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FEASIBILITY OF WIND POWER IN RURAL AREAS OF EGYPT BASED ON THE EVALUATION OF AN EXISTING WIND ATLAS

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AFFIDAVIT

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Kurzfassung

Die vorherrschende Energieversorgung in Ägypten basiert im Wesentlichen auf fossilen Brennstoffen wie Öl und Gas, welche von der Regierung seit Beginn der eigenen Ölproduktion hochsubventioniert an das Volk zu minimalen Kosten „verschenkt“ wurden. Das starke Bevölkerungswachstum in Ägypten sorgte dafür, dass in den letzten Jahren der Erdölverbrauch die lokalen Förderungskapazitäten überstieg. Was folgte war eine Energieverknappung und letztendlich eine Verdoppelung des lokalen Ölpreises innerhalb der letzten zwei Jahre. Weitere Pläne, bis zum Jahr 2021 die Subventionen für Erdöl und Gas gänzlich zu eliminieren, sind von der Regierung unterzeichnet, sodass der rapide Anstieg der ägyptischen Ölpreise fortgesetzt wird. Die Bevölkerung ist dadurch sowohl im industriellen als auch im privaten Sektor gezwungen, einen Ausweg aus der fossilen Abhängigkeit zu finden und alternative Energieerzeugungsformen zu nutzen.

Aktuell werden in Österreich durch neue Einspeisegesetze bestehende Windkraftanlagen noch weit vor dem Erreichen ihrer ausgelegten Lebensdauer durch neue ertragreichere Großanlagen ersetzt. Diese Studie befasst sich u.a. damit, diesen gebrauchten aber überholten Anlagen „frischen Wind“ in Ägypten einzuhauchen. Die Investitionskosten für potentielle ägyptischen Betreiber bzw. Großverbraucher ließen sich dadurch im Vergleich zu einer Neuanlage erheblich minimieren.

Eine Wirtschaftlichkeitsbetrachtung mit einer aussagekräftigen Windmessung an einem potentiellen Standort ist vor der Installation einer derartigen Windkraftanlage unumgänglich, um Umweltbedingungen zu erheben und spätere Energieerträge zu ermitteln. Die vorhandenen Winddaten von früheren Studien und Projekten werden untersucht und evaluiert. Ein Messkonzept, welches mit minimalen Importaufwand auskommt und stattdessen auf hohe lokale Wertschöpfung setzt wurde im Zuge der Arbeit mitentwickelt. Sämtliches Material des eingesetzten Masten kommt aus Ägypten und wurde mit lokalen Werkstätten bearbeitet. Bis auf die hochsensible Sensorik und einen eigens entwickelten Datenlogger ist alles „Made in Egypt“. Mit den gewonnenen Datenreihen aus dreizehn Monaten Aufzeichnungsdauer sind Charakteristiken zum Messstandort sowie Berechnungen zur Wirtschaftlichkeit von Windenergie möglich und bilden einen wesentlichen Teil dieser Studie.

ABSTRACT

While the top wind sites in Egypt are well documented and assessed in terms of wind energy, rural areas are still neglected in any climate assessment. Fayoum is one of these regions, 100km southwest of Cairo, where available wind resource tools show a weak accuracy and come with bad resolutions.

To check if given data shows sufficient accuracy to determine an area as a feasible site for wind energy or not was part of this survey. An installation of a wind measuring system was seen as necessary. Because the import of such systems is expensive and difficult a local system was developed and a 30 meter wind pole erected on the shores of the lake Qarun. A self-developed data logger to convert, store and transmit the data was part of this practical task.

Following a 13 months measuring period a data analyses showed that the wind speed was not as expected. The theory that the available wind data is not accurate proved to be true for this site. It turned out that the present wind speed is lower than any other given data would have suggested. Following a comprehensive feasibility analyses, the theory that wind energy is feasible for this site failed, even with the approach of installing refurbished second hand turbines of central Europe. Nevertheless a different scenario, which is very likely to be present in rural areas of Egypt, displayed economic feasibility.

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1 INTRODUCTION

The energy crisis in Egypt is influencing all areas of the economy and society. Especially consumers who are running their energy production based solely on fossil fuels are forced to start thinking about alternative possibilities. Egypt offers a huge potential of solar energy, which is documented in several studies and projects. Beside these sun-based technologies, which currently show low efficiencies, the wind sector of Egypt has been neglected so far mainly due to high investment costs and missing know-how.

At the same time wind power in Europe develops very fast based on the European energy goals and the intensive subsidisation in many European countries. After the subsidisation period the used wind turbines are often replaced by bigger and more powerful ones, which offers the opportunity of a prolonged use of those used wind mills.

This study is about the feasibility of refurbished wind turbines in Egypt. This approach would result in a minimization of investment costs, while local human resources could be trained for doing necessary maintenance works, adding further value to respective communities. Especially the replacement of existing diesel generators should be targeted for this study since the price for the operation has doubled in the last two years and further price increases are expected as a consequence of the reduction of the fossil fuel subsidisation in Egypt.

The existing wind atlas shows that Egypt offers a lot of potential sites with high wind speeds, but there are also many areas which should be investigated in depth. Local thermal wind systems which exist in the area of the red sea as well as near the Nile region are not well documented so far.

Before the erection of a wind power plant, it is in any case necessary to measure the wind speed at the potential site in a certain height. Within this project a wind measuring station will be placed at a site with a potential local wind system, a certain electricity demand and the according technical infrastructure. The area Fayoum Oasis, which is located 100 km south of Cairo, also called “the garden of the capital” is chosen therefor. Agriculture is the major economic sector and therefore a lot of energy is needed for irrigation and food production processes.

For the wind measuring at the chosen site; sensors, data logger and software were prepared following Austrian best-practice and a 30 meters measuring mast was constructed with the help of local welding workshops. A special self-made data logging system allows a stand-alone online data streaming and web based data analysis.

1.1 EGYPT, THE GATE TO AFRICA

With a population of 97 million people, Egypt represents the largest market in the Arab world and third most populous country in Africa. [1] With a yearly population growth rate of about 2,45%, it places a significant strain on limited natural resources, whether in agriculture, water supply, or mineral resources such as oil and gas. 46% of its population growth took place in the years between 1994 and 2004. Estimations promise a further increase in population until the year 2065 to 160 million inhabitants. [2] Currently 95% of Egypt's population is concentrated along the Nile.

Figure 1: Satellite view of Egypt [1]

Given by strategically important geographical position, the Suez channel, connecting Mediterranean and Red Sea, provides a major source of income besides the tourism sector and gas/oil products. Egypt, shown in Figure 1, plays a key role in Arab and North African, it is therefore called "the gate to Africa". Close to the European borders it not only holds long lasting trade and business relations with the EU but also plays a key role as negotiator between the EU and African countries in terms of regulating migration flows.

