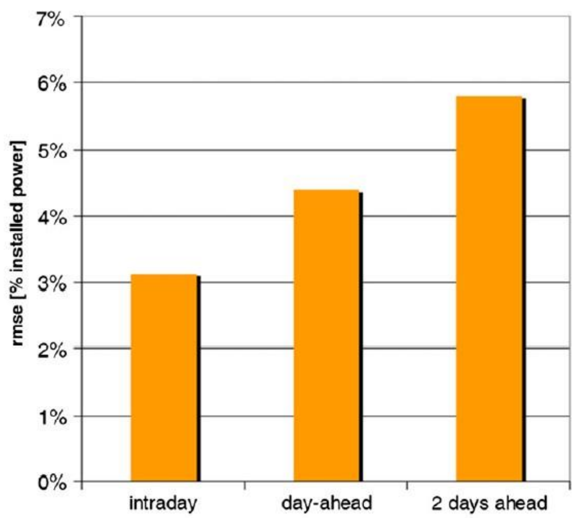


Fig. 4. Relative forecast error for aggregated production of all German wind farms.

Figure 4.8 Source (Christoph Weber, 2009)

Figure 4.8 Shows that the closer the distance to the dispatch the lower the forecasting error is for the German market. This means that reducing the intermittency of the wind requires market reforms when it comes to unit dispatching. These reforms are such as ensuring the functioning of the intraday market, as well as allowing for intraday and real-time internal portfolio optimization within large producers.

The relation between better market reforms and further integration of renewables and storage is two sided. A main benefit of storage is witnessed in Norway; the high reliance on Hydropower with storage techniques has moved the country towards using the spot market with a high percentage. This could be accredited to the good basis for hedging and optimizing through the market (Christoph Weber, 2009). Spot market increases market flexibility as mentioned before and adds to the overall efficiency of the process.

1. Market reforming for storage:

Storage devices have been known to be able to provide ancillary services such as frequency or voltage regulation. These services have not been previously given credit like the traditional providers of this service. Table 2 illustrates the monetary reward market operators gave to energy storage throughout the past years. This low per KW rewards does not begin to compensate the storage devices for their costs. The change in regulation helps making storage more economically competitive and more capable of joining the electricity grid. The US was one of the first to acknowledge this and the federal energy regulatory commission (FERC) issued two orders to support this. Orders number 755 and 784 requires grid operators to factor in the speed and accuracy of ancillary services in the market prices (Bohdi Rader, 2013). This will give advantage to more responsive and accurate storage devices like flywheels and batteries against traditional plants. This will break the monopolies over ancillary services by some utilities and allow for selling energy storage in a more organized fashion. Table 4.3 shows the value given to some of the ancillary services that would be provided by storages. These will compensate some of the costs of storage and make renewable energy integration more feasible.

Market Type	Location	Year Evaluated	Annual Value ($/KW)
Time-shifting	PJM	2002-2007	$60-115
	NYISO	2001-2005	$87-240
	USA	1997-2001	$37-45

	CA	2003	$49
Regulation	NYISO	2001-2005	$163-248
	USA	2003-2006	$236-429
Contingency Reserves	USA	2004-2005	$66-149

Table 4.3 Energy Storage Value in Competitive Electricity Markets (Source National Renewable Energy Laboratory) (U.S)

To sum up there are many ways to help overcome the problems of renewable energy integration in the market. Some are already implemented in countries and some are still theory. Some are even restricted by the technological progress in the field, and in many cases the government's legal policies. This chapter tried to shed a little light on these set of solutions, more research would be needed to analyze each topic separately.

Proposed solutions

6. Case studies from around the world

In the previous chapters we introduced theory, problems and proposed solutions to the overall view of the thesis. In this chapter we take a look at some real live examples seen around the world. Four sets of examples were investigated to give a wider understanding of the current situation in the world. Brazil was first investigated as the host country of the thesis and a leading country in the developing countries, in terms of economic boom and process of electrification. The investigation into the Brazilian case was focused on presenting the current situation with the failures as well as the success stories. The second case study was the US, one of the world leaders in renewable energy growth and progressive regulations towards increasing renewable energy share. The focus was on positive examples as a guideline and motivation for other countries lagging behind in renewable energy.

The third example was different islands from different parts of the world such as Hawaii and The Canary Islands and the Azorean islands. The focus was set on the potential for renewable energy in those Islands and the progress already made. That was because many places around the world suffer from no or scarce electricity due to its remoteness. The reason for that is that price of delivering electricity and sustaining it to these islands tends to have significant high costs in terms of transmission and distribution costs, while users of the grid in these areas do not use the grid at rate valuable enough to make up for the investment costs. On the contrary Islands usually enjoy high levels of wind, solar and tides needed for renewable energy generation.

The final example was an analysis of English data on wind speeds, solar irradiation levels and demand for electricity in comparison with different storage techniques and the resulting Net present value and return on investment. The motivation here was to give a real life example of how there is limit to the ability to predict and develop a formula for the return on investment in renewable energy given all necessary information.

The choice of the four different examples was to tackle the discussed problems and solutions from different angles. Brazil represents a real time snapshot from a rising economy. The USA represents a positive example from a leader in renewable energy. The Islands represented an example for micro grids and independence from central grid and a window for opportunity with their high levels of resources. And finally the Data analysis from England was to give a projection of the limit of the accuracy level that could be achieved.

1. Brazil

Brazil is definitely an interesting country when it comes to case studies about renewable energy integration. Brazil's resource base gives it potential to become the world's leader in integrating renewable energy. The country is also enjoying a dramatic increase in renewable energy penetration especially in biomass.

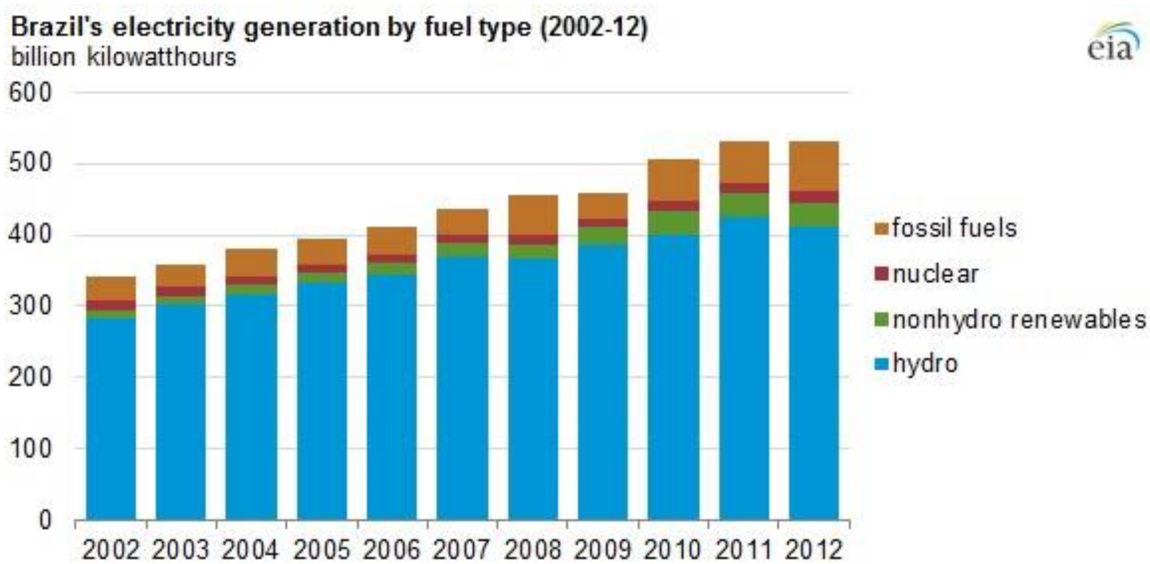


Figure 5.3 Brazil's electricity generation by fuel type 2002-2012, (source: U.S. Energy Information Administration, International Energy Statistics)

Figure 5.1 shows the legal system of Brazil that organizes the policy making of managing the energy market. Brazil introduced an enacting decree in 2004 called PROINFA to increase renewable energy penetration. Brazil failed however to meet the 1.4 GW of wind energy capacity target in 2008 (only 902 MW in 2011). Brazil however, has now passed that level aiming to reach 13.8 GW in 2018 from the current operating and under construction capacity of 3.5 GW. The estimate of the potential for wind energy in Brazil varies as analytical techniques progresses; In 2001 Brazilian wind atlas estimated wind energy potential to be around 145 GW (Figure 5.2 demonstrates the geographical distribution of the wind energy potential). In 2014 this number doubled to 300 GW according to academics. This suggests that Brazil still needs more accurate studies of its wind and solar potential.

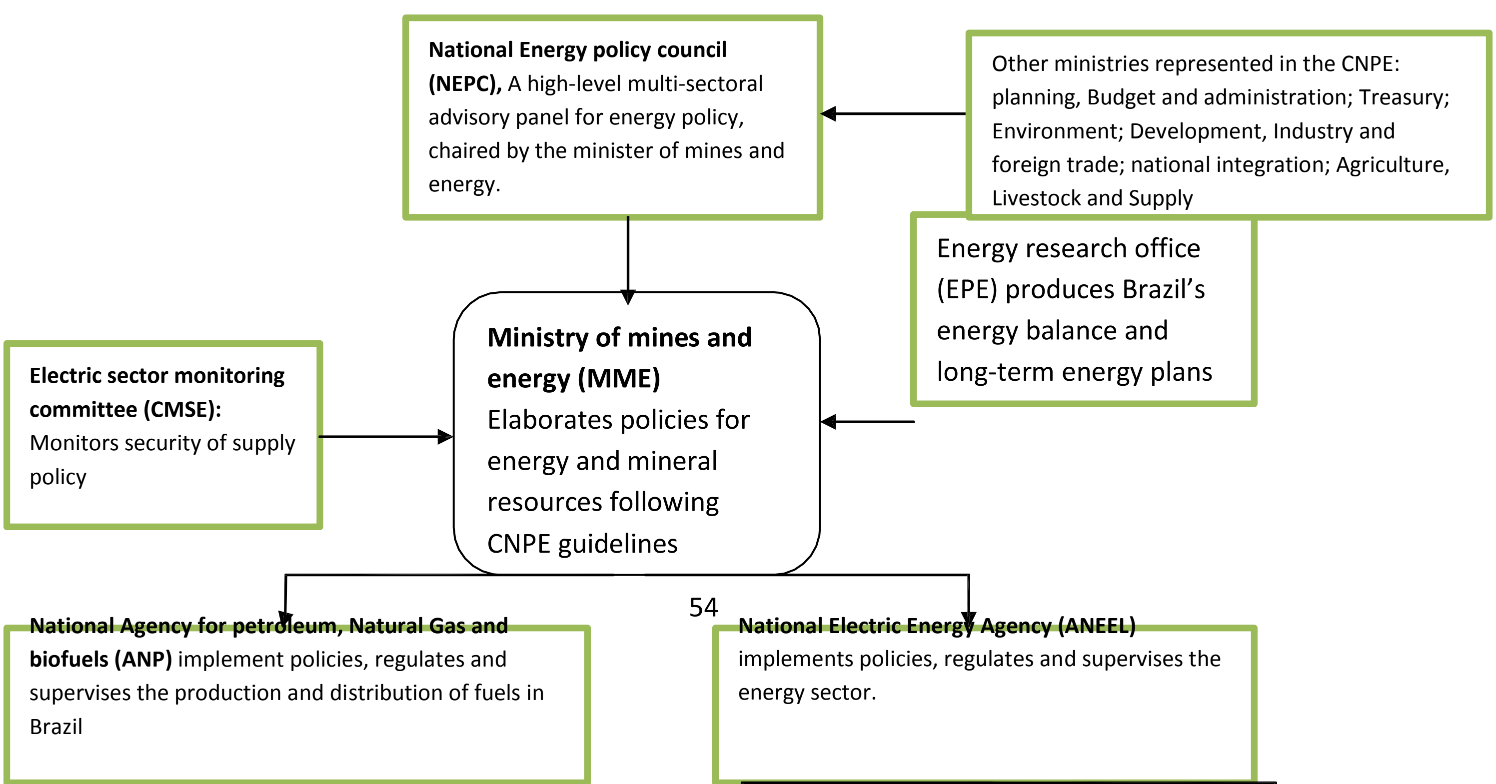


Figure 5.2 Brazil's energy policy and regulatory institutions (EIA ,2013)

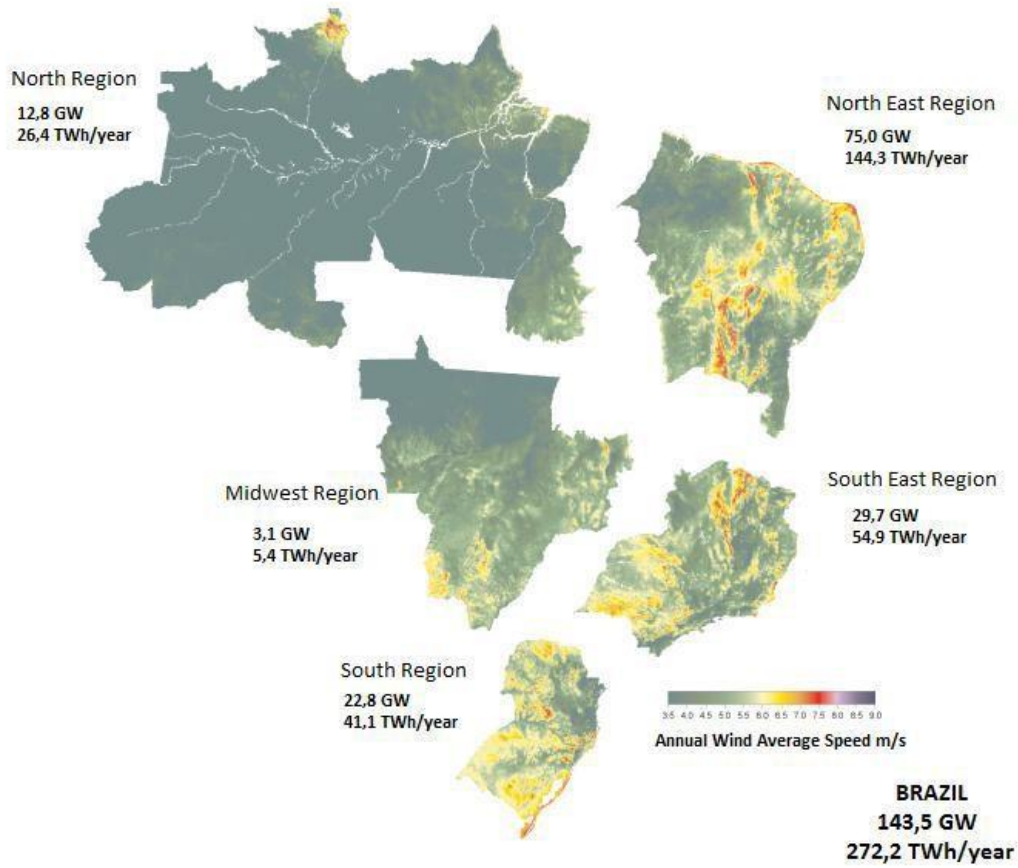


Figure 5.3 Potential wind estimated average annual wind less than 7.0 m/s. Source: Brazilian Wind Atlas:

Brazil unlike traditionally thought, does not suffer from huge intermittency problem from renewable energy sources. In fact Brazil enjoys compatibility between wind and rain resources. If wind energy is deployed in large quantities, it could be used to save water in the reservoirs during dry seasons according to (F.R. Martins, 2011). Wind speed is even found to be higher in the northeastern region which has a large water reservoir available for storage, increasing the benefits of compatibility. There is also compatibility between solar and hydro energies since solar Irradiation decreases mainly in rainy seasons with the increase in clouds, making solar and hydro a substitute for one another. However, the latter matter still needs further research to be proven. Furthermore Brazil does not only enjoy high levels of solar irradiation but also clear sky, the large areas of tropical regions in the country insures minimum inter-day/inter-annual variability.