1.2 SOCIO-ECONOMIC FRAMEWORK

Egypt faces several challenges which are not only caused by economic drivers. The Arab spring, starting in 2011, shook the political and economic foundations of the entire region. The protesting society, leading to a one way dynamic, was not only forced by a political reason, furthermore the economy and especially the private sector was not satisfied with the situation. The revolution following in a weak tourist sector with empty hotels but furthermore political changes and can’t bring a targeted recovery overnight. The economic growth rate still lags behind the vast population growth rate, an expensive subsidy system and a slowly recovering tourism sector. Several national efforts were put on track to overcome the economic crisis but their outcome remains unclear. Megaprojects like the Suez Canal expansion or the New capital[1] have a positive socio-economic impact but their ability to overcome actual challenges are not investigated in depth. The unemployment rate dropped in the last years but is still high at 13 %, and is much higher considering the youth unemployment rate of more than 27%. [3] With an illiteracy rate of about 40% of the adult population, and more than 10% of children not visiting primary school, a major lack of education exists. In the midst of the economically challenging situation, a massive devaluation of the Egyptian pound arose with its currency flooding, which was a condition of the IMF (International Monetary Fund). Overnight the Pound lost half of its value, as shown in Figure 2. For Egypt, which relies on imports, products and services became much more expensive with inflation rates exceeding 30 Percent in 2017, shown in Figure 3.

[1] The New Capital is a huge city built from scratch colloquial and should inhabit 5 Million people starting with the re-location of the government in the year 2020.

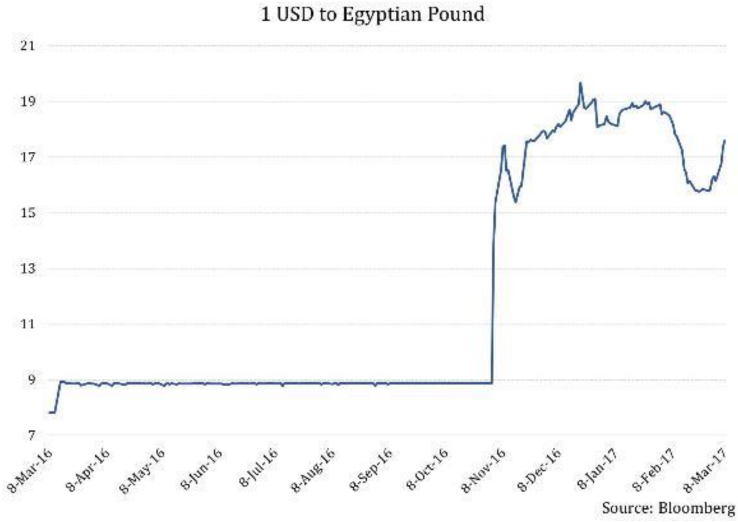


Figure 2: The massive devaluation of the Egyptian pound in November 2016

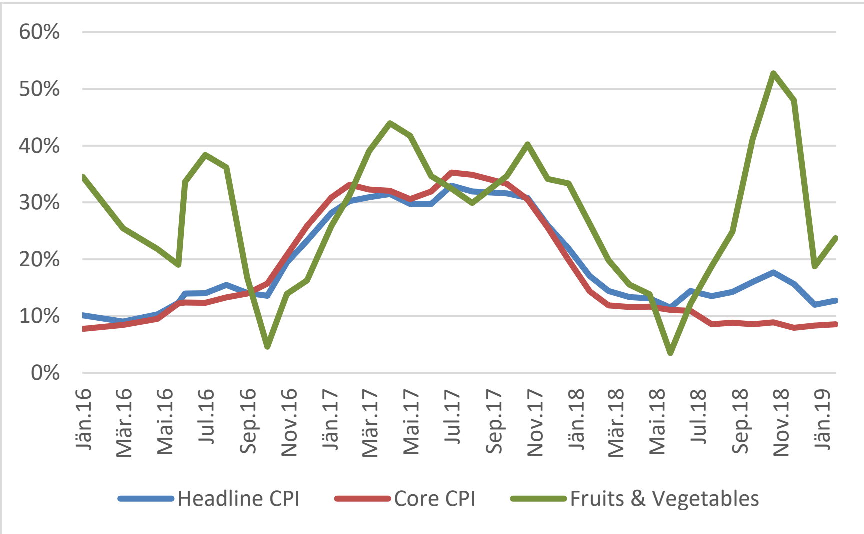


Figure 3: Inflation rates in Egypt, source: Central Bank of Egypt

The Big Mac Index is published each year by the magazine “The Economist” suggests that the devaluation in 2016 is still stressing the currency. A big mac (sold at McDonald’s) is converted from the local price to the USD. Figure 4 shows that Egypt was among the participating countries on the second last place shortly before Ukraine. The graphic should reflect the behaviour of the local currency. The case of a very cheap “Big Mac” could mean that the currency is undervalued.

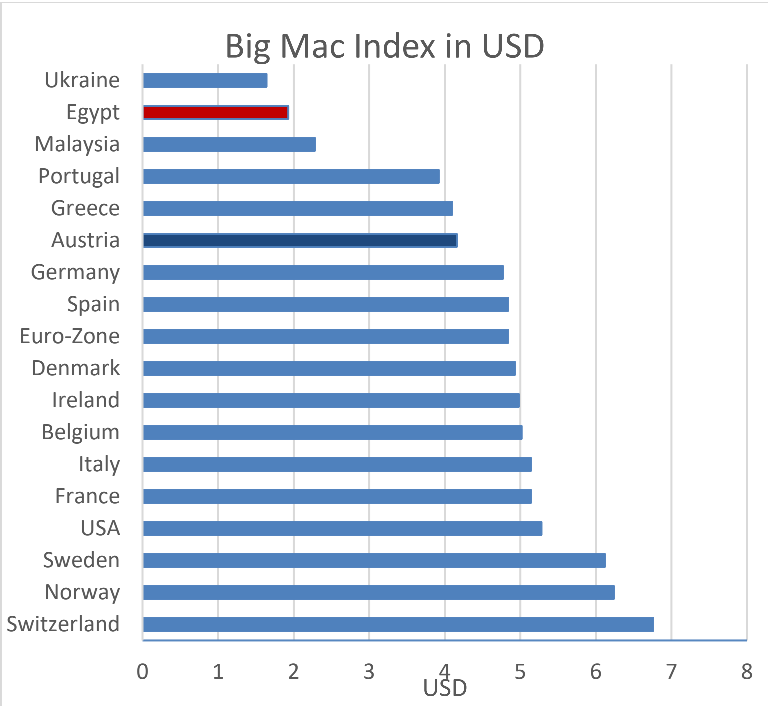


Figure 4: The Big Mac Index, January 2018

Many industrial efforts by the government were put on track to push local production and overcome the import dependency. This led to strict import regulations. The willingness to invest in imported products was low because of doubled prices. These circumstances also forced the practical field research of this study to a local solution. Instead of importing a wind measuring system from Austria (which was initially planned), a local solution was conceptualized. A 30m mast then was manufactured with local workshops and materials.