The seasonality of rainfalls in Brazil, especially with the northeast and southern regions enjoying similar hydrological seasonal regimes as studied by Amarante et al. (2001c) gives the country a potential advantage. However, mismanagement of resources and lack of accurate forecasting has been posing historical challenges for the Brazilian interconnected electric system. This is then reflected in the losses incurred by the federal government.

In fact Brazil´s biggest obstacle is the lack of knowledge as well as regulatory measures as will be mentioned in the next paragraphs Figure 5.3 demonstrates the solar irradiation level in Brazil in comparison with other countries. While Brazil has the third highest level, it enjoys one of the lowest market shares for solar energy. When compared with wind energy for example, Brazil did not make significant improvement in gathering information on the capability of solar. Fernando Martinz in the previously cited paper does a study on the number of researches conducted on Solar and wind energies. For wind energy the author found more than 11 studies over the last years starting from 2001 and continuing covering the main Brazilian geographies. On the other hand the study only found 3 researches conducted about solar energy, one of which does not have a spatial resolution. The same was found for actual legislations and government programs. Much more effort laws and mandates were issued to support wind energy including numerous annual biddings for wind farms, not the same was found for solar.In comparison with other nations of similar solar irradiation levels like Australia, Brazil is still lagging behind. Just between 2008 and August 2013 Australia increased its total installed photovoltaic system capacity from 29.3 MW to more than 1.03 GW (Clean Energy Australia report, 2013). The Australian website for clean energy explains to the Australians that they could reduce their electricity bill through rooftop solar panels. The website does a breakdown of the PV capacity needed as following; the most common household PV solar systems are 1 KW or 1.5 KW. This produces from 3.9 to 5.KWh per day in Sydney to 5.0 to 7.5 kilowatt-hours per day in Alice Springs, respectively. A four persons household in Sydney that consumes on average 9,000 kilowatt-hours per year - about 25 KWh/day - would require a 1 KW PV system in order to displace 15.6% of their average electricity bill. A 4 KW system could cover up to 62.4%, and a 6.5 KW system would cover 100% of this four person household's electricity consumption (Clean Energy council, 2013).

In the second half of 2014, however, the government launched a program for solar. They have organized a auction dedicated to solar and gave incentives for panel makers to start production in Brazil. The government has also regulated the net metering in Brazil through the resolution 482 of ANEEL. This is a step forward although more effort needs to be done for a solar rich country like Brazil.

We can see the advantages of giving more attention to wind than solar, translated in the different ratio of the market. This could also be witnessed between wind and Hydro. In Brazil, the Energy Research Enterprise (EPE) expects Hydropower to decrease by 9% to reach 67% by 2020. On the other hand the institute expects wind to rise to 7% from just over 1% currently. This expected change to happen over the next 6 years still lacks the regulatory framework to support it. While water is considered as public goods wind is not. This translates in the amount of research done by the government to estimate the optimal use of both.

The law and constitution of Brazil (article 176 and art. 5 of Law No. 9,074, 1995) insures the optimum use of lands where hydropower plants is built. The lands in question must undergo tests and measures to estimate the capacity of the river and the company purchasing the land must installed similar installed capacity. On the other hand, the same is not applied for wind. Operators are free to define the installed capacity and to conduct their own research; all they are required to do is to buy the land. This reflects negatively on the overall exploitation of wind energy compared to hydropower. The lack of supervision has led to delays in achievement of the goals of PROINFA. Over estimation of potential to secure bids has led to; most estimated capacity not producing at the 30% estimated capacity factor the legal system could not do anything.

Nowadays Brazil has moved passed PROINFA into the auction system in which the lower bidders gets a contract. The reserve and A-3 auction is now saving the Brazilian society a lot of money. The program had proven to become very costly for Brazilians almost $137/MWh compared an average of one third that price nowadays. This is due to the greater technological advancements and the development of local wind turbine producers in Brazil

such as IMPSA WIND, Wobben WindPower, General Electric do Brasil, ENERSUD, ELETROVENTO, TECSIS and for commercial representatives from multinational companies.
Another example of the problems facing Brazil is that mentioned earlier in chapter 3 regarding the limit on wind farm size. The Federal government decided to limit the TUSD and TUST incentives to wind farms less than 30 MW. The result was increasing separate farms with capacity of 30 MW from the same company. The distortion of the farms like that raises the problem of intermittency of wind.

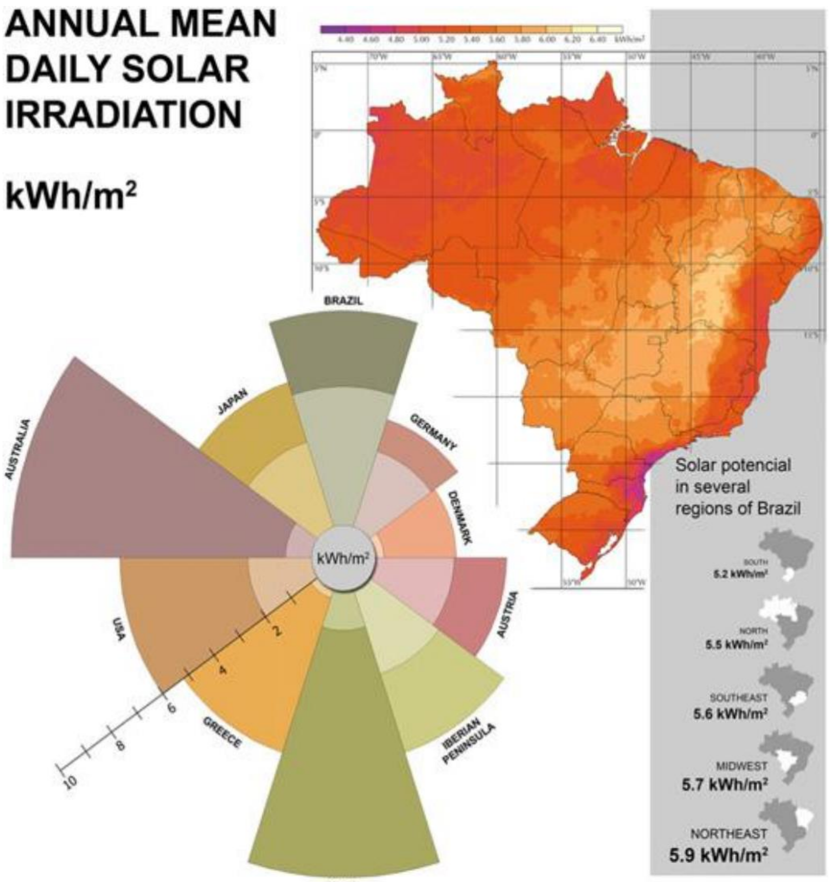


Figure 5.3 Mean annual range of the solar resources in Brazil compared to other countries. Source: Pereira et al. (2006).

1. Managing the Stakeholders

If Brazil hopes to maintain high level of renewable energy integration they need to pay attention to their stakeholder's opinions. Martins (2011) conducts a survey among academic researchers, entrepreneurs and businessmen, and national organizations and associations. The survey was a simple 1 to 5 rating of how much they agree with each statement presented. The choice of stake holders is particularly interesting since the three groups represent the main formation of the contributors to change in the energy mix. The NGO's role was noticed significantly with the block to new Hydropower plants such as Belo Monte due to environmental reasons. The pressure provided by these groups was strong enough, that it pushed the Brazilian government to meet its increasing demand for power from wind power instead of Hydropower. The understanding of the opinion of the NGO's help avoid future conflicts or mitigate unplanned risks of blockages to projects. The entrepreneurs and business men are the main source for investment and keeping a competitive market and prevent market failure. Already Brazil is considered one of the hottest places on the planet for investment. Paying attention to the needs of investors for investing in renewable energy will in return stimulate the market. Lastly the researchers are the ones who have the insight on where the new technologies are heading and how the problems could be managed given the condition.

The result of the survey (summary presented in Table 5.1) highlights the future of Brazil's energy mix. Many conclusions are made out of the result of the survey; first all groups interviewed agree that the PRONIFA initiative was not a success. In fact entrepreneurs name integrating the program further to include solar energy as one of the most important factors to contribute in renewable energy in Brazil. All groups put little importance to the effect of future climate change on the levels of wind and solar received. This might be understandable given that the budget of R&D in Brazil has more important concerns at the moment. However, as highlighted in the previous chapter, climate change is expected to affect wind speed and solar irradiation levels resulting in inaccurate of future capacity. The entrepreneurs had a clear support to market regulation solutions. The entrepreneurs had the clearest vision of how they see the future of renewable energy. They focused on giving high ratings only to certain problems. On the other hand NGOs averaged maximum score for many statements. The entrepreneurs disagreed with NGOs in the role of public awareness campaigns. While the latter gave high importance of motivating the public in buying solar thermal panels, business men disagreed. This is understood since businessmen would rather push for more central grids that yields more profit to them than decentralization. Businessmen puts little value to any sort of awareness campaigns or any form of reliance on consumers for efficiency and remains focused on the government. NGOs believe in the role of research centers as a stimulus for increasing knowledge about renewable technology. They also believe in awareness campaigns but in certain areas of focus and not in the absolute.

The Stakeholder	The Most important factors	The least important factors
Entrepreneurs and businessmen	Facilitate credit lines for the small investor and for the end-users to purchase, install and system maintenance; and guarantee contracts for small private plants for solar energy and wind power generation Promote regularly energy auctions to provide a long-term vision by the market of solar and wind energies and to create confidence amongst investors Establishment of reference values for the price of solar and wind power in order to ensure the economic viability of power plants, and thus, stimulating the market. Adoption of tax reduction on equipment and profits of companies operating on renewable technologies for the consolidation of this type of generation. Create mechanisms, incentives and the	Evaluate the impacts of the climate changes on the solar and wind energy resources in the medium and long term. Perform awareness campaigns in order to demonstrate opportunities and economic advantages of solar thermal energy by residential users, industry and commerce, thus removing the existing natural barrier to new technologies.

	necessary support to foster collaborations between research centers and the local industry for the development of national market for solar and wind technologies.	
National Organizations and Associations	Perform awareness campaigns in order to demonstrate opportunities and economic advantages of solar thermal energy by residential users, industry and commerce, thus removing the existing natural barrier to new technologies. Encourage national collaborations between research centers and the industry for the development of solar and wind technologies. Facilitate credit lines for the small investor and for the end-users to purchase, install and system maintenance; and guarantee contracts for small private plants for solar energy and wind power generation.	Evaluate the impact of climate changes on the solar and wind energy resources in the medium and long term. Perform actions and awareness campaigns to promote the energy efficiency in dwellings and in commercial and industrial buildings
Universities	Enhance the government policy to promote a broad capacity for training human resources in the areas of solar and wind energy. Improve the government regulations for the electricity generation with intermittent sources (solar and wind). Perform actions and awareness campaigns to promote the energy efficiency in dwellings and in commercial and industrial buildings.	Evaluate the impact of climate changes on the solar and wind energy resources in the medium and long term. Reduce the financial risks associated with investments in renewable energy in order to encourage greater participation of the Brazilian companies of generation and distribution of electricity.

Table 5.2 the assessment of Stakeholder's opinion in the most and least important factors of the energy market in Brazil Source: (Fernando Martins, 2011)

If we take a look at Brazil's map for connection of electricity we find a very strange relation. Areas with minimum electricity penetration (the poorer regions in Brazil) such as Amazonia, is usually the areas with most potential for renewable energy. These areas usually suffer from the problem of remoteness mentioned in the introduction of the chapter. The Brazilian government should benefit from many governments that took advantage of the resources in such areas and created their own isolated micro grids (as seen later in the case studies of; the US and the Islands). With the high solar irradiation levels and wind speeds in such areas, many regions in Brazil could have electricity in complete isolation from the national grid.

2. The U.S

The US is a world leader in renewable energy integration. Studying the US as an example of certain fields of renewable energy integration was important. In fact the US is mentioned twice in this chapter once here as a country and once in the Islands through Hawaii. The US renewable energy supply between 2006 and 2015 (projected) is presented in the following figure 5.3.

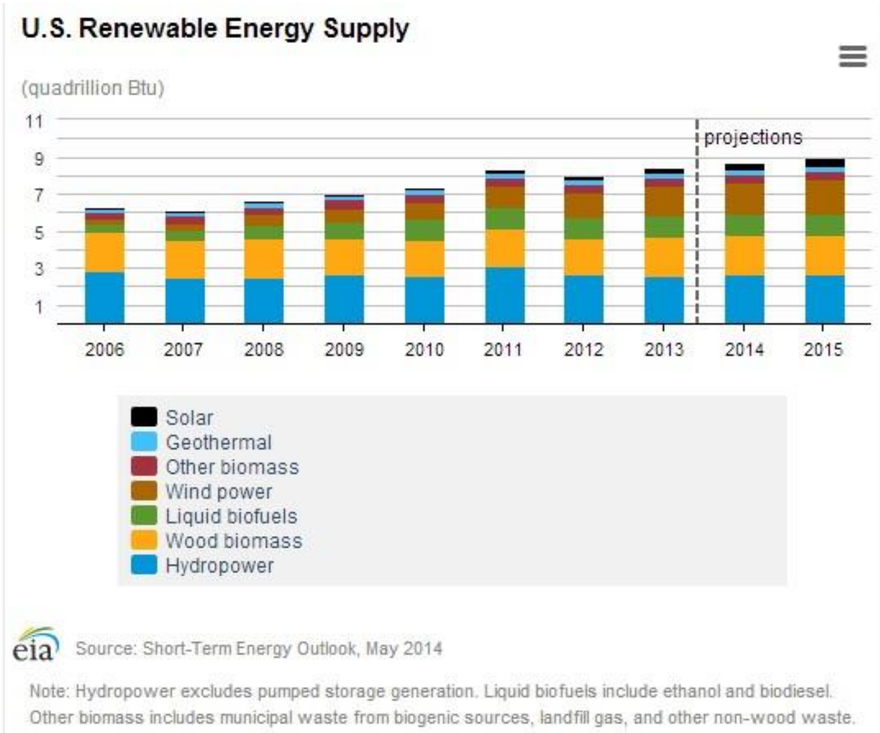


Figure 5.9 The US growth in Renewable energy

The US energy information association predicts total of 3.3% increase in 2014 in energy consumption from renewable. Hydropower increases by 2.9% and the rest increase by 3.6%. Wind energy has very optimistic future in the US with 9% increase in capacity in 2014 and 15% in 2015. The US aims to supply 4.5% of its electricity generation from wind in 2015.

The solar energy has the greatest percentage of increase in the US in the coming years but with still very little market share. This is due to the fact that solar energy is centralized around household consumers rather than offered for electricity intensive consumers. In 2013 alone solar capacity doubled and it's expected to increase by further 56% by the end of 2015. 70% of this increase in capacity comes from California (which is the main focus of our case study).