While the largest scale wind turbine clusters (wind farms) show a very slow development in Egypt due to high investments, smaller scale solutions increasingly seem to be an option for suitable sites. Wind power in Europe is developing very quickly based on the European energy goals and the intensive subsidisation available in many European countries. At the end of the subsidisation period, the used wind turbines are often replaced by bigger and more powerful ones. This offers the opportunity to prolong the life-cycle of the used windmills, exporting them to countries like Egypt after suitable refurbishment. This approach would result in a reduction in the investment costs, while local personnel could be trained in completing necessary maintenance works, thus further enhancing the local added value.

2 Economic framework and general conditions

2.1 The Egyptian energy economy

The Egyptian Energy economy is highly dependent on fossil fuels. More than half of its energy demand is covered by natural gas, nearly 45% is covered by primary and secondary oil. Figure 5 shows the share of Primary energy supply in the year 2016. As in many Arab countries, Egypt based its energy supply on fossil fuels, since it exported oil products in the past. The subsidization of fossil fuels was a very common principle of the Arab regimes and made any renewable energy developments less competitive. In the year 2010 Egypt switched from an oil exporting country to an oil importing country. This undertaking caused massive price increases on the governmental expenses. In the year 2014 the amount of governmental expenses on fuel subsidies was greater than the combined expenditures spent on health and education in the same time. [4]

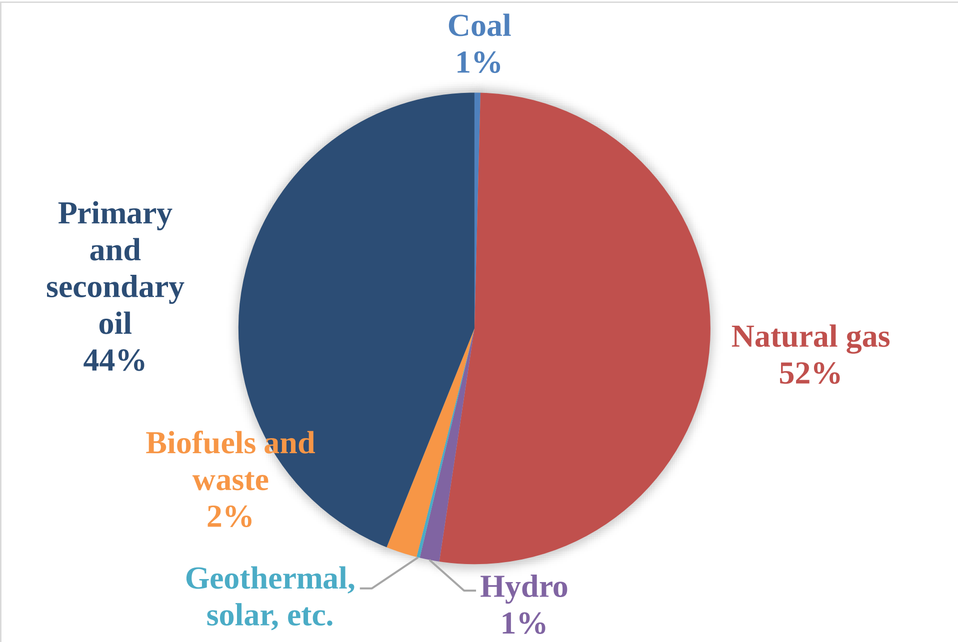


Figure 5: Total Primary Energy supply by fuel, Egypt, 2016 [5]

The total supply distribution and demand is shown in a Sankey Diagram in Appendix A.

Due to a renovation of the electric power supply following a massive supply problem several gas-fired power plants were newly installed and added urgently needed power to the grid, further decreasing the oil driven supply share.

Caused by the fast population growth and it induced increase of energy demand Egypt switches more and more to gas and renewable sources as seen in Figure 6.

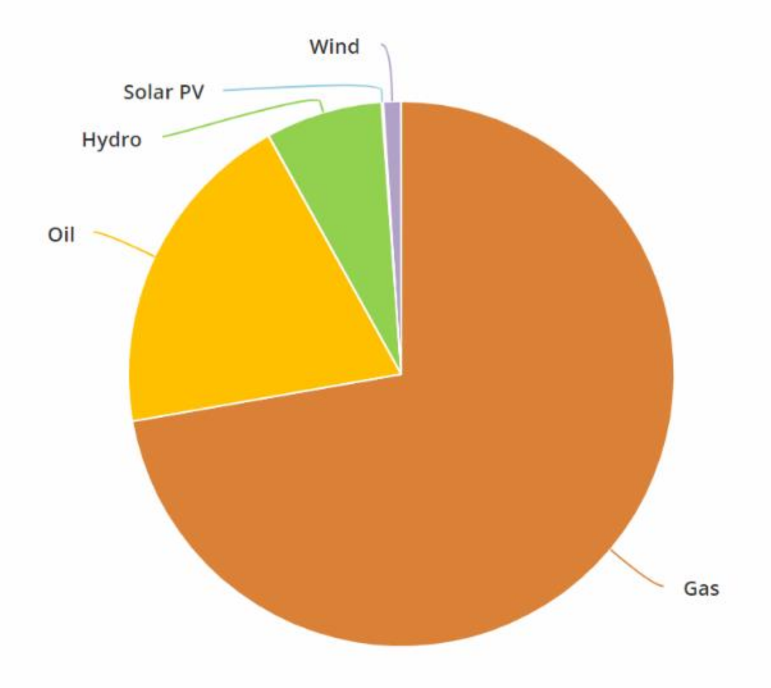


Figure 6: Share of electricity generation by fuel, Egypt 2016 [5]

The electrification rate in Egypt is high with 99,6% of its population having access to electricity. Nonetheless, this number does not say how the electricity is generated or if access to the grid is present. Only 5% of Egypts area is populated. 95% of Egyptians live along the Nile, where also most of the electricity transmission infrastructure is installed. Moving sideways off the river north to south axis, only a few grid connections are present. The main side paths are situated to big tourist or agriculture centers and consumers such as Hurghada, Charga Oasis or Bahareya Oasis and in the Nile Delta.

The electricity market is mainly dominated by the Egyptian Electricity Holding Company (EEHC), which owns about 90% of all generation facilities and nearly 100% of transmission and distribution facilities. Nonetheless there are also private owned generation facilities which have contracts with the EEHC. The Egyptian Electric Utility and Consumer

Protection Regulatory Agency (EgyptEra) takes the regulatory role between different parties from generation, transmission and distribution. They ensure availability of supply to consumers and set the price levels of different consumer sizes. Especially with the fast rise of renewable energy plants several proposal of an electricity market reform are in discussion with the aim of an unbundled structure. [6]

Because of the cut of subsidies for fossil fuels, energy prices are rising fast, both direct fuel prices as well as dependent electricity rates. As shown in Figure 2, especially large-scale users, e.g. larger SMEs (Small and Medium-sized Enterprises), that are affected dramatically by the price increase; the electricity costs for small private households are rising slowly.

The pricing system is organized in different consumer classes, first monthly 50kWh consumed are calculated with the lowest rates, next 50kWh are priced with a higher rate and so on. If consumption exceeds 100kWh it gets priced with the next consumer class (0 – 200kWh), the highest and most expensive consumer class starts at 1000kWh consumption.

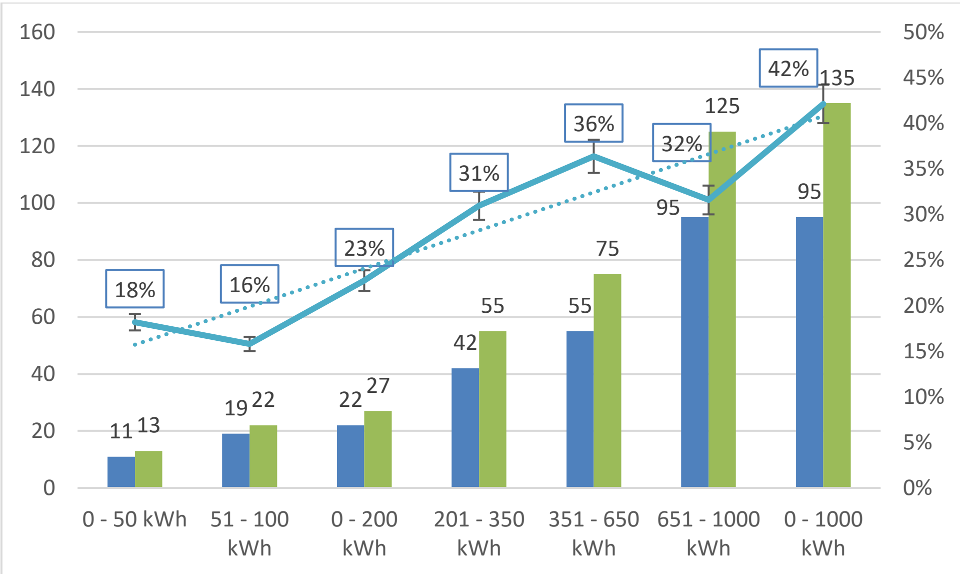


Figure 7: Electricity price increase by consumer size in EGP pt/kWh (2016/17 – 2017/18)[2]

[2] Own figure, data from fiscal years 2016 – 2018, accessed online at the Ministry of Electricity, March 2018

2.2 FOSSIL FUELS

Egypt is the largest oil and natural gas consumer in Africa, accounting for about 22% of petroleum and other liquids consumption and 37% of dry natural gas consumption in Africa in 2016. The reduction of energy subsidies may dampen consumption growth in the near term, but energy consumption is expected to continue growing in the long term. [7]

2.2.1 OIL

Egypt has oil reserves and contracts with several international oil companies which are present in Egypt. Currently Egypt is not a member of the OPEC but an important partner because of its geopolitical position. As shown in Figure 5, oil plays a major role in the energy supply of Egypt. As is typical for Arab countries, the energy supply was based on oil, and old fashioned oil fired plants are still in operation. Besides such expensive power plants, a lot of remote oil-driven generators are present in rural areas and tourist areas in the southern red sea coast. Water irrigation in the oases regions is mainly driven by diesel generators. Apart from national grids the deep wells have high energy demands. The national grid doesn't supply southern red sea coastal tourist villages. There it is still very common running on 500kW -up to several Megawatt sized diesel generators. Except from energy production traffic and transport sectors are major oil consumers. According to the Energy Information Administration, EIA, 60% of Oil products are consumed by the transport sector. [8]

Caused by the fast increase in oil demand, Egypt switched from an oil exporter to an oil importer in 2011, as shown in Figure 8. As this expensive undertaking stressed the national bills, the subsidisation system of fossil fuels was revised and the exit strategy of the subsidization was announced. The government has foreseen a total fossil fuel subsidization end until the end of 2021. So far, fuel prices doubled twice in the previous two years and are likely to rise again in July 2019. [9]

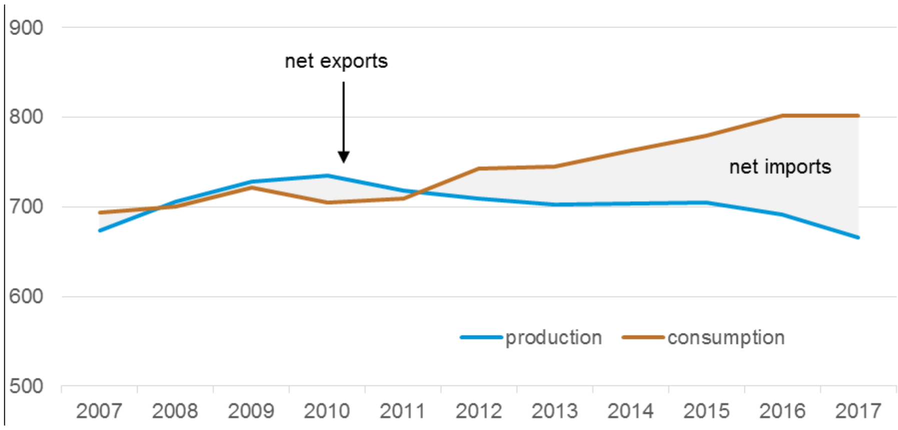


Figure 8: Annual petroleum and other oil liquids production and consumption in Egypt, in thousand barrels per day [7]

2.2.2 Gas

The Gas sector achieved the highest growth in the previous years in Egypt. With the biggest individual order in Siemens history, the German engineering giant transitioned Egypt from undersupply to a sufficient supply with a high amount of backup capacity in the space of a few years. It´s 14,4 GW of capacity was built within the record time of two years by major efforts. The Styrian transformer branch of Siemens in Weiz participated in this mega project and delivered 24 transformers to Egypt. Figure 9 shows one of the new plants.

Figure 9: New installed Combined Cycle plants in Egypt by Siemens

The construction of the 12 combined cycle turbines marks the governmental strategy to meet it´s annually increasing energy demand of about 4% per year with a combination of gas fired and renewable powered plants. The strategy follows several publications of discovered gas fields, especially near the Mediterranean coast. Similar to the oil Sector, Egypt used to be a net gas exporter, but in 2015 Egypt had to import LNG (Liquefied Natural Gas) for the first time. With the biggest gas field ever discovered in the Mediterranean by the Italian company Eni, Egypt wants to regain it´s gas self-sufficiency and furthermore start exporting gas in the beginning of 2019. [9] Figure 10 shows the previous consumption and production curve with its similarities to the oil curve mentioned in chapter 2.2.1.