The US offers cuts from federal taxes and rebates as large as 30% offered to households buying roof top solar panels. That incentive is solely offered to solar photovoltaic panels. However, Electricity generated by wind, solar thermal and other solar the technologies have different incentives of smaller value. This incentive is not restricted to certain type of end users. Although, dominated by households and off the grid systems, the incentives are available for schools, businesses or even industrial customers. The only requirement to be applicable for the incentive is to have the PV cells installed by a licensed installer and connected to the grid by licensed electrician. Many companies in the US sell the Solar cells with the 30% tax included. The different local governments in the US offer different types of incentives, such as one-time payment of rebates or credits or stepped down annual credit.

The price for a grid varies depending on the state and the size. The value of the grid in terms of KWh produced and dollar saved depends on the state for the solar irradiation level and the electricity price. However an average sized grid generates around 815 KWh per month which could cover the average needs of an American House hold if battery storage was present. This would cost around $10,000 and with the 30% federal tax would be $7000.

1. Micro Grids in the U.S:

The US (especially the state of California) has been a leading contributor to Micro grid technology. The examples mentioned in this subsection have saved a large amount of money on their electricity bill. They also kept steady operations at times of power cuts and aided the central grid by helping reducing peak demand. The micro grid technology is still under development, However good examples have already proven the worthwhile of this technology. Some of the real life examples are presented here;

1. San Diego, California

The University of California is one of the most progressive locations in the world in terms of renewable energy and storage. The Micro-grid in the university saves around $850,000 a month of the electricity bill (Ken Wells, 2013). The grid was originally designed as storage system for back up. The University research director *said "We have an electron microscope that every Time we have a supply disruption; it takes six weeks to recalibrate. We can't let that happen"*.

However the storage became one of the biggest microgrids in the world with capacity of over 42 MW (Enough energy to power 8000 houses). The grid supplies 95% of heating and cooling and 92% of campus electricity needs. The system has both thermal and battery energy storage. This helped the campus survive a 2011 blackout and maintaining essential power supply by:

- Reducing power consumption the building
- Taping thermal water storage
- Cycling off cooling system

The micro grid consists of:

- 2.2 MW of solar
- 2.8 MW from a methane-powered fuel-cell (methane from landfill gas)
- Two 13.5 MW combined-heat-and-power gas turbines
- A 3 MW steam turbine
- Several hundred kW of battery storage
- Steam and electric chillers to store cool water at night for building cooling during daytime. (John Farrell, 2014)

The system is also planning to increase the current 15% share of renewables by installing rooftop solar panels. The campus is planning to use the grid to deploy more EV in the streets through providing stations for recharging using Solar and methane fuel cells. The system will use solar power directly to charge to save on all losses and unnecessary transformations (Byron Washom, 2013).

2. U.S. FDA – White Oak, MD

The white Oak is a good example of Micro grid excellence. The federal research centre costed around $900 million in construction. The centre is a food and drugs administration office and a lab compound. The centre is operated by a central utility micro grid with 26 MW of capacity. The site already has:

- 10,520-tons absorption & electric chillers
- Four 4.5MW natural gas turbine generators
- 5.8 MW dual-fuel generator

Case studies from around the world

- Three 10 MMBtu/hr hot water boilers
- 2 MW standby ‘black start‘ diesel generator (Honeywell, 2013)

The system also includes one axis PV arrays and has all ancillary services already installed. The research centre is already planning further integration of 29 MW relying on renewables and providing peak energy demand[13]. The Micro grid will include storage in the form of 2M gallon thermal energy storage tank to be used as backup for cooling.

3. Borrego Springs, CA

According to Thomas Bialek (the principle investigator of the project), the project is: *"a pilot scale "proof of concept" demonstration of how advanced information-based technologies and distributed energy resources (DER) may increase asset utilization and reliability of the power grid in support of the national agenda"*[14]. The project was a joint funded project between SDG&E and the US department of energy. The micro grid focuses most of its interest on energy storage and the efficiency and capacity of its batteries. The project also focuses on reducing peak load and local resilience.

The grid has its own 12KV/480V transformer and two 1.8 MW diesel generator as long as 5 way trayer switch with a control fan. The grid has 3 different type of storage:

- One substation 500 KW battery on the site of Borrego sub with 3 hours supplying ability.
- 3 community storage 25 KW Units with 2 hours supply ability. The batteries have the capability of operating as a fleet or independently. The batteries operate at the mode of peak shaving and renewable support, as well as providing ancillary service such as voltage support.
- 6 home energy storage units each with capacity of 4KW and capable of supplying the houses for 2 hours.

"On the afternoon of Sept. 6, 2013, intense thunderstorms blew into Borrego Springs, causing heavy rain, flash floods, high winds and severe lightning in the area. Lightning from the storm struck and shattered a power pole on the only transmission line serving the community, cutting electricity to all the town's 2,780 power customers"[15].

The micro grid storage capability was able to restore 33% of the power cut to its customers (St. John Jeff., 2013). "*The Micro grid was really a crucial tool during this emergency situation*," said Linda Haddock, executive director of the Borrego Springs Chamber of Commerce.

"*It provided electricity to the essential areas of our town and kept vital air conditioners running during the extremely hot weather we saw that day. This innovative project, coupled with the hard work of SDG&E repair crews and their collaboration with local residents, helped Borrego Springs make it through this emergency unscathed. It truly made a difference in the lives of our residents in Borrego Springs."*

4. Laurel, Maryland

A smaller example of Micro grid is the one in Maryland, the grid from its description is a trial grid and not a response to necessity like the white Oak or the one in San Diego University. The grid

[13] http://www.districtenergy.org/assets/pdfs/2013CampConference/MicroGrids/Whats-new-in- controls/BRAINARDHoneywell-IDEA-Feb-2013-gbb.pdf
[14] http://energy.gov/sites/prod/files/30_SDGE_Borrego_Springs_Microgrid.pdf

[15] http://www.sdge.com/newsroom/press-releases/2013-11-10/borrego-springs-microgrid-keeps- electricity-flowing-customers

has power capacity of 402 KW of solar PV over carports. That amounts to 20% of the energy production of the grid. The grid also has a 50KW lithium ion battery with a capacity of 200 KWh. The main addition of the small system is that its self-sufficient and requires no energy from the central grid, not only that but it provides ancillary services such as frequency and voltage regulation through its storage capacity.

5. Other States

The Connecticut state in the U.S created a state wide MG program that invested $18 million in 9 new projects in 2013. New York also created a prize pool of $40 million as a support mechanism to more disaster resilience micro grids in an effort of serving 40,000 each (Jeff St. John, 2014). This comes with reports of the poor grid resilience in times of weather disasters like hurricane sandy.

2. Case Study US integration of EV and its Benefits:

The main scope of this thesis is discussing the proposition of introducing the Renewable energy on a wider scale in the energy market on the centralized scale as well as the decentralized scale. This involves of course discussing energy storage techniques such as batteries and pump hydro storage and the implications of those technologies on normalizing the intermittency of renewable energy. In this section however we discuss the Electrical vehicles technology into more detail with more focus on its benefits economically on households. Electrical vehicles does have a substantial benefits on the renewable energy integration and energy storage and the entire electricity market, But it also has greater on the energy market in the broader sense due to its substitution of petroleum fuelled cars, which in turn decreases CO_2 emission, which is one of the reasons of integrating renewable energy from the beginning.

3. Policies towards more EVs:

In this section we name some of the policies by the U.S state governments and the possible benefits of increasing EVs. In 2011 President Obama said in the state of the union "*With more research and incentives, we can break our dependence on oil with biofuels, and become the first country to have a million electric vehicles on the road by 2015".* The president might be very optimistic given that by the end of 2013 The US had only 177,000 EVs on the road. However, the IEA estimates this number to rise to 5.3 Million by 2020 (Global EV outlook, 2013).

South California Edison has created an EV plan to offer discounted price for late evening or overnight charging of the battery. This however, may contradict with the proposition of coupling EVs with solar panels which is only available at day time. On the other hand at this moment with the proposed policy by south California State; it's cheaper to charge on the normal grid than on the solar grid. Other states like Texas provide a better deal and one that helps Renewable energy. The Texas utility TXU offers "Free Charging nights" for owners of EV between 10pm and 6am. This is motivated by the increasing production beyond need of Wind energy at night (Danny King, 2013). This shows that energy storage is gaining ground in the battle against power plants as discussed in chapter 2, especially that Texas is one of the oil rich states.

Not only public utilities are providing incentives for EV penetration, Private companies are also pushing towards the Obama goal. Ford and Solarcity are joining forces to provide a 2.5

KW solar array for every purchase of a Ford Focus EV (Chicago Tribune, 2013). The economical and environmental implication of these policies is discussed in the next subsection.

4. Economic and environmental benefits of EV policies:

The policies offered by the state governments will have varying effects (positive in general) depending on electricity prices and other factors. For example the policy offered by south California is expected to decrease annual costs of fuel by 33% (around $231 assuming average of $700 of annual consumption) for households with moderate consumption and 60% (around $720 assuming $1200 of annual spending on fuel), for households with high energy consumption (South California Edison, 2013). This comes with the assumption of plugging the EV at midnight with half full capacity. The calculation is made with moderate consumers are assumed to be in the second tier pricing for the South California category for pricing. Heavy consumers are thus considered to be using the 3rd tier pricing.
According to the institute of local self reliance 60% of U.S car users drive their cars for the range of 30 miles per day (Solar Journey USA, 2012). The Ford initiative of providing 2.5 KW solar panels could provide in an average day and an average city (in terms of sun irradiation) 40% of the battery capacity (23 KWh or 76 miles). Converting 10% of the vehicles owners with the 30 miles average into EV drivers along side with reliance on solar array for charging their battery could cut annual US CO_2 emission by around 31 million metric tons. This is equivalent of removing 6 million cars from the road (Environmental protection agency, 2011).

3. The Islands

Islands all around the world propose serious challenges to their governments for energy distribution. Islands such as the Canary Islands in Spain is located 1000 Km away from the mainland and some is even further away. The transportation, distribution and retail costs often double and prove unprofitable for providing energy from the mainland to these Islands. These islands especially the ones that own their own power plants imports fossil fuels for their energy supply. The rise in prices of fuel affects electricity prices in the islands at a larger scale, with extra costs of transportation included. On the other hand, these Islands often have high potential for energy generation through; wind, solar, tidal and hydropower. This is due to the nature of the islands with large spaces and extended coasts which provides water, high wind speeds, strong tides and clear sky.
These Islands also have more flexible schedule when it comes to demand. The island is characterized with low presence of energy intensive consumers such as factories and research labs. This opens the room for more intermittent resources deployment with storage techniques. Finally the low population and the control from the governor over the island makes the case study of the islands very useful for discussing policies that include high percentage of public participation such as rooftop solar grids.
Two sets of islands were investigated from different approaches. The first was the Hawaiian island Kaua'I and the Canary island Grand Canaria. The first was presented as a good example of an island that is expanding its independence from the grid through rooftop solar projects. The second is an example of an island with a huge potential for wind energy and Pumped hydro storage. The case study also talks about the potential for tidal energy in different islands around the world.

1. The Hawaiian Islands

Case studies from around the world

The Hawaiian island of Kaua’I is a good example of renewable energy and storage integration. The small island of 67,000 residents responded quickly to oil price rise in 2008 and decided to increase reliance on renewable energy. The rise in oil prices and the energy crises made the price of a KWh of electricity increase by 33% reaching 3-4 times that of the average in the US mainland. Figure 1 shows the spike rise in electricity prices that triggered the change in the Hawaiian Islands.

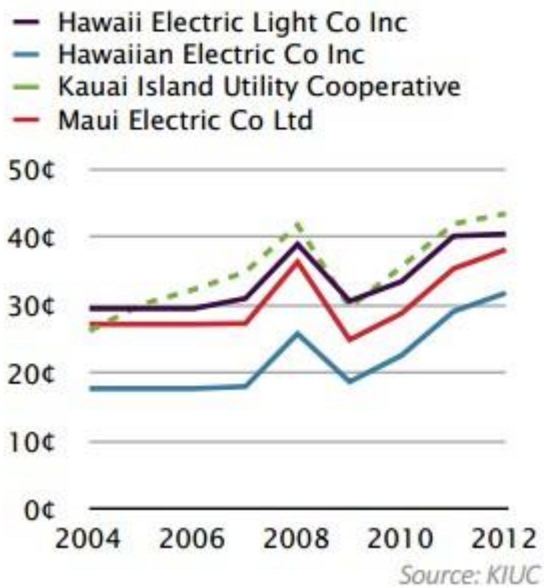


Figure 5.10 the evolvement of price in Hawaiian Islands

The island has 65 MW of capacity owned by a community cooperation called Kaua'I island utility which consists of business men who bought the power plants from the existing electricity company there in 2002. The cooperative moved immediately towards giving local users control over the electricity consumption through ownership. The island increased its reliance on renewables from 8% to 15% between 2006 and 2013 but is planning to raise it further to 42% by the end of 2015 through rooftop solar panels (KIUC Annual Report 2012). Figure 2 shows the current and proposed energy mix in the Hawaiian island.

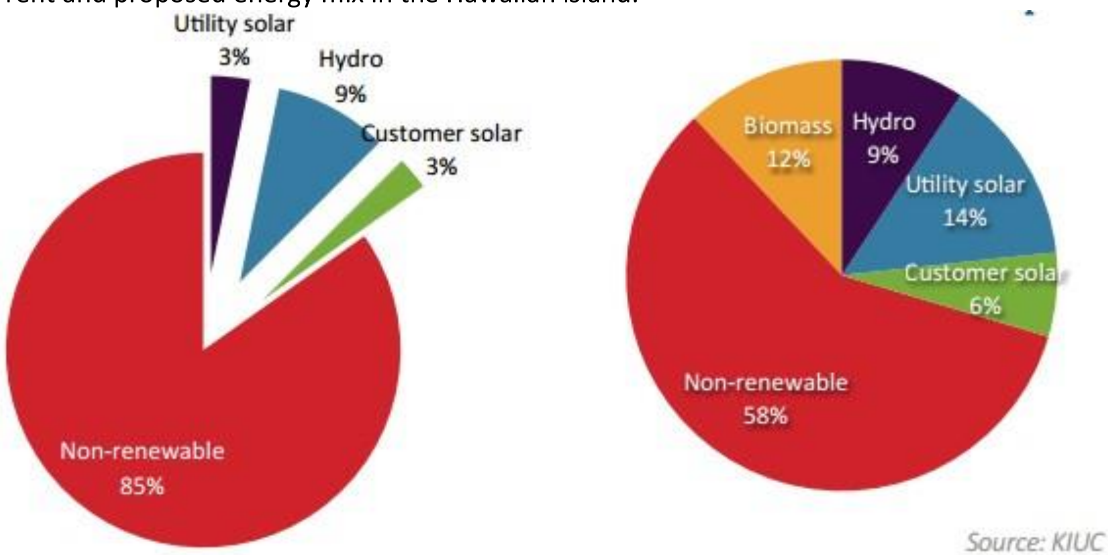


Figure 3 Current and proposed energy mix in the island

The decentralization within the already small island is the main reason the island is of great interest to the thesis. By 2012, 1200 solar rooftop panels were installed with 7 MW capacities. By 2013, 1500 further panels were installed with 9 MW additional capacities. This puts the island on second Per capita solar deployment in the US with 282 Watts per person. This is more than the total installed capacity of Watts/capita for all energy sources in countries like Afghanistan. The island does not have the highest solar irradiation in the US; the island's solar system is capable of producing 1343 KWh/year for every installed unit of 1 KW (National renewable Energy Laboratory, 2014). This amounts to capacity factor of 15% which is 4% higher than the global average and 2% lower than the optimistic global average of 2035 (EIA, 2013).
Therefore the KIUC needed to rely on large storage capacity and increasing decentralization in the solar panel system to maintain their production levels. The utility did a first of a kind market reform, after reaching the aggregate limit on net metering (1% of energy sales) the cost was discontinued. Net metering was then replaced with a lower cost feed in tariff of 20 cents per KWh from small scale solar arrays lasting for 20 years. The 3MW project expected to supply 4% of energy supply of the island supports up to 200 KW solar panels for customers. Energy Storage in the island is significant; two 3 MW batteries are already installed in solar panel sites and a further 2 MW is planned to support the next 12 MW of planned solar panels. The result of the energy storage induction was 1% saving in utility budget (around $135,000) reduced from Operating and maintenance fuel costs for the existing diesel and gas power plants (Sandia,2009). The utility plans to meet half of its daytime energy use through solar by 2015.