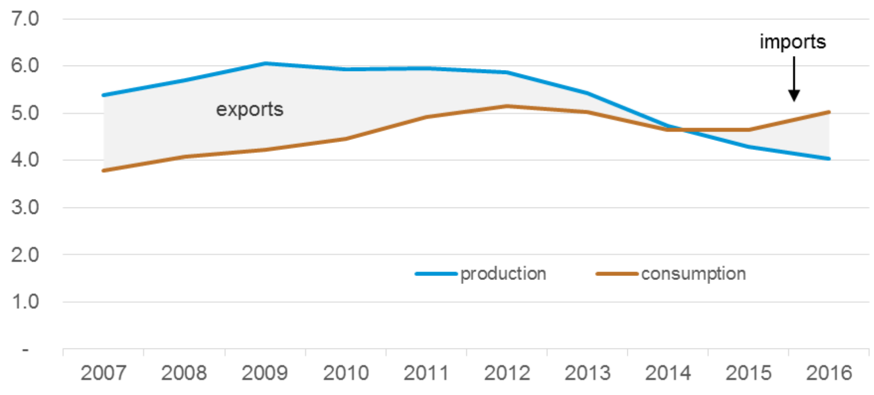


Figure 10: Dry natural gas production and consumption in Egypt in billion cubic feet per day [10]

2.3 RENEWABLE ENERGY

Egypt has great potential in renewable energy (RE), especially in solar and wind. Hydro power on the Nile presents with the Aswan High Dam, and some run-of-river dams, Egypt's third largest energy source after gas and oil. The generation out of hydro power reached with an installed capacity of 2800 MW about 85% of the total potential resources of the Nile. The present RE targets are optimistic with reaching 20% renewable energy installations in the electricity mix until the year 2022.

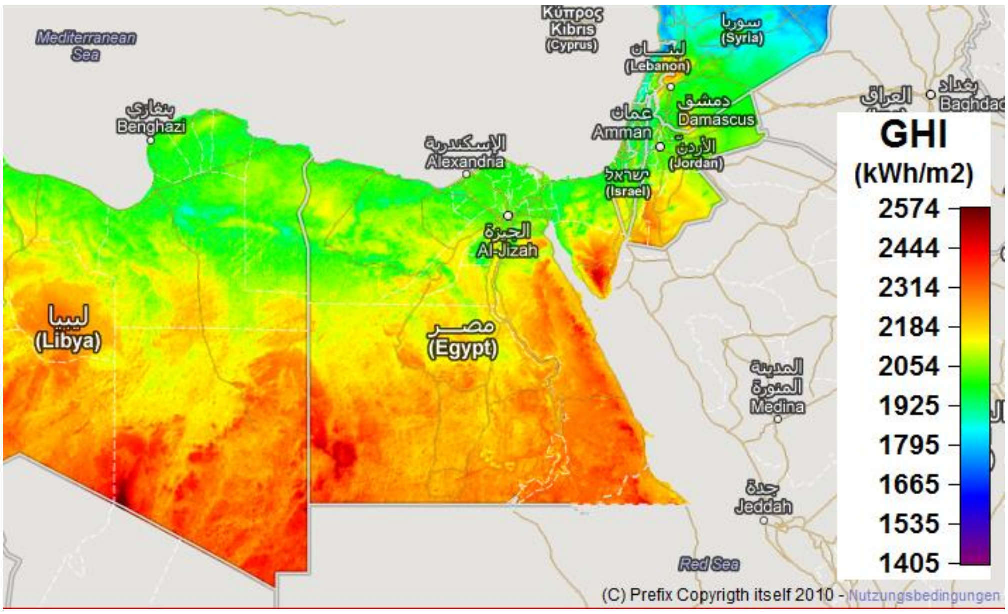


Figure 11: Solaratlas, Global Horizontal Irradiance/Irradiation, www.solar-medatlas.org

Figure 11 shows the immense solar potential of Egypt, which is approximately twice as high as in central Europe. In previous years the photovoltaic sector boomed in Egypt. Especially the ambitious plans, building the world biggest photovoltaic plant, aroused a lot of interest for investors. Following its initiation, a lot of solar companies were founded. Without proper training or education for this technology can generally a leak of quality be identified. Missing quality standards also contribute to the expectation that many installations will fail after some years of operation.

Nevertheless the PV sector is still growing continuously, even with the ending of the feed in tariff (FIT) program for PV. Therefore, plants are getting more competitive with rising electricity costs.

2.4 SUBSIDIES

2.4.1 FEED IN TARIFF PROGRAM

Two cases with main difference in the applying process for the program are present:

1. PV projects below 500kW

A shortened apply process with a certified System Integrator and the regional distribution company is sufficient. Additionally the investor of the project signs a Power Purchase Agreement, PPA, according to the actual feed in tariff, FIT.

2. PV projects greater than 500kW and wind energy projects

The process to apply for FIT is much more complicated and mentioned in Figure 12: How to apply for a FIT with a project greater than 500kWFigure 12. It´s bureaucracy was a major hindering point for many PV projects. On the other hand it was still in the hand of governmental parties to control who is winning the process. However out of all bidders, which were applying for feed in tariff round one, shown in Table 1, only one got the positive generation license.

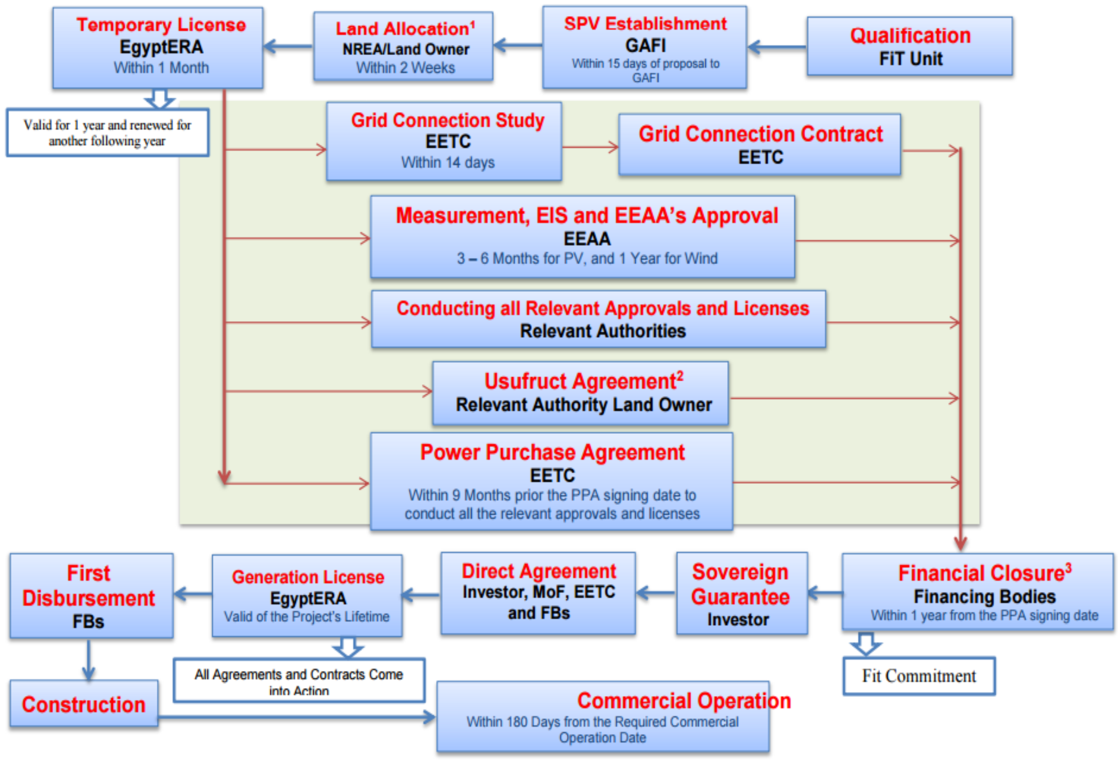


Figure 12: How to apply for a FIT with a project greater than 500kW

With the first round of the feed in tariff, Egypt aroused huge interest of big international investors in autumn 2014. Unfortunately, only one project managed to a positive contract closure.

Table 1: Feed in tariff of round one

PV Power Plant Installed Capacity	Corresponding Feed-in Tariff
Residential	84.4 P.T./kWh
Installed Capacity ≤ 200 kW	90.1 P.T./kWh
200 kW ≤ Installed Capacity < 500 kW	97.3 P.T./kWh
500 kW ≤ Installed Capacity < 20 MW	13.6 $.Cent/kWh
20 MW ≤ Installed Capacity ≤ 50 MW	14.34 $.Cent/kWh

After round one followed round two in September 2016, listed in Table 2. This tariff was in place for more than one year but ended during summer 2018. The biggest change happened at the larger scale plants, more than 100kWp with a heavily lowered tariff.

Table 2: Feed in tariff of round two

PV Power Plant Installed Capacity	Corresponding Feed-in Tariff
Residential	102.8 P.T./kWh
Installed Capacity ≤ 200 kW	108.5 P.T./kWh
200 kW ≤ Installed Capacity < 500 kW	108.5 P.T./kWh
500 kW ≤ Installed Capacity < 20 MW	7.8 $.Cent/kWh
20 MW ≤ Installed Capacity ≤ 50 MW	8.4 $.Cent/kWh

The tariff for wind energy projects diverges from the solar tariffs in the amount and as well in the structure. The tariff depends on the full operating hours, that a good wind site receives less than a weaker wind site. Additionally there are two segments, one segment is fixed for the first five years and another segement counts for the remaining 15 years of the total 20 years contractual period. [6]

According to an announcement of Egyptera the feed in tariff is payed in Egyptian pounds. 70 percent are converted due to the bill issuance exchange rate date, and 30 percent are paid due to fixed course. The regulation was published before the devalution of the Egyptian pound took place, it is assumed that the convertion of exchange rates is revised.

Table 3: Feed in tariff program for wind energy plants

Full Operating Hours (FOH)	Feed-in Tariff for the 1st tariff segment (5-year period) ($.Cent/kWh)	Feed-in Tariff for the 2nd tariff segment (15-year period) ($.Cent/kWh)
2500	11.48	11.48
2600		10.56
2700		9.71
2800		8.93
2900		8.19
3000		7.51
3100	9.57	8.93
3200		8.33
3300		7.76
3400		7.23
3500		6.73
3600		6.26
3700		5.81
3800		5.39
3900		4.98
4000		4.60

2.5 Technical Aspects of Wind Turbines in Egyptian Conditions

By Egyptian law exists a height limit of 120m for any type of construction. This undertaking makes it especially difficult to show feasibility for light wind areas since it doesn't count for the nacelle but for the upper blade tip. The turbine manufacturer "Envion" once introduced on a wind conference in Cairo their idea of the "Egyptian Wind Wind Turbine" which would maximize the production within the given restrictions. With a tower height of 63m and a rotor diameter of 114m they would reach a nominal capacity of 3,4MW. The tight ground clearance of 6m questions their practical sincerity.

Alongside governmental regulations, the climate conditions are lowering the wind energy production. The named producer also mentioned that operation of the turbine is only guaranteed to temperatures up to 45 degrees Celsius. At temperatures exceeding 35 degrees they already admit a successive de-rate of the turbines output and further stop the turbine at 45 degrees Celsius.

Another issue is the Dust and, especially at the coastal areas, a salt crystal loaded air. For the bearings, generators and electronics a lot of research was conducted with the increase of offshore wind power and their corrosion protection. They e.g. deliver over pressure systems for the nacelles with filters and air humidity reducing technologies.

Another issue are yield losses because of dust on the rotor surface. A film of dust can cause an increase of the drag of the airfoil force and diminish the power output of the turbine. Depending on the region it can lead to major energy losses. A research paper in Egypt mentioned that in the region around Zafarana, such environmental conditions are likely to appear. [11]

2.6 ENVIRONMENTAL ASPECTS

When observing the current energy mix of Egypt's energy supply, it seems clear that renewable energy can contribute in a positive manner to the environment and help to reduce CO2 emissions in the country. As shown in Figure 13 Energy contributes about three quarters to Egypt´s GHG emissions. Out of that, more than 40% are caused directly by the generation of electric energy.

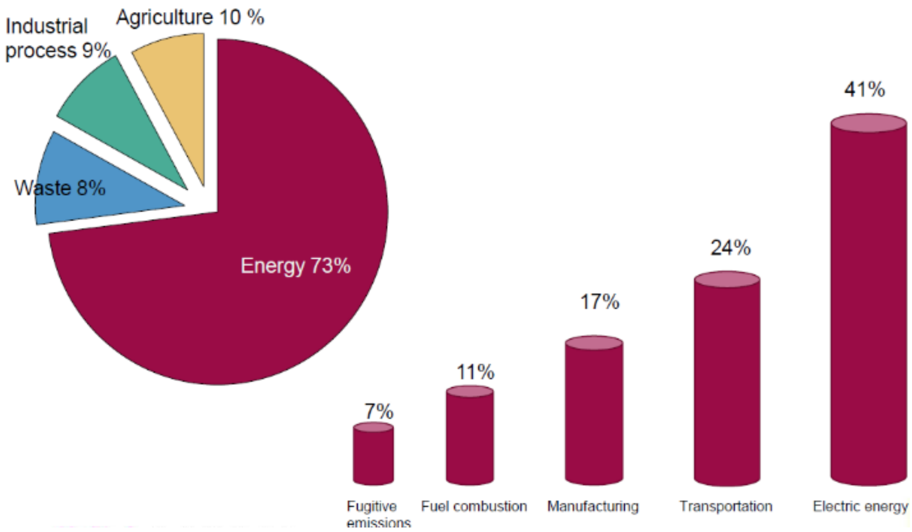


Figure 13: Green House Gas emission profile of Egypt [12]

Especially in the last few years, Egypt presented its obligations for the environmental impact of new energy plants. Therefore, the Egyptian Environmental Affairs Agency (EEAA) is involved in every commission of energy capacities exceeding 500kWp and e.g. applying for a feed in tariff. EEAA has the role to guide such projects from an environmental perspective.