2. The Canary Islands

The Canary Islands has an extraordinary topology with present water reservoirs already with nearby lower level reservoirs. Alongside with very high wind energy produced and higher potential, the Island is considered as good option for the proposal of wind+ PHS mix. The islands started very early in wind energy in the early 1990's production supplying 34% of the wind energy production of Spain putting the country second only to Germany in wind energy production. The Canary Islands doesn't maintain anywhere close to this share anymore as the Spanish wind capacity rose to 22 GW. However continuous expansion in the wind capacity in the islands is happening reaching 200 MW of capacity. The main reason behind the high deployment of wind energy in the islands is the decentralization of the islands. Each island of the 7 islands works with their own small-midscale electricity grid and power plants.
The governments of the islands of Canary are motivated to exploit their wind energy potential further. The islands are providing wind-diesel systems to remote villages in the islands that are not connected to the grid (Carta and Gonzalez, 2001). The islands are also using energy storage in the form of sea water distillation. The storage here is in the form of converting electrical energy to kinetic energy in the form of the process of distillation. The water is then used for consumption such as agriculture. The supposed electricity needed then to do the purification is saved (Carta JA, Gonzalez J, 2004).
An academic paper by Bueno (2004), discusses a model that takes into account rain and wind levels in Gran Canaria (The biggest Island of the 7) throughout the year. The paper discusses the economics of installing hydropower dams with pumped hydro storage alongside with wind. The Island has not actually implemented the proposed model but its feasibility seems quit high. The choice of Island was because Gran Canaria contributes alone to 50% of the Archipelago´s total energy consumption and capacity. The islands receive 12.5 million visitors every year which opens wider scope for subjecting people to renewable energy. The island also has decentralized

heating system due to the warm weather of the island. This adds off to the flexibility of the system that doesn't dictate the need for a huge liability such as central heating. In a presentation by the European RE islands conference in 2005[16], the island´s government blames lack of knowledge to the low penetration of renewables in the island. This was the motivation to include the mentioned paper in the case study as a presentation of the available information and potential for the island.

The paper takes wind speed data from studying the wind level in the year 2000 in the airport site. The year was chosen as a low wind year to show that even with low wind levels the combination of wind and PHS could prove profitable. The Chosen Island has over 60 natural reservoirs at different heights, which creates the possibility for a PHS system with 2 reservoirs at different heights connected by a pumping system. The paper models all different possibilities for integration of the different reservoirs and arrives at 2 reservoirs near a possible wind farm at a height difference of 281 meter. The model presents the optimal number of wind turbines, pumps and hydraulic turbines needed at 24, 89 and six respectively. The model also calculates the per KWh cost of the system at 0.084 euros based on dividing investment cost of 32 million euros over 20 years, alongside with annual operation and maintenance cost and external costs for wind and hydraulic energy cycles of 1.2 and 0.185 million. The author compares the cost of the system with that of conventional which ranges between 0.08-0.096 euros/KWh. This calculation does not include externalities costs due to fuel cycle which amount to 0.08euros/ KWh favoring the proposed system. The paper (which was published 10 years ago) also mentions the CO_2 costs proposed by the EU at that time at 20 Euros/ton as a further advantage to the profitability of the proposed system. This is particularly interesting since the model estimates an annual saving on CO_2 emission of 43,064 m^3 tons.

The paper however, does not yield very optimistic results about the share of wind +PHS that can serve the demand. A Maximum share of 3.5% in July and a minimum of 1% during April with an average of 1.93% or 52.5 GWh/year are found in the study. However, at times of high water levels; 11% of demand could be covered and 8% maximum at lower water levels. This contributes to removing peak load units from the system.

The paper also discusses an important remark that serves as part of the complications proposed to wind + PHS combination, which is the problem of coordination between the systems. The model analyzes the compatibility between times of high wind levels and the corresponding level of available space in the top reservoir. In other words, the model checks for the times wind energy produced is needed to pump water up from the second reservoir to the first. Figure 2 and 3 shows the relation between non-exploited wind energy and the level of water at the reservoirs. Clearly the months with high levels of water in the first reservoirs exploitation of wind energy are low (March, April and May).

The model was designed to optimize the system in the most economic manner, thus the resulted water levels during March-May is not just a result of natural rain water. The model shows that the best economic solution is to pump water prior to these months that have high demand. The result is that 11.28% of the wind energy that can be exploited is not being used. This puts down the overall capacity factor of the wind turbines from 50.25% to 44.58% which is still a very high level for wind energy. The capacity water of the dam on the other hand was found to be very low (less than 10%), this is compared to the Spanish average of 18% (Martı´nez G, 2004), which increases to 50% with hydro-pumped storage.

[16] http://www.erec.org/fileadmin/erec_docs/Projcet_Documents/RE_Islands/Canary_Islands.pdf

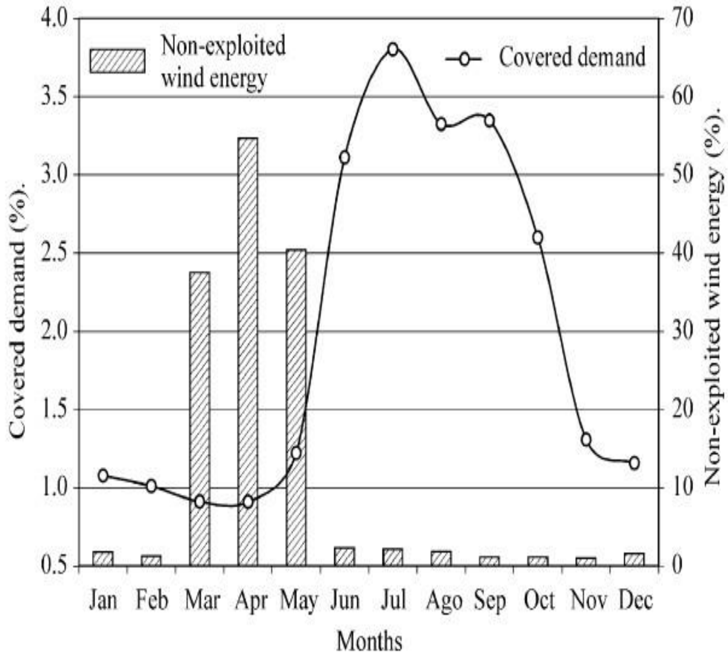


Figure 11 non-exploited wind energy at every given year

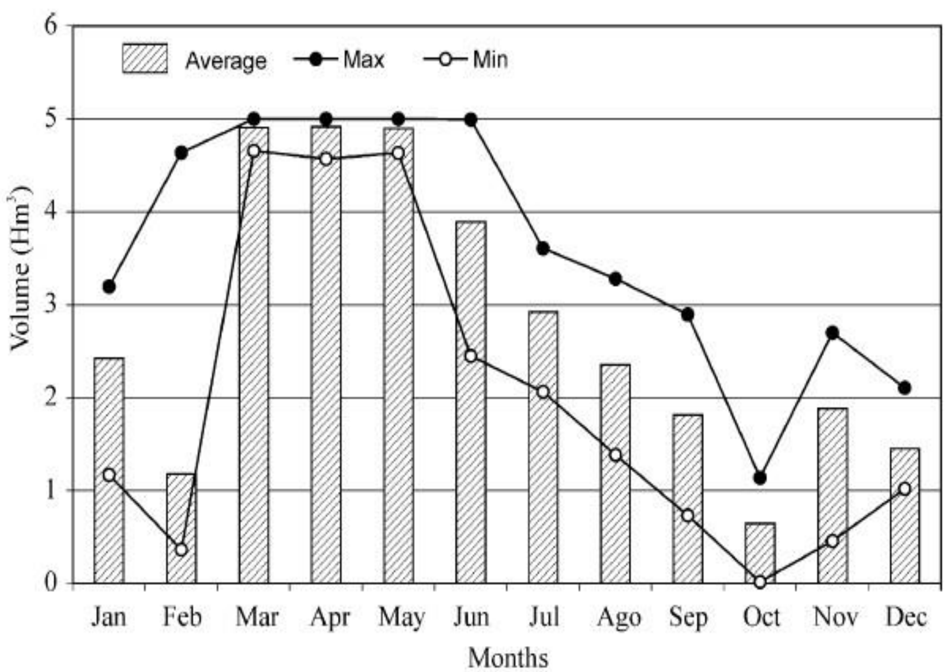


Figure 12 Evolution of the water volume in the upper reservoir.

The system proposed in the canary island presents a realistic image of the potential of increase in renewables share in the energy mix as well as potential of decrease in electricity price. The model results do not show the need for subsidies to fund the power plant, however for the system to be competitive the externality social costs of thermal plants needs to be include. The model shows that getting rid of the intermittency of wind through storage will still end in some wind energy not being used in the system. The model also shows that there is a limit to the needed wind turbines and water pumps and their rated power. Although increasing capacity might increase production level, it will decrease the profitability of the proposed technology.

3. Wave energy in the Islands

Wave or tidal energy is a relatively low penetrated energy in terms of renewable energy resources. In fact since 1890 attempts to deploy this energy for electricity generation among others only produced a farm in Portugal in 2008. The global potential is estimated to be around 2 TW according to (Cruz J, 2008). There are 4 countries currently with wind farms operating or officially constructed:

- Portugal: Portugal was the first country to install wind farms in an offshore location 5 KM's north from Porto. The Aguçadoura Wave Farm has capacity of 2.25MW and is scheduled to increase to 21MW if the investing company recovers from the financial crises.
- The UK: The country is planning to operate 2 farms one in Scotland and the other in the north coast of Cornwall. The first has capacity of 3 MW and the second has capacity of 21 MW and potential to increase to 40 MW. According to the (Guardian, 2007), the second site has potential for electrifying 7500 homes and decreasing $C0_2$ emission by 300,000 tons.
- The US: The US is planning for 10 1.5 MW Wave conversion farms in the west coast near Oregon. The plants were put to halt for legal obstacles.
- Australia: the federal government of Australia has a very progressive attitude towards renewable energy and wave energy in particular. The government and research institutes are devolving farms to assess the possibility of using them commercially. There is 1 operating and 2 under development farms in the country, while the federal government is supporting a 19 MW power plant near Portland with $66 million budget.

Thus the only operating wave farms were found on mainland. However, according to Rusu, (2012) there is higher potential for wave farms in the islands than in the main land from a scientific perspective. The paper considers an average of 1.2 m higher waves in Azores than in mainland Portugal in the winter. The scientific paper gathers data about the altitude of waves in Portugal in mainland and the Azores islands. The paper further discusses the potential of wave energy in these islands alongside other islands such as the Canary Islands and the Hawaiian islands. Energy produced per meter was recorded between 37 KW/M in Sao Maria and 78 KW/m in Terceira. The study estimates potential electricity production of 4.1 MWh/day. Other studies suggest similar results for different locations. A study by (Stopa JE et al., 2011) estimates 65 KW/m for Hawaii. (Iglesias G et al., 2010) also estimates that wave energy could contribute to self-sufficiency of the Canary Islands from the Spanish central grid. Great Caution needs to be taken into regard however for islands with possible wave heights of 14 and 20 Meters. Such Islands propose huge threat on the potential for wave energy. The huge waves could destroy the wave converters deployed in the water to extract electricity.

4. The UK

The case study of UK is different in the approach. In this study we discuss a country with a long history of research papers on renewable energy integration and storage techniques such as (van der Linden, 2006; Solomon et al., 2010; Exarchakos, 2008; Wilson et al., 2010; Weber, 2005). The country also has well established information about its wind resources and the impact on the electric system (Gross et al., 2006; Sinden, 2007). Although the country has low market share of renewable energies, the efforts to overcome that is increasing. In this section we look at the complications facing governments and investors in situations where full information required is present. The idea is discussing how models and simulation on its own does not make the policy makers able to predict accurately the impact of increasing market share for renewable energy. The volatility of electricity prices, the uncertainty of the future market share of each technology and variability of future prices of storage among other things creates very complicated scenarios. That sometimes takes away any chance of getting firm solution to use in decision making in investment for example.

The papers discussed analyzed the possibility of large scale storage being used in the energy market to cover the rising intermittency problem in the UK. The hypothesis is that; given that most data fed in to the models are probabilities of occurrence of different events with different weights, the result is going to be a range (rather than a discrete number) wide enough to make the result useless. The author of the main paper used (P. Gr¨unewald et al, 2011), discusses the ambitions of the UK for 2050 for large scale deployment of renewable energy, and the proposition that large scale storage can be part of the mix. The paper identifies many factors affecting the return on investment on storage over a tested period of 6 years. The years chosen was 2003-2009 and the demand profile along with the metrological data about wind and sun in those specified years were included in the model. The model does not run over the six years, but compares between the return from each year, to reflect the arising complication due to the stochastic variation between years. The model does not conclude the profitability or the unprofitability of large scale storage, but rather the variability of the system.

Four figures are drawn from the simulation of the data given to support the general idea. The first figure analyzes the NPV over 20 years from increasing capacity of renewable for different storage techniques. The second

The first figure, Figure 6 shows the different NPV in million pounds, yielded over the 20 years for different storage technologies at different levels of renewable energy integration. The bar at each point represents standard variation between different years of data indicating the margin of error. As it can see the bar length differs for different level of renewable energy as well as different types of storage. The graph shows great variation of NPV depending on the year examined, installed capacity of renewable energy and type of technology. Difference between maximum and minimum possible NPV varies between as high as 1.4 Billion pounds (Hydrogen storage at 60 GW of renewable energy installed) to as low as 0 pounds (less than 40 GW of installed capacity).

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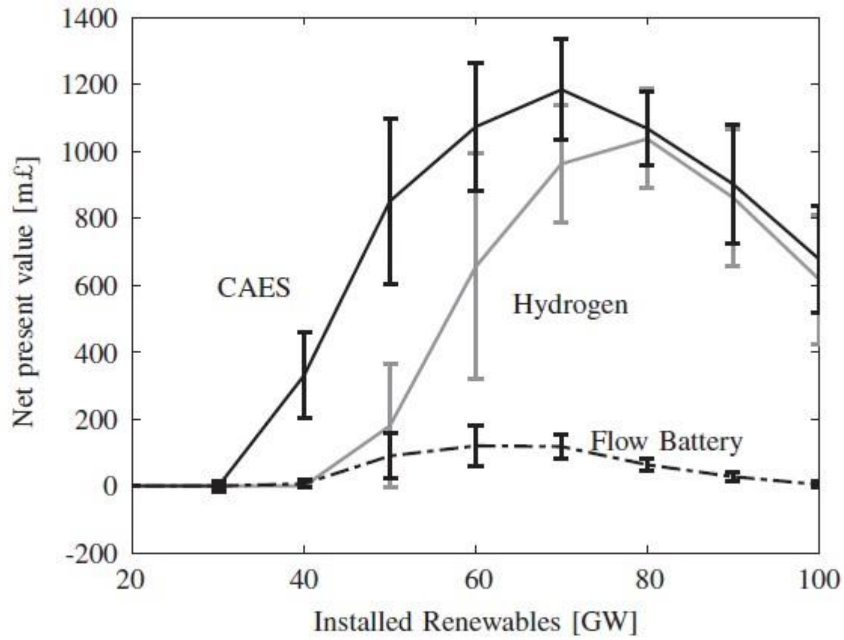


Figure 4 Mean NPV for storage technologies based on historical data for six years. Error bars represent standard variation between different years of data

A comparison is then done between storage as a substitute to CCGT and the probability of it being more economically profitable to deal with intermittency. The comparisons assumes many variations such as the load factor of the storage (which depends on the length of the charge and discharge and the frequency the storage is needed), price of electricity, price of the fuel (gas), cost of CO_2 emission. The comparisons yields multiple scenarios modeled as a Monte Carlo simulation of 100,000 samples. The results as shown in figure 7 that hydrogen storage can only be cheaper than CCGT if its the cost is +£56/MWh, And only with a probability of 50%.

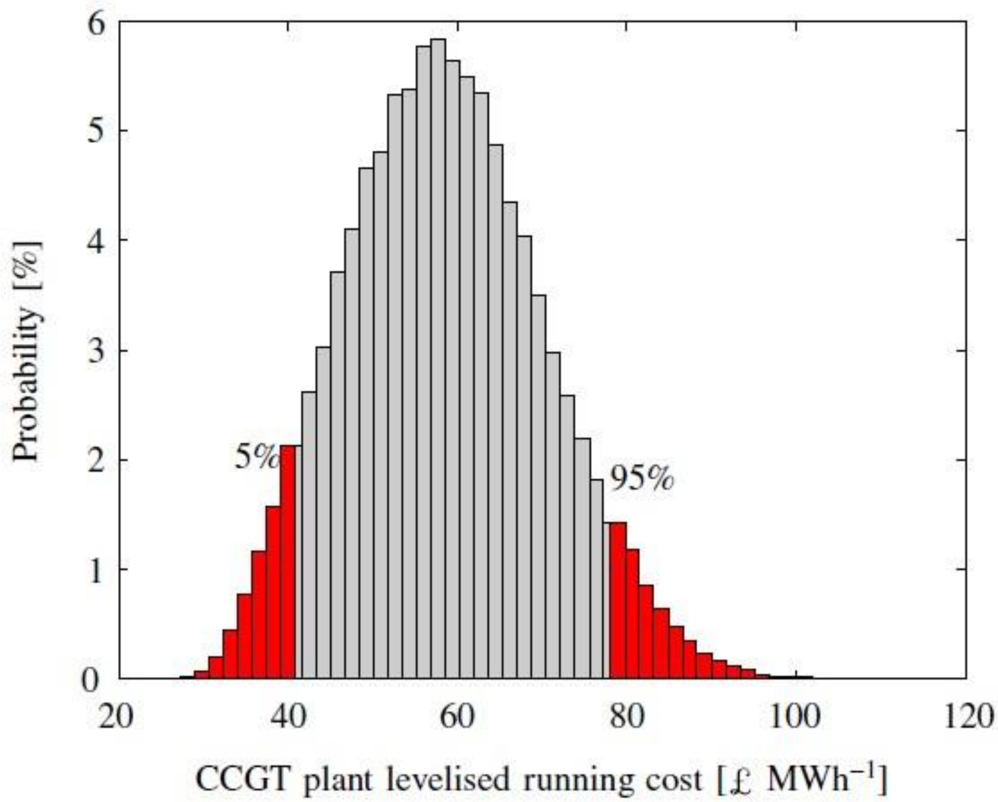


Figure 5 Probability distribution of storage being commercially more attractive than CCGT plants.

The third graph is a sensitivity analysis of the NPV on storage. The base case assumptions (usually decided beforehand in any model) were changed by a certain percentage and the effect on NPV was monitored. Some changes made little to no effect on the return on storage such the total increase in energy capacity. Some show very sensitive response to a 25% increase such as the economic life span of the device. Figure 7 shows the drawn graph based on the analysis done.

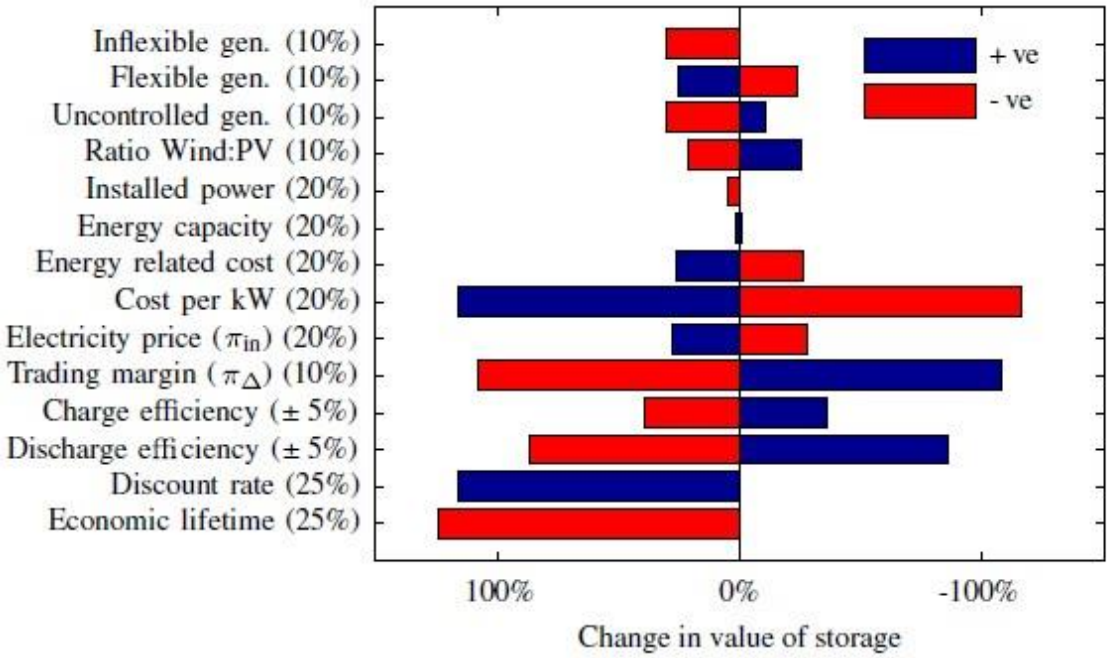


Figure 6 Base case parameters for the storage system have been subjected to the changes shown in brackets, both positively and negatively (in the case of efficiencies, the values have been added and subtracted).

The last graph focuses on the metrological data from wind and solar in comparisons with the demand profile for the 6 examined years. The research shows that different demand profile and different metrological data yield different return on investment for storage at each specific year. The paper assumes identical storage installing for the entire different years. The author gathered the effect of each of the two factors separately on return on investment in storage technology for each separate year.

The Author then arranged the years from worst (year 1) to best (year 6) for both situations separately (year 1 does not necessary mean 2003). Then the author measured the effect of each the 36 different combinations. The assumption would be that keeping the data set of one of the parameters constant and changing the other to a data set with better return on investment for storage would increase the overall return on investment i.e. the combination of year 6 in both parameters has the best return on investment. The assumption however, was not satisfied. Figure 9 shows the results from the research paper. The meaning of the circles is explained in the legend.

A better understanding of the issue is presented through the presentation of the standard deviation of each parameter between its different years. The standard deviation is normalized to that of the reference case. There is a greater variation within the different combination for meteorological data than in the demand parameter. This means that renewable energy, when integrated in the mix, creates more variability. In other words the problem of intermittency of wind does not stop with accurate forecasting of the wind speeds and solar irradiations. The problem extends to scenario building for the future.

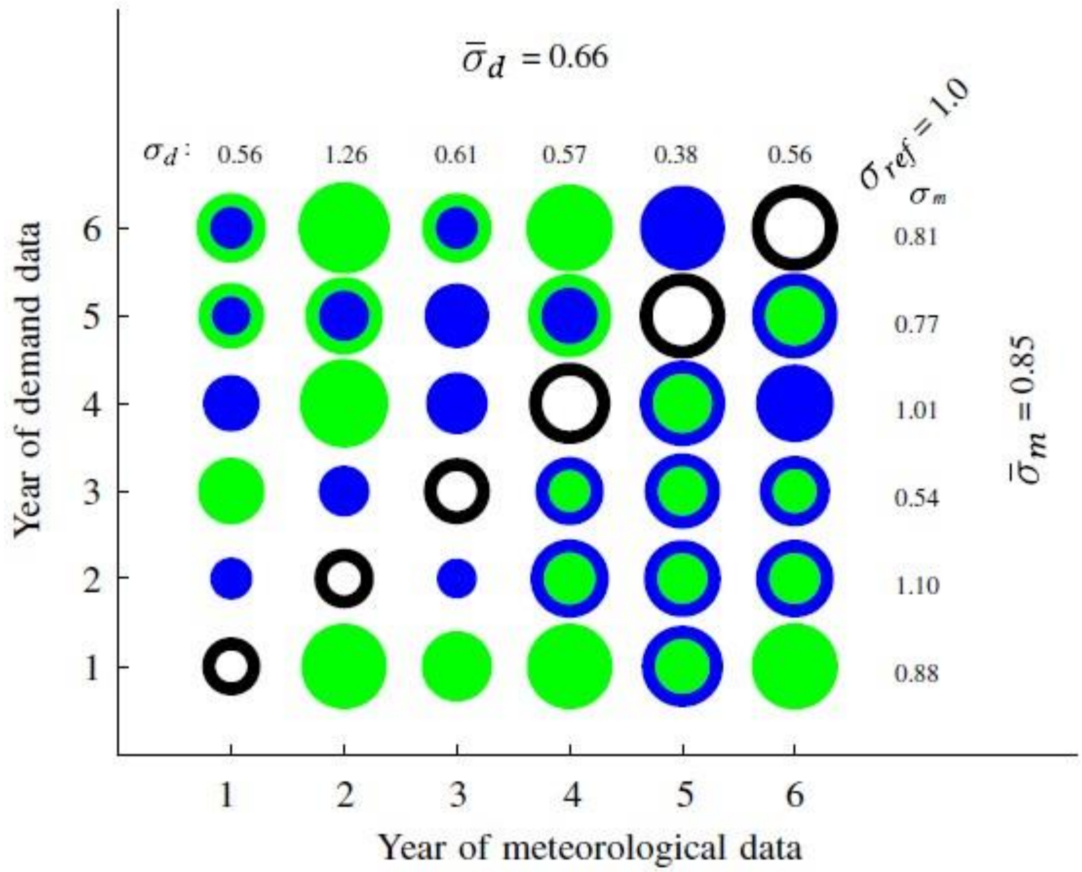


Figure 7 The six years of metrological and demand data are ranked by the value they provide for storage, the values of storage of each year is represented by the size of the circle along the diagonal (the reference values). All other circles show the value of storage simulated with meteorological data of one year and demand data from another. Light green indicates a higher return, dark blue a lower one. The outer color is the comparison with the reference demand data (the black circle in this column) and the inner color is the comparison with the reference meteorological year (black circle in this row).

This case study was specific to measure possible return on investment for large scale storage deployment in the UK. But it's most probably applicable to anywhere in the world. In fact the choice of the UK as an example where numerous researches was done to gather accurate data strengthens the conclusion even further. If we consider other countries with lest studies and possibly higher volatility in changes in prices and demand, we'd see even wider ranges of result increasing the risk in investing in storage. The same conclusions could also be drawn when discussing modeling the profitability of renewable energy.

6 Conclusion

In this thesis we tried into give a realistic picture of the future challenges of renewable energy integration in the electricity market. The main hypothesis was that renewable energy as a clean source of energy as it is, doesn't come without constraints. Over the course of 4 chapters arguments were given to explain the key points identifying renewable energy as a technology.

The thesis began by covering up the theoretical background including, First, the rise in prices of fossil fuels and the rise in carbon emission levels and the protocols and legal framework paving the road for renewable energy. Second, the different types of renewable energy and why one source is considered renewable and why another isn't. Finally because it's not possible to have renewable energy without storage we gave a summary of all types of storage and the concept itself.

The thesis then moved to discuss the main complications of integrating renewable energy. The chapter shed light on how most aspects of the matter is double sword. While renewable energy may save externalities costs from emission for example, subsidy costs and losses to thermal power plants remain an issue. While renewable energy could insure a more secure source of energy for each country (less reliance on importing that is subject to political instability), there is always a risk of failing to deliver due to intermittency of the sources.

The third chapter discussed how the previous chapter could in fact be compensated with the right approach. Combinations of different renewable energy sources and storage technologies were mentioned and comparisons were presented. Regulation and reforming of the energy market as well as the demand side management was explained with reference to possible economic benefits in monetary terms.

The forth chapter was presented as a reference case, in which 4 different countries/regions were introduced as a showcase for what was previously mentioned. The Brazilian case was presented as a full in which pro and con's were explained and the future potential. The U.S was given as a leading example, especially in the area of Micro Grids and E.V's. The different islands were put as a reference case for remote and rural areas where transmission and distribution costs hold as barriers to introducing electricity there. Finally the UK was given not as a market model but as source of information for testing ability to forecast and predict NPV of investing in renewable technologies. This later model was chosen as the last part of the thesis precisely to give a final message that at our present levels of uncertainties, even based on knowledge of past data of solar radiation levels and wind speeds and demand for energy, the variances within other factors creates a huge uncertainty in the levels of NPV, making investing in renewables a risky project.

The discussion mainly focused on OECD countries or developed countries in general. This choice was due to the achievements in both; available data and research, as well as in actual implementations and examples. However, if the world is looking forward to having a large share of renewable energy in the electricity mix, they have to start paying attention to the developing countries. Most of the developed world lies in the upper part of the northern hemisphere, where natural resources are less convenient to produce renewable energy. This is either because of the low availability of space such in Europe or low availability of high solar irradiation levels or rivers for solar and hydropower energies. The opposite is in the developing countries that enjoy wide areas of low to no inhabitancy with high wind/solar levels as well as available rivers and biofuels etc. These countries also have the advantage of low demand

The developing world however, needs much attention from researchers and decision makers in the west in order to integrate renewable energy. The problems holding renewable energy back in the west is multiplied in the developing world. The lack of data collection centres and weather forecasts, as well as the centralized public energy market, are huge barriers to renewable energy integration. On the other hand the incentives for renewable energy may not be a problem as it seems. Most developing countries subsidize their electricity market to provide affordable electricity to their citizens. Moving these subsidies from fossil fuels to renewable could prove viable. This however, would need extensive political and economical research. Fossil fuel tycoons', either national or international will not accept their losses like in Germany and other western countries. Most of these companies enjoy very strong share of the market and influence on the decision making of the country and the economy.

In summary renewable energy is the inevitable future of the energy market, neither this thesis nor any other report could deny that eventually we will run out of fossil fuels. However, what this thesis tried to say is that renewable energy is not a magical solution, much effort needs to be done in the political and technological fields in order for it to be economically and environmentally beneficial.

7. Annex A

Picture showing the world's first solar energy field in Maadi District in Egypt built by American engineer Frank Shuman. The panel was built in 1912 and operated in 1913. It had the ability to provide 100hp worth of energy pumping water at a rate of 6 Thousand Gallons per minute. The engineer said "What happened in Egypt is a revolution towards the future of energy. Unfortunately as the world took a step forward in Integration of renewable energy Egypt has fallen behind in the field. The solar plant has seized to exist at least since the 70s according to the people living in the district and no trace of any solar energy was present again until the mid-90s

Analysis of the Egyptian market

An extended case study

This part of the masters was developed after the defense of the thesis as a support to the main motivation of the thesis. The thesis was compiled to serve as a guide to any government working towards further integration of renewable energy in its market. Thus the thesis analyzed the challenges and opportunities for renewable energy integration and aided them with some case studies from different countries covering different aspects of the topic. In this part I try to apply this guideline for my own country; Egypt.