An environmental topic that is gaining significance is bird migration. The birds use the advantage of the strong northerly winds to navigate towards the South and cross Egypt usually at the windiest spots on the coastal regions of the Gulf of Suez, Zafarana. The Regional Center for Renewable Energy and Energy Efficiency (RCREEE) is, together with international consultants, currently integrating bird protective systems. In pipeline is an active turbine shut down management for crossing birds. For both existing turbines and new ones in the coast regions, it would have a significant impact on the energy output of a wind park.

3 WIND RESOURCES

Wind is the movement of air, which is caused by pressure differences due to the sun irradiation and is influenced by a huge variety of earth surface- and atmospheric parameters. Thus wind at a certain site or area is always a product of more than one input effect, depending on the surrounding parameters. Egypt is a region where the different wind systems have to be considered. Due to the position 30-degree north of the equator the atmospheric circulation called "Hadley cell" causes the north-east to north-west Passat trade winds. The north Passat is affecting Egypt's climatology throughout the year, from north to south it is turning from north-west to north-east winds. [13] The changing orography of the land between coasts, deserts, small mountains and cultured landscape has an important influence in accelerating and deflecting these constant trade winds. [14]

The infinite values and input parameters therefore do not allow to predict or detect the current wind speed over an area, rather wind analyses are the product of grid-based models of certain observations, combined with meteorological satellite data.

For an evaluation of an existing wind atlas it is necessary to follow used data sources and chosen models and compare this data with valuate combination of a more precise model.

3.1 AVAILABLE WIND DATA

3.1.1 THE EXISTING WIND ATLAS

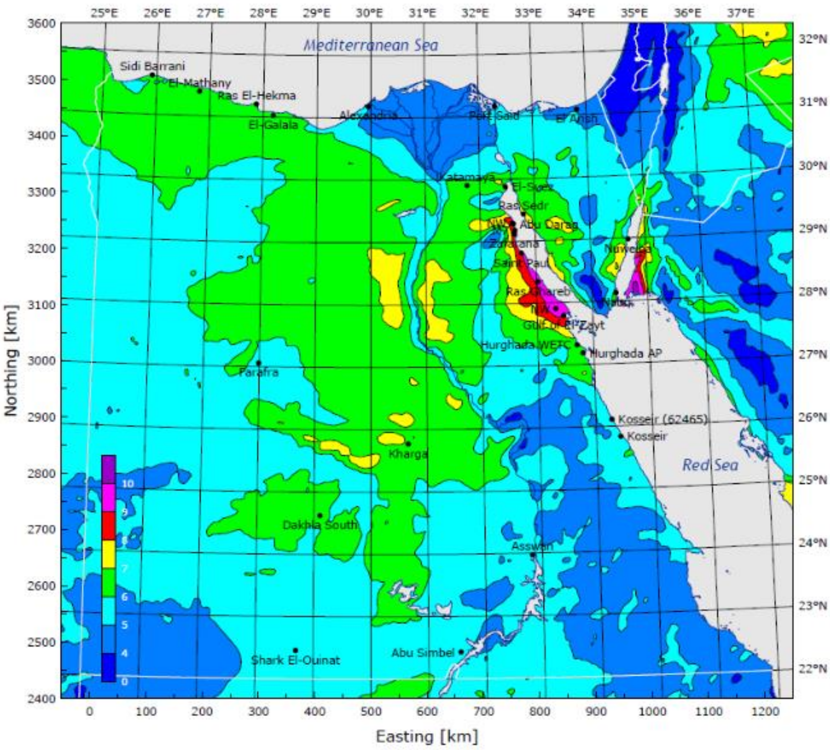


Figure 14: Wind atlas of Egypt, mean wind speed 50m o.g.l. using mesoscale modelling [15]

The Egyptian wind atlas, shown in Figure 14, is based on two input parameters, an observation based model and numerical long-term reanalysis data. The stations for observations were mainly placed on the Mediterranean and red-sea coast and in populated areas. The black dots in Figure 15 show the positions of the meteorological stations used for the wind atlas of Egypt.

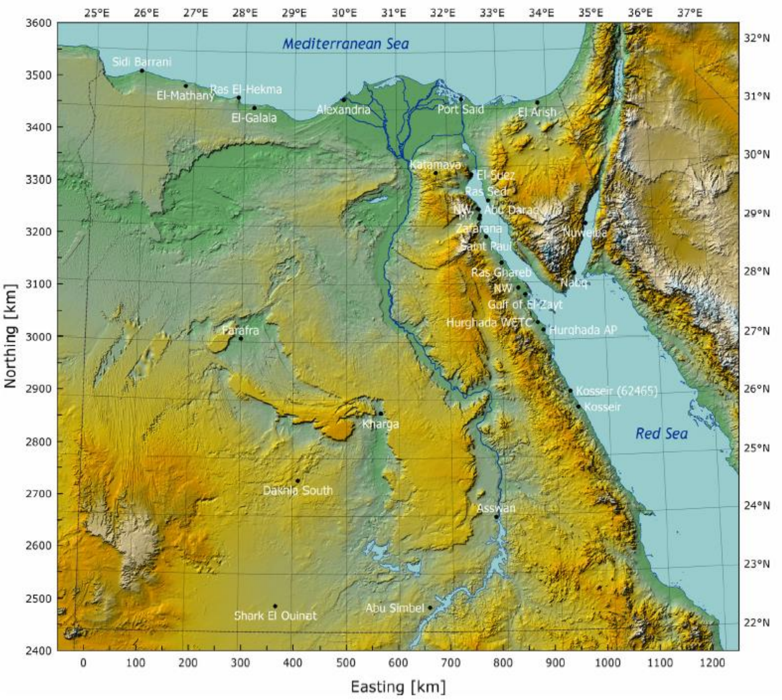


Figure 15: Elevation map of Egypt showing the meteorological stations used for the wind atlas of Egypt [15]

A second approach for the wind atlas modelling was a long-term reanalysis data model by NCEP/NCAR[3] which offered plenty of climate parameters through a numeric atmospheric model scheme. This 3D -grid of atmospheric states was based on radiosondes and weather satellites. The resolution of this data grid varies, depending on the location, between 5 and 7,5 km.