We first take a look at the current situation of the Energy market in Egypt with its complications and rooms for opportunity. Then a look at how the future looks like in light of the recent changes in the mindset of the department of electricity in Egypt. We finish the study by analyzing a case study for a household introducing solar panel on their roof top and the possible return on investment for such project with the new regulations.

The current status of the Market

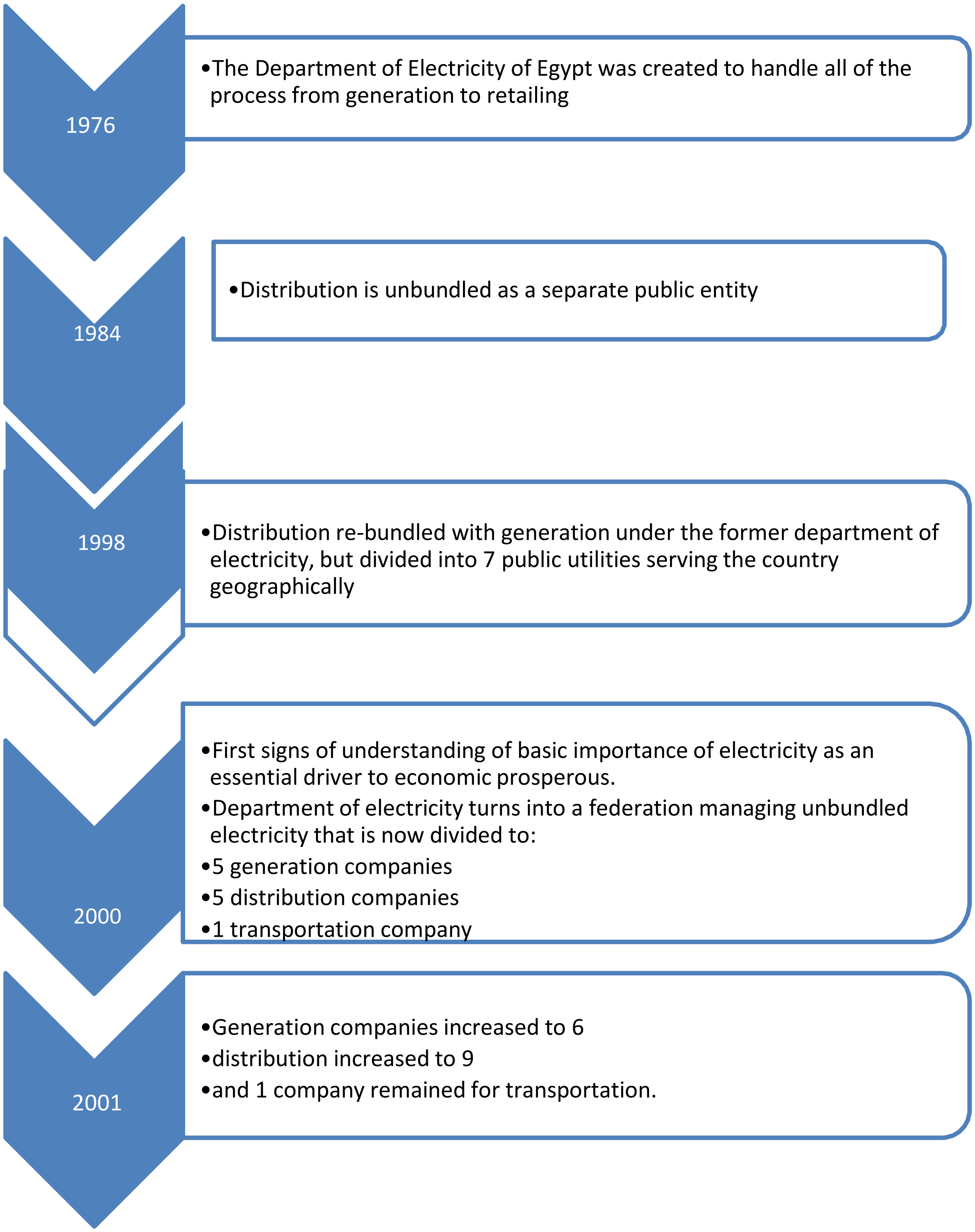
History

On September 6th 2014 Egypt suffered from what was known as “Black Thursday”. From 6 am till Midday (some cities till midnight), power cuts ran through the country from north to south and from east to west. Almost no provenance or building was an exception from the power cut. The issue reached all premises of the country and triggered a country wide debate and drove the president to speak openly of the issue for the first time. Egyptian President Abdel-Fattah El-Sisi said that electricity production and distribution were not developed enough to keep up with consumption .He estimated that Egypt needs 2.5 GW annually for the next five years to meet rising demands, at a total cost of LE12.5 billion (1.7 Billion euro).

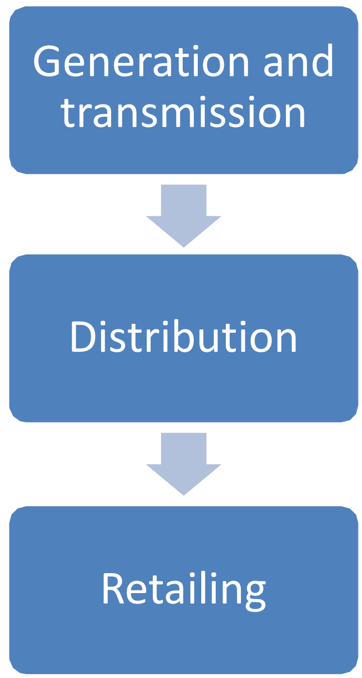
This was not a new matter, the country had been seeing this phenomenon on a daily basis since March of the same year, And seasonally for the past 5 years. The previous occurrences off course weren’t with the same magnitude or spread, the country had decided to regulate the power cuts by regions organizing around 1-2 hour of daily power cuts in each district in the country. This came as an approach to change to the previous socially unjust division of power cuts. In the previous years, power cuts were almost exclusive to poorer areas and suburban cities. Some cities in Upper Egypt (the southern part of the country) witnessed over 12 hours of consecutive power cuts under the pre-regulated times of the power cuts.

Electricity Market in Egypt

Egypt does not have an energy market. Energy production is centralized, run and controlled by the ministry of Electricity. Transmission lines and distribution is owned and operated by the government through different companies. The Electricity utility went through different procedures from nationalization and privatization of its production to consumption cycle.


1976
•The Department of Electricity of Egypt was created to handle all of the process from generation to retailing
1984
•Distribution is unbundled as a separate public entity
1998
•Distribution re-bundled with generation under the former department of electricity, but divided into 7 public utilities serving the country geographically
2000
•First signs of understanding of basic importance of electricity as an essential driver to economic prosperous.
•Department of electricity turns into a federation managing unbundled electricity that is now divided to:
•5 generation companies
•5 distribution companies
•1 transportation company
2001
•Generation companies increased to 6
•distribution increased to 9
•and 1 company remained for transportation.

The latest hierarchy created unbundling in the form of publicly owned companies divided as following.



The government has already approved to allow private companies to bid for managing some of its generation and transmission and distribution. Ownership of power plants and lines will remain under government assets. This is a very progressive attitude in the government coming largely due to the new minister of Electricity H.E. Mohamed Shaker who is an expert in the field of electricity and is a consultant for the 2022 Qatar world cup.

Retailing and Tariff:

There is no retailing, electricity is sold as a utility and prices are fixed. Prices in Egypt are categorized by consumption divided into 7 categories as presented in the following table. Each user pays the corresponding tariff to each level consumed, and not a single tariff for the last level consumed. For example for a low income user consuming 100 KWh in a certain month, he will pay 50 x 0.09 + 50x0.17= 13 pounds. This mix costs the government 134 pounds in subsidies.

Consumption category in KWh	Tariff in Egyptian pounds as of July 2015/KWh
<50	0.09
51-100	0.17
101-200	0.20
201-350	0.29
351-650	0.39
651-1000	0.68

>1000	0.78

Currently, the government pays an average price of LE1.47 to produce one kilowatt of energy per hour, while the average selling price registers LE0.22. However, as of last July 2014 the government began a five year plan to cut electricity subsidies by 67 percent. The government announced on February 18th 2015 the second phase expected to take place in the project. The minister announced the intentions to cut down subsidies on electricity price to 9 billion pounds or around 1 billion Euros by the end of the 5 year plan. Large share of the remaining subsidy would be directed to poorer categories and the industry. However, large opposition came towards this claim by the government. People believe that the new pricing scheme does not serve the poor, as the lower category does not nearly cover the demand of any household in Egypt, which would push them to the second or third category. A lot of opposition also comes to the subsidies given to industries that receive much cheaper electricity and gas than any part of the world and are subjected to much tax exemptions and a large portion of the produced goods is exported.

The minister announced that by summer 2015 an additional 4000 MW would be introduced to the capacity of the electricity utility and a total of 6400 by the end of the year. It is not yet clear from where the additional capacity will come. Most experts in the market claim it will come from maintenances and repair of both generators in plants as well as transmission and distribution systems. Some also believe that its largely due to the import of resources such as gas that was lacking in the previous year due to political reason and lack of cash.

Regulatory bodies

Since Egypt enjoys a very centralized publicly owned utility system, there is no presence of TSO's or markets or ancillary services. The government awards some of its operations to different publicly owned companies for oil and gas and Transmission and distribution, in addition to private investors interested in investing in renewables.

Energy Mix

Coal

Egypt does not produce any electricity relying on coal currently, however in light of the recent energy crises the country the country decided to begin producing electricity relying on what is called "clean coal". Many Ngo's as well as the ministry of environment were very skeptical about the decision but with absence of any regulatory framework, no one can really block the decision. The power plant is expected to join the mix in 3 years China is the main supplier. What is further bothering to the public is that Egypt does not have Coal as natural resource; it will have to import the fossil fuel just like the rest of the energy sources.

Oil and Gas

Egypt's Oil and Gas meets roughly 59% of Egypt's energy demands and exports. Egypt ranks 7th among Non-OPEC countries and 16th worldwide in natural gas reserves. Egypt has 76 trillion cubic feet of natural gas reserves. Production is expected to increase from 630 Billion to 800 billion by 2030 to meet the new demand. Egypt has been and continues to become a victim of corruption when it comes to this sector (outside the sector of this annex) that had forced Egypt to export gas at 1.5$ compared to global average of 9$ and 12 at other times. This is mainly due to long term contracts with Israel, Jordan and Spain. This poses a huge problem at the future of growth in Egypt

As for oil Egypt ranks 25th with 4.5 billion barrels of crude oil making up 0.3% of the world's reserves. However Egypt has a diminishing production level and is relying heavily on Gulf imports as mentioned earlier. Egypt is expected to have a staggering level of 1.5 billion barrels by 2030 compared to the world average reserves of 800 billion. Egypt could maintain production of 280,000 barrels per day by 2030 but import more than 400,000 that is to keep its refineries running at current capacity. In other worlds Egypt would need to import additional 22-45 mtoe of net crude oil to meet Energy consumption.

Nuclear Energy

There have been frequent talks about Nuclear energy in Egypt for years, however due to political reasons the plant in *Al-Daba'e* region hadn't seen birth. A Schneider Electric engineer informed me during an interview that the Army had settled the deal for the plant and will begin operation by mid- 2016 with an expected capacity of 6 GWs. Information regarding Nuclear energy has been very vague and widely distorted due to the secretive nature of the operation of the army.

Renewable energy in Egypt

In Egypt talks of renewable energy joining the energy mix did not come out of environmental concerns or sustainability or even security of supply of energy resources, as was the case with most OECD nations that considered introduction of renewable energy to meet the rising concerns about climate change and greenhouse gas emission. Environmental laws in Egypt and ineffective and the strength of the ministry of the Environment in the decision making process is very weak. As shown in the next graph, CO_2 emission is rising dramatically each year with no clear signs of braking. As well as the large reserves of natural Gas in Egypt and neighboring allies minimizes the Egyptian concerns of security of supply. In the summer of 2013 when the leadership in Egypt changed due to a popular uprising against the elected government Gulf countries rewarded the new leadership with 12 billion Dollars as aid and loans to support the fragile Egyptian system. Among those large sums of money 3-4 Billion dollars were dedicated to the energy sector in the form of oil barrels or direct cash to support imports of oil and gas. This was aid was repeated at the Economic conference held in March of 2015 with the same amount reimbursed in the form of oil and gas. The country needs monthly more than 1 billion dollars to meet its requirements of oil and gas to supply the energy sector.

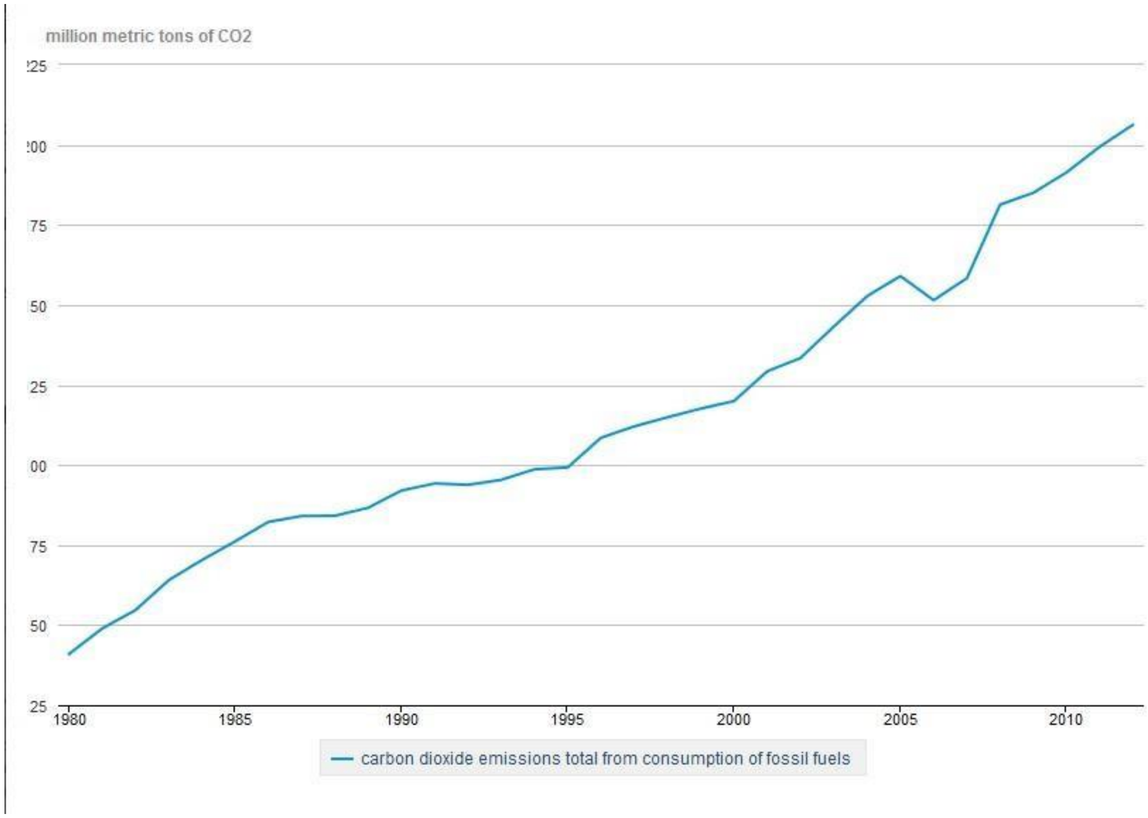


Figure 1 Source: EIA Outlook express 2015

Renewable energy in Egypt is a matter of meeting rising demand of electricity with many plants deteriorating from lack of maintenance or end of its life cycle. Renewable energy provides as fast (relatively easy solution) for the lack of sufficient capacity. Egypt is a fast growing population and a market with huge potential for growth. Egyptian GDP was growing at a rate of 5-7% before 2011 and is now beginning to recover from the unrest posed in the last 4 years and retrieving its ability to grow at a rate expected to be 3.8% in 2015. This along with cheap labor and weak regulations on polluting industries such as cement opens a market for foreign investment that will bring about further need for electricity. Figure shows the rising levels of energy consumptions over the years, It is particularly interesting to notice how the graph follows an identical trend to that of CO_2 even in periods o decline in consumption such as in 2005, CO_2 emission followed a similar trend. This shows for the enormous dependence of the Egyptian Electricity mix on fossil fuel technologies.

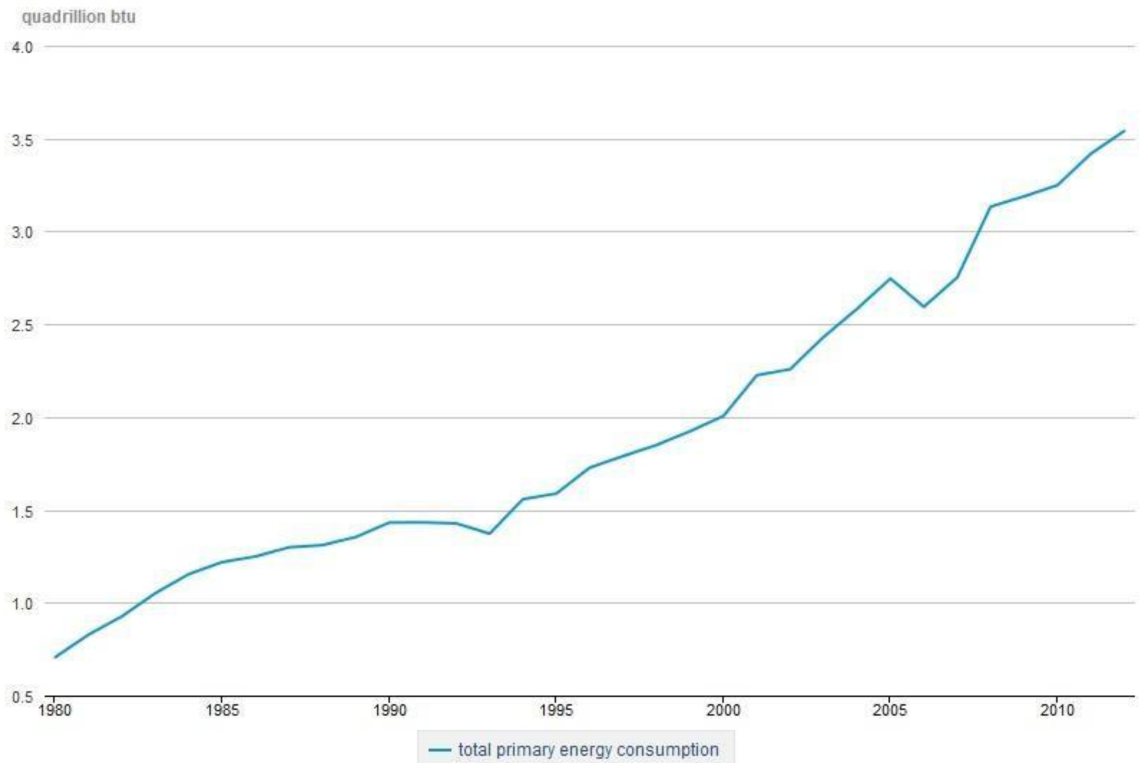
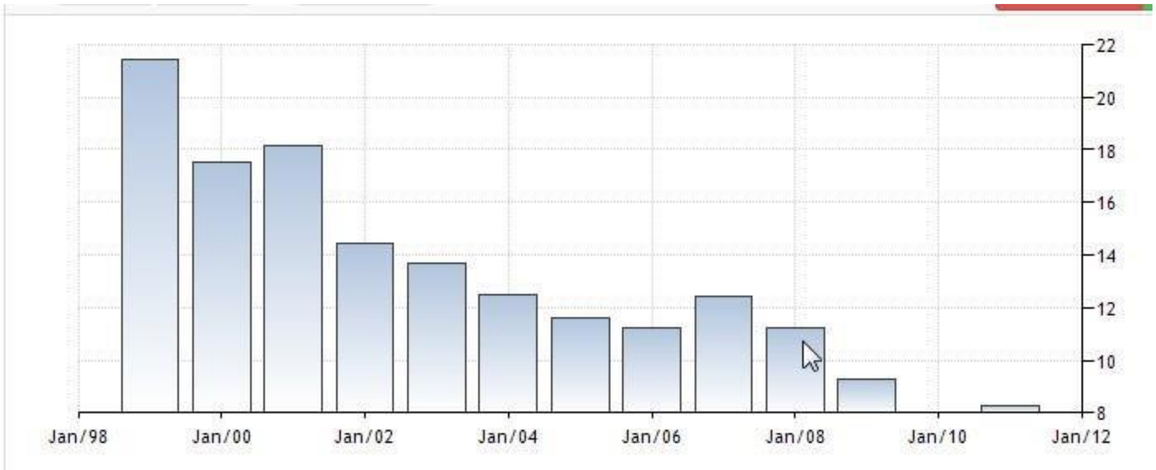


Figure 2 Source: EIA outlook express 2015

The lack of presence of a liberalized market and auction system saves Egypt some of the complexity associated with introducing renewable energy in the market. Aside from the relatively stable wind speeds and solar radiation the country, intermittency does not pose a huge problem for the country that relies heavily on natural gas as a prime source of energy (since natural gas is a fast ramping technology). The absence of real time markets and the fact that power cuts are relatively acceptable among the country makes renewable energy flow into the energy mix with little complications.

Hydropower

11.2% of Egypt's energy today originates from hydropower offices, the first of which was inherent 1960. The Aswan Dam, was developed to control the Nile water release for watering system. In 1967, the 2.1 GW High Dam hydropower plant was dispatched, followed by the dispatching of the Aswan 2 force plant in 1985, the authorizing of the Isna hydro force plant in 1993 and that of Naga-Hamadi in 2008. Power era from gasification of sewage slop in waste water treatment plants is as of now being utilized (for instance, the El-Gabal El-Asfer 23 MW plant), with a potential era of 1,000 MW from agrarian waste. However as seen in the figure below, hydropower share actually decreased from 23.8% in the early 1990's to what is present now. This phenomena as witnessed in Brazil is quite common in a growing demand of electricity and limited areas for growth of hydropower in Egypt. However, part of the decline in market share for hydropower comes originally from deformation of the dam and wear and tear.



Wind

Wind contributes less than 2% of Egypt's present vitality blend, regardless of a wealth of wind assets, especially in the Suez Gulf region:

- Western Egypt (west bank of the Nile),
- Kharga district, Eastern Egypt (east bank of the Nile)
- And the Gulf of Aquaba zone.

Starting 2010, The new and Renewable Energy Authority (NREA), the power subsidiary with the Ministry of Energy that deals with Egypt's clean vitality portfolio has an aggregate introduced wind capacity of 550 MW in Zafarana and Hurghada in 2010. These activities were actualized in co-operation with Denmark, Germany, Spain and Japan. There are present activities under arrangement with a capacity of 1120 MW. in the Gulf of Zayt on the Red Sea Coast.. Zafarana has been operational since 2004 and has a capacity of 360 MW, where wind speed is on average 9 meters/second. Egypt has enrolled Zafarana as a CDM project. Various studies show that power produced from wind assets speaks to the best open door for Egypt's RE to achieve aggressive costs with power created from oil and gas.

Solar

Solar energy contribution to the energy mix in Egypt is insignificant (however experiencing radical advances), however Egypt gets a portion of the most elevated sun based radiation on the planet (up to 3,000 kWh every square meters every year) and 96% of the nation is desert, making it a prime area for utilization of this asset.

A 140 MW Integrated Solar Combined Cycle Power Plant spotted at Kuraymat is in operation since 2011. The venture is in light of explanatory trough innovation coordinated with joined cycle force plant utilizing regular gas as a fuel. The limit of the venture is 140 MW including sunlight based offer of 20 MW. It is one of 3 comparative undertakings are being executed in Africa (Morocco, Algeria, Egypt), which chiefly rely on, upon coordinating a sun powered field with a consolidated gas cycle.

More than 20 years prior, Egypt issued an ecclesiastical declaration obliging all houses in new groups to use sun powered water warming frameworks. Around 500,000 square meters of such units were installed, although this is humble with respect to Egypt's neighbours (for instance, Jordan introduced 6 million square meters). Sun oriented warming for inns was obliged starting in the 1980's, yet execution was impeded by the substantial requests of four and five star hotels, dust covering the sun powered boards (decreasing their productivity), and hard water bringing on calcification in the channelling. Notwithstanding support troubles, the high starting venture required for these ventures has demonstrated a trouble in bringing extra sun powered to the business sector.

Solar panels had also been present in Egypt in the past (20 MW) as a solution for rural areas where little connection to the grid was present. Although it was not an economically viable solution, business men were willing to incur the extra cost to make up for lack of alternatives. Many of these projects are in the middle of the desert like Siwa oasis in the North-west of the country where even relying on Diesel generator was not very easy since owners would need to make frequent trips to bring the fuel required. The energy from solar is used to extract and heat water from wells bellow the ground. This process served as renewable+ storage scheme, since electricity wasn’t needed in real time but used whenever available, making the process of storage of water some sort of storage on its own of energy.

Solar heaters

Renewables in Egypt also had a relatively significant presence in the past through solar heaters and electrification of rural areas. Since mid-eighties the government had been pushing real estate investors building housing compounds with roof top to force household owners to rely on solar heaters to provide hot water. Solar heaters cost went down from 10,000 to less than 5,000 Egyptian pounds for 100 liter tanks. This could help save up to 15-30% of the electricity bill of the household. With an average annual bill for such households of 4000 pounds, the investment could be recovered within 4-5 years leaving more than 10 years of annual savings of 1500 Egyptian pounds or return on investment of 20%.

Future of the energy market

This part attempts to highlight the possible proposed solutions and suggestions to enhance the energy market in Egypt. This is based on the structure suggested in chapter 4 of the thesis.

Interconnection:

As mentioned previously in the solutions for renewable energy problems, Interconnection is a huge potential for Egypt. Already in close ties with Israel in natural Gas trading, and politically aligned with Saudi Arabia, Egypt has a good chance of mitigating the problems that could arise from increasing the complexity of its energy Mix. Already alerted to the possible instability that could arise from high level penetration of renewables, The minister of Electricity announced the construction of underwater cable transmission between Egypt and Saudi Arabia with the Capacity of 3000 MW. According to the ministry's studies of peak hours of Egypt and Saudi Arabia, the two countries have different peak demand/supply hours. This according to the studies would open a huge potential of trading that will help decrease peak load production that is expensive and inefficient.

The ministry of electricity had expressed in its latest interest in upgrading its electricity service and decentralizing it in the hopes of further integration with other countries. The minister of electricity had clearly set the goal of liberalizing the market before the upcoming economic conference held in Egypt. The ministry expects contracts linking the country across Mediterranean Sea to Cyprus, Greece and possibly Italy. Egypt had formally rejected an offer from the EU to become a sun bed for Europe, by providing solar energy to the thriving continent. Talks about re-initiating the project have been resumed.

Demand side management

The hopes of smart meters and demand responsive protocols to decrease demand in response to peak demand hours is farfetched. Until prices are liberalized there is little motive for customers to decrease their electricity usage during peak hours, since prices are fixed and power cuts hits households that consumes minimum or maximum electricity. However, Demand side management has emerged in a different way. With the numerous power cuts that hit the country last summer many households and commercial users resorted to UPS systems with batteries and rechargeable light sources. Those UPS systems are designed to use electricity efficiently, supplying electricity from the battery (previously charged from the grid before the power cut) to only specific appliances. This theoretically means that users will absorb electricity during excess supply and use it during peak demand with levels much lower than that would normally be used during peak times.

The government also has big room for improvement in terms of efficiency. Start-up businesses like waffar.ly, IceCairo and 'el nour geh' (النور جه) and numerous other organisations working with the Giz (Gesellschaft für Internationale Zusammenarbeit or the German society for international cooperation) and other international entities are working towards promoting more sustainable solution and efficient usage of electricity. The presidential campaign of the current president included a huge campaign for promoting light saving bulbs with power ratings of 10 W compared to the regular ones of 60 Ws. The initiative is aiming to introduce the 10 million light bulbs to poorer regions (although LEDs have a much longer life span, they do cost relatively much more than regular inefficient ones). At waffar.ly we calculate for users the relative savings in money from replacing one light bulb with another more efficient one, since many only consider the cost of the bulb and neglect the savings on electricity bills from using light bulbs with lower power ratings.

The government also is working now to adjust the metering system; first to provide a more just system for calculating costs for users, and second to allow net metering or two ways metering for those who are aiming at introducing roof top solar panels. The government has announced its willingness to provide 10 million meters with subsidized prices to compensate for the past bad experience users have been having with wrong calculations of the used electricity. This is particularly important for users wanting to conduct a Return on Investment analysis for introducing rooftop solar panels. If users would be willing to buy solar panels they need to know their expected monthly cost on a steady base and ensure that they only pay for what they consume – what they produce with the appropriate tariffs.

Most of the initiatives taken nowadays are private and small scale to compensate for the lack of liberalized unbundled market where retail is an entity on its own. However the Telecommunication business is booming in Egypt and decided to invade the market of demand side management especially in the field of home automation and smart metering. Already in many private compounds some sort of smart metering exists, where meters are connected through sim cards to the internet and a database of the usage is kept. Households could also use their smart phones to switch on and off home appliances at different periods of the day depending on their need.

Solar Energy:

Feed in Tariffs

In September 2014 and after the “Black Thursday”, the government held a press conference that announced the beginning of the introduction of Feed in tariff for solar energy production. The tariff introduced in the tables below will be in the form of net metering for households and direct payments for high producers. The decision came after a long process of pushing from many young entrepreneurs whom had studied the field and read about the matter and thought to bring the EU and the USA experience into the Egyptian Electricity market. The minister expects to have 4.3 out of the 8 GW installed capacity over the next 10 years to come from solar energy.

At First the government had decided to only allow permission for promotion of the tariff to households to companies that had been operating in the market for more than 3 years. This was not reasonable since before the introduction of the tariff there was very limited market for selling solar panels to households, the focus was only on rural areas where electricity distribution was minimal. After several rounds of negotiation the government reached an agreement to grant permission for start-up companies to operate if they pass a technical exam regarding electrical power systems and solar systems in particular. Today an Estimate of 300 companies are already licensed and operating in the market out of which 170 took part in the first annual Conference for Renewable energy in Cairo last November. However, only 56 of the total companies in the business are licensed to operate on small and large scale.

Small scale

Type	Capacity	Tariff[1]
House hold		LE 0.848
Commercial	<200 KW	LE 0.901
	200-500 KW	LE 0.973

Large scale

Type	Capacity	Tariff[2]
Mega projects	500 KW- 20 MW	13.6 Cents
	20 MW - 50 MW	14.34 Cents

At the first Glance we Notice the regulatory flows in the tariff system provided by the government. The limitation on the capacity of solar farms (50 MW for mega projects) makes little sense and reminds us of the issue Brazil suffered from in its limit on remuneration on electricity produced from wind farms which was limited to 30 MW. The government had announced its willingness to consider accepting increased capacity. Limiting the size of solar farms forces companies to try and go around the law by duplicating solar farms at different locations to benefit from the tariff. This involves extra costs for distribution and invertors and different electricity appliances.

Households suffer from even bigger challenges in the country since the tariff (as will be presented) is not nearly enough to cover the divided cost of the panel. Compared to most of the world the tariff is very low, in addition to the fact that the government decided not remunerate users by deducting from their monthly electricity bills up to the total cost of the bill, i.e. users producing more electricity in monetary terms than consuming will not be rewarded. This reduces the overall return on investment for users buying the panel. To further understand the implication of the decision to cap the return; it's important to note that electricity price (categorized for different rates of consumption) is much lower on average than the tariff. This means that if on average electricity costs 0.47 L.E and a tariff of 0.84 LE, the house owner would only save money up till the point he is producing half of what he is consuming, any further increase in capacity, and thus production would be an extra cost with no benefit. This serves against the government's goal of increasing its electricity capacity. This is however only for the time being, as prices of electricity rise the panel will prove more viable.

[1] Money in Egyptian currency, Currently (March 2015) 1 euro equivalent to 8.7 Egyptian pounds
[2] Large-scale projects are expected to resort to foreign financing for lower costs, their tariff rates were calculated in US dollars.

Wind:

Wind Energy was one of 2 renewable energy technologies that were to be supported by the government. The Technology as mentioned earlier, has a stronger presence in Egypt than solar energy and a relatively strong potential for Growth. The government decided to focus on areas with strong wind presence, typically between 2500-4000 hours of production/year. For lower capacity factors Egypt would need much higher tariffs to motivate investors to invest in farms. The feed in Tariff would be only awarded to farms of 20 MW or larger capacities. Estimated cost of 20 MW farms was 22.6 Million Dollars, while 56.7 Million Dollars.

The government set the tariffs presented bellow in the tables to be awarded for any project contracted within the next two years or until the government reaches the targeted capacity of 2000 MW, Whichever comes first. The tariff would then be re-evaluated. The tariff were divided into 2 time clusters. and 15 (100 hours each) production clusters. The first table presents the first time cluster (the first 5 years) where tariffs are only divided between 2 production categories; 2500-3000 and 3100-4000 hours. The tariff then decrease in the second time cluster since the learning curve is expected to rise as well as a drop in the cost o the technology. Furthermore a higher chunk of the electricity is set to have been covered in the first time period.

For the first 5 years

Number of operating hours per year	Tariff in Pounds (dollars)/KWh
2500-3000	0.8202 (0.1148)
3100-4000	0.684(0.0957)

For the second period of 15 years

Number of operating hours per year	Tariff in pounds (dollars)/KWh
2500	0.8204 (0.1148)
2600	0.7553 (0.1056)
2700	0.6946 (0.0971)
2800	0.6383(0.0893)
2900	0.5858(0.0819)
3000	0.5368(0.0751)
3100	0.6382(0.0893)
3200	0.5953(0.0833)
3300	0.5549(0.0776)
3400	0.517(0.0723)
3500	0.4812(0.0673)
3600	0.4473(0.0626)
3700	0.4154(0.0626)
3800	0.3851(0.0539)
4000	0.329(0.046)

I tried contacting government officials to ask why (unlike the trend of the tariff) the panels was working for 3100 hours awarded more than that of the 3000 hours, but no satisfactory answer was given. The contacted official stated that the range between 2500-3000 was treated clustered on its own compared to that of 3100-4000 as was the case for the first 5 years, thus both clusters followed descending orders and started at different points (higher for 2500 hours), but 3100 didn't have to start lower than that of 3000. The official didn't however have an explanation for why no pricing was present for a production of 3900 hours. One technical expert elaborated that the panels aiming for efficiency higher than 30% (approximately 3000 hours) was more expensive than that of lower capacities. They were still more profitable but the required to start at a higher tariff for a fair allocation of the subsidy.

One point worth noting that in my opinion is that this very detailed tariff system would require careful monitoring of the produced hours of wind energy to allocate the right remuneration. This is not very feasible in the current operating system of the electricity utility in Egypt, with lacking TSO's it seems impossible to monitor such wide scale. It is not yet clear if the government is planning to pay wind farms owners for the actual produced energy or the expected based on the location of the wind farm. Many metrological studies have been done for wind energy in Egypt that would support the decision make process for the awarding of land.

Unlike Solar energy Wind energy is heavily relied on foreign investment and large business men due to the large costs of the farm. There is little discussion and debate in the government's decisions in this area as the public has little interest in this part. In the last conference for renewable energy some hybrid solar and wind panels were presented for residential use. No one really knows how the government would treat these kinds of inventions; it is clear that most of the customers willing to buy such technology is more concerned about securing electricity rather than saving money or participating in a greener Egypt.

A study of the Return on Investment of purchasing roof top solar panel:

In this part we try to make an estimation of the average return on investment for household installing solar panels. Data was collected about solar radiation level in Cairo and a collection of different monthly electricity bills for average top middle class household. Points worth noting are:

- There is a variation between electricity bills for the same month in different years partly due to long vacations (typically in the summer), but mainly due to variation in the methodology of reading the consumption on the meter. It happens quite often that costs are allocated to different months than the ones electricity was consumed in. Sometimes bills are presented where months are combined. The later in particular is a very serious issue, because if cost is allocated to more than one month, then the energy consumed in the second month will be charged as part of the higher tariff and not divided upon all tariffs. Furthermore since the net metering stipulates that the remuneration does not exceed the cost of the consumed electricity in the same month it's important to make sure that the reading is accurate.

- Some testimonies from experts in the field claims that the charge of electricity in fact depends on the ampere rather than on the total power, this allows the government to decrease the voltage and raise the current and maintain the same energy reading and raise the price. This is not confirmed information however.

- After studying the electricity bills from different years it was noticed that there is an average decline in the KWh of consumed electricity per month. This makes sense of course as power cuts are increasing, however the trend is more explained if we look at the change in relative to the upgrade of the distribution to the grid. Since losses are charged to the final user, the improvement in the grid decreases the total consumed electricity. The same is noticed when analysing households that installed new meters. The new meters give more accurate and persistent estimation of the consumption across different years of the same month.

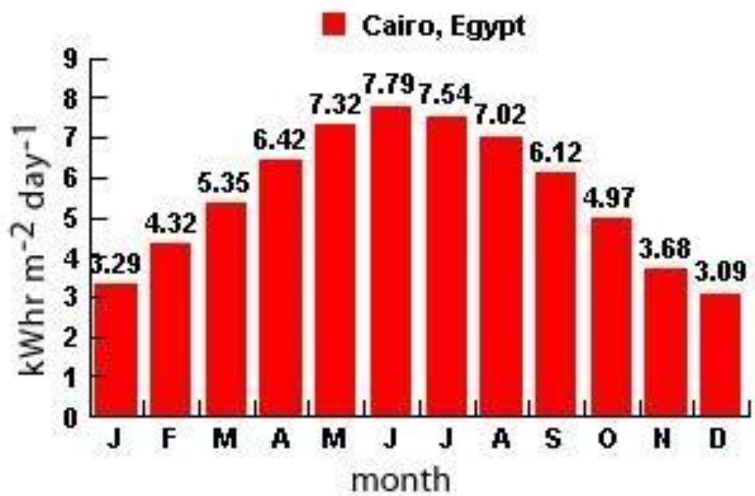
- No actual installed grids were available to test monthly production, rough estimates of the average was taken relative to testimonies of users of the same grid at different parts of the world (accounting for the seasonality and the different solar radiation).

- No information was present about the future tariff for solar panel. We thus assumed that; no increase in, neither the feed in tariff or the electricity cost aside from the annual increase over the coming 4 years. This is a very conservative estimation giving the volatile nature of the past of electricity of Egypt. However, it's believed that the volatility is only a current state due to the accumulation of poor regulation and management of the electricity utility in Egypt. Once prices and grid are up to universal standards changes should be more gradual.

- After surveying the market we found the most common panel was the Renesola Virtus moldelle[3] 250 W with efficiency 16% and a dimension of 1.6 m x 0.992m sold for $187. Realistically speaking this efficiency declines greatly in Egypt due to the dusty nature of the country. Many research papers discuss this problem as a barrier towards introduction of solar panels.

- The average monthly solar radiation levels were obtained from the website: http://pveducation.org/pvcdrom/properties-of-sunlight/average-solar-radiation#

[3] http://www.cairo-solar.com/portfolio/renesola-250w-polycrystalline-solar-panels/



Assuming the user will buy a 3KW panel that is 12X250 W with a total dimension of $19.52m^2$. And a total price of 2244 dollars or 17121 pounds. This will allow the user to harvest almost 730 KWh of electricity on a sunny day in July, but only 289 KWh in December. Since the government only provides compensation for users up to the actual consumed electricity this would mean that the user might be better off with a 2KW panel instead of a 3KW one (with reference to the monthly cost of electricity currently). The price listed here would only double with the inverter and the maintenance and all the needed installation, and would triple if we introduce batteries. For the sake of simplicity and representativeness we include the price provided by average vendors such as Cairo solar which is 10,000 Egyptian pounds per 1 KW or 30,000 for the 3KW.

The Return on the first year of operation is as follow:

	Costs without Solar		Costs with Solar				
2014	Usage (kWh)	Cost in pounds	Hours of sunshine	Solar radiation in KWh/m2/day	Generates KWh	Feed in Tariff in Pounds	Monthly bill
Jan	519	$142.41	6.7	3.29	308.25984	261.40	-$118.99
Feb	633	$186.87	7.6	4.32	404.76672	343.24	-$156.37
Mar	500	$135.00	8.1	5.35	501.2736	425.08	-$290.08
Apr	468	$122.50	9	6.42	601.52832	510.10	-$387.60
May	589	$169.71	11	7.32	685.85472	581.60	-$411.89
Jun	632	$186.48	12.2	7.79	729.89184	618.95	-$432.47

Jul	73	$261.50	11.9	7.54	706.46784	599.08	-$337.58
Aug	113	$509.50	11.7	7.02	657.74592	557.77	-$48.27
Sep	60	$174.00	10.2	6.12	573.41952	486.26	-$312.26
Oct	52	$142.80	8.3	4.97	465.66912	394.89	-$252.09
Nov	53	$145.53	8.3	3.68	344.80128	292.39	-$146.86
Dec	60	$174.00	6.8	3.09	289.52064	245.51	-$71.51
Annual	7,46	$2,350.30			**6,269**	**5,316.28**	**- 2,965.98**

We the extended the model to show the return over 25 years to get the NPV value of the project which produced this:

Lifetime Cost Evaluation based on 25 Year Operation								
		Electricity			**Solar**			**Opportunity Cost**
Year	**Usage**		**Cost (Actual saving)**	**Generates**		**Cost**	**Theoretical**	Bank savings at 10%
1	7,469	Annual Planned increase of 20% for 4 years	$2,350.30	6,269	Assumes 0.8% Annual Degradation of the panel abilities, based on the product's specification	$5,316.28	$2,965.98	$33,000.00
2	7394.31		$2,820.36	6,219		$5,273.75	$2,453.39	$36,300.00
3	7320.3669		$3,384.43	6,169		$5,231.56	$1,847.13	$39,930.00
4	7247.1632		$4,061.32	6,120		$5,189.71	$1,128.39	$43,923.00
5	7174.6916		$4,061.32	6,071		$5,148.19	$1,086.87	$48,315.30
6	7102.9447		$4,020.71	6,022		$5,107.01	$1,086.30	$53,146.83
7	7031.9152	Assumes $.08/ Kwh (Inflation Adjusted)	$3,980.50	5,974		$5,066.15	$1,085.65	$58,461.51
8	6961.5961		$3,940.69	5,926		$5,025.62	$1,084.93	$64,307.66
9	6891.9801		$3,901.29	5,879		$4,985.41	$1,084.13	$70,738.43
10	6823.0603		$3,862.27	5,832		$4,945.53	$1,083.26	$77,812.27
11	6754.8297		$3,823.65	5,785		$4,905.97	$1,082.32	$85,593.50
12	6687.2814		$3,785.41	5,739		$4,866.72	$1,081.31	$94,152.85

13	6620.4086	Assumes Home Becomes 1% More Efficient Annually	$3,747.56	5,693		$4,827.79	$1,080.23	$103,568.14
14	6554.2045		$3,710.08	5,648		$4,789.16	$1,079.08	$113,924.95
15	6488.6625		$3,672.98	5,602		$4,750.85	$1,077.87	$125,317.45
16	6423.7759		$3,636.25	5,558		$4,712.84	$1,076.59	$137,849.19
17	6359.5381		$3,599.89	5,513		$4,675.14	$1,075.25	$151,634.11
18	6295.9427		$3,563.89	5,469		$4,637.74	$1,073.85	$166,797.52
19	6232.9833		$3,528.25	5,425		$4,600.64	$1,072.38	$183,477.27
20	6170.6535		$3,492.97	5,382		$4,563.83	$1,070.86	$201,825.00
21	6108.9469		$3,458.04	5,339		$4,527.32	$1,069.28	$222,007.50
22	6047.8574		$3,423.46	5,296		$4,491.10	$1,067.64	$244,208.25
23	5987.3789		$3,389.23	5,254		$4,455.17	$1,065.95	$268,629.07
24	5927.5051		$3,355.33	5,212		$4,419.53	$1,064.20	$295,491.98
25	5868.23		$3,321.78	5,170		$4,384.18	$1,062.40	$325,041.18
Total			**$89,891.98**			**$120,897.20**	**$33,483.40**	**$295,041.18**

Please note that the $ sign is a reference to The Egyptian pound not US dollars.

As presented here the actual production from the panel is less than the consumed, however the total cost is much less than the supposed feed in tariff. The user would not be compensated with the excess money that is owed to him, thus motivating him to originally buy less capacity of solar panel.

We then calculated the total return on investment over the 25 year lifetime of the panel and compare it with a 10% interest rate if invested in the bank. The project breaks even at 8.5 years. We had other alternatives with higher rate of return such as government bonds for the Suez Canal with 16% but this is not expected to last longer than the 3 year duration of the project. It is clear that at these prices the project is very unfavorable. There is almost 33,500 pounds of lost money to the user that he will not be compensated for because they are excess money dropped at the end of each fiscal year. Of course we realize that no one actually invests money in the bank and leaves it unused for 25 years and with adjustments for inflation the money value of the saved money from electricity bill becomes more.

Conclusion

To sum up Egypt has a very unstructured and semi-liberalized electricity market where politics and business co-exist and many of its policies are issued in a traditional top-down approach and consistency is lacking (many of the information presented was updated almost weekly due to changes from the ministry or original misinformation from the press). The presented case study does not conclude the rooftop solar panels as a profitable option. However, there is huge potential for improvement; there is a will partly from the new vision brought by academia's and the private sector and partly because of the need to diversify the energy mix. There is no room for any renewable energy technology to be profitable with the accounting of environmental costs. Pollution in Egypt is costing a lot of life and making life in cities harder every day and if tackled seriously could add the integration of renewable energy by making private businesses baring part of the burden they've created.

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