Information about the long-term, large-scale meteorological situation over Egypt was obtained from the NCEP/NCAR reanalysis data-set. Time-series data of wind and temperature profiles for the period 1965 to 1998 were used to create around 100 different large-scale wind situations or wind classes. These wind classes form a representative set of wind conditions for the region and represent different wind speeds, wind directions, atmospheric stability or shear. [15]

[3] Based on observations and numerical weather prediction, the NCEP, National Centers for Environmental Prediction, Reanalysis- and the NCAR, National Center for Athmospheric Research, Reanaylses are continually updated data sets representing the athmospheric climatic state of the Earth.

3.1.2 NASA's Modern-Era Retrospective Analysis for Research and Applications (MERRA)

MERRA is a further development of the before used NCEP. The provided data is (like in earlier Versions) open to use and allow a wide scope of climate observations. [16]

MERRA has some advantages compared to earlier versions. Beside the longer statistical series (1979-2010) with continuous improvement of measure parameters and output quality, a higher resolution (1 x 1 km) are additional benefits. The online tool called "Global wind atlas" allows an illustrative and numerical entering of this data. [17]

Figure 16 shows a graphical output of the available "Global Wind Atlas" for Egypt. The shown wind speeds, (vary in different colours) already show several differences compared to the existing wind atlas. Inspections in chosen sights are also available.

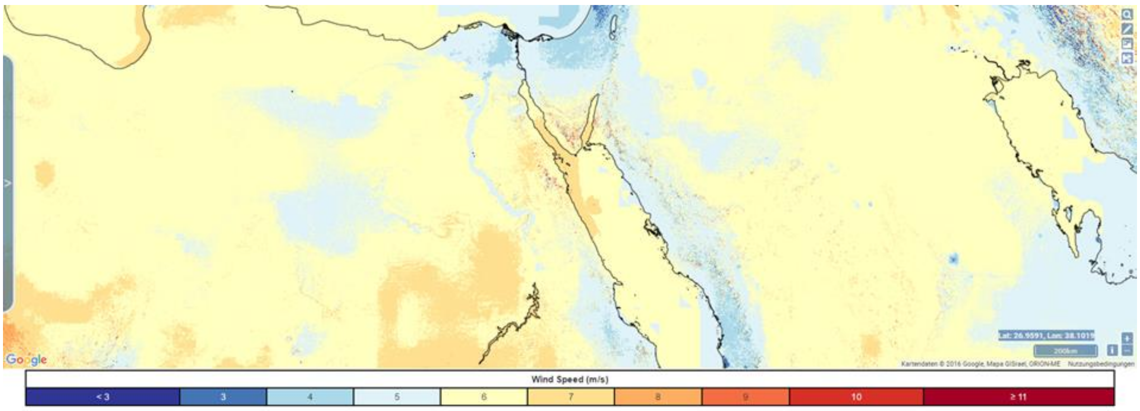
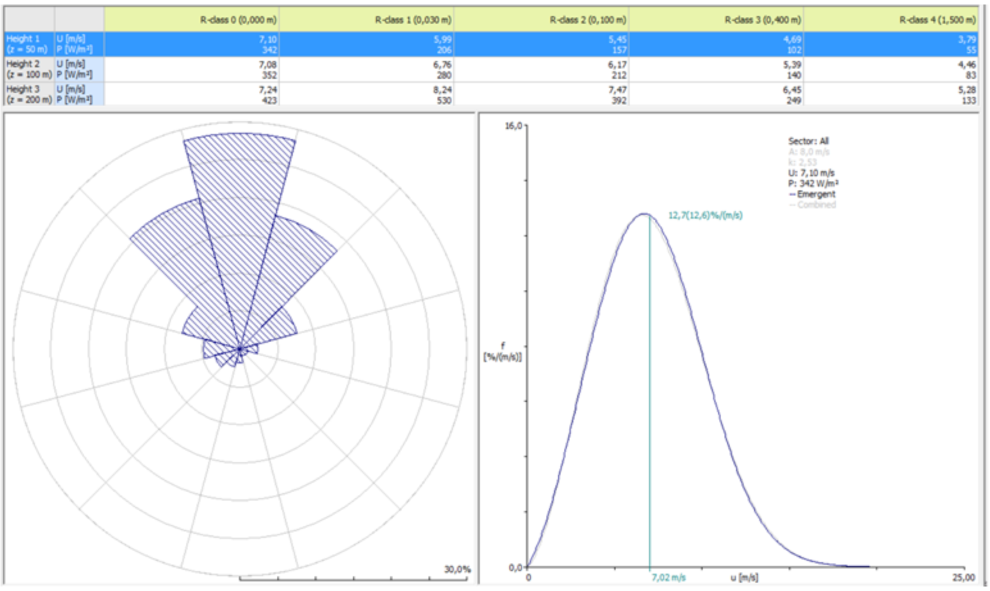


Figure 16: Egyptian mean wind speed MERRA, 50m o.g.l.

An example of data output for a below described feasibility analyses is made for the region Fayoum shown in Figure 17. MERRA allows sector wise analyses of wind direction and speed and already provides Weibull parameters for further calculations.

It is divided in different surface roughness layers and available in three different heights (50m, 100m, 200m o.g.l). For the graphical wind atlas (see Figure 16) are different orographic models used to find the right surface roughness – regarding these models, the most suitable roughness for the area Fayoum would be 0,030m.



		R-class 0 (0,000 m)	R-class 1 (0,030 m)	R-class 2 (0,100 m)	R-class 3 (0,400 m)	R-class 4 (1,500 m)
Height 1 (z = 50 m)	U [m/s] P [W/m²]	7,10 342	5,99 206	5,45 157	4,69 102	3,79 55
Height 2 (z = 100 m)	U [m/s] P [W/m²]	7,08 352	6,76 280	6,17 212	5,39 140	4,46 83
Height 3 (z = 200 m)	U [m/s] P [W/m²]	7,24 423	8,24 530	7,47 392	6,45 249	5,28 133

Figure 17: Mean wind speed and direction in region Fayoum, MERRA data analyses with WAsP

3.2 Wind Measuring

To get clarity what wind conditions are present on a specific site, a wind measurement is absolutely essential and not replaced by any climate observation model by now. The aim is to have a clear picture of what a potential wind turbine can generate out of this present flow of air. Most accurate systems are measuring wind conditions in several heights and are as tall as a future wind turbine (hub height) would be. The time series are analysed for several years to consider seasonal effects. Such systems are costly and come with the risk that something can fail or the site assessment can be negative. In many cases such a measurement of the wind is not possible because of very exposed sites or because of economic and financial reasons. Therefore adaptions in slimmed measuring set ups are possible with additional extrapolation of the data.

The strategy to generate input data for this study was to get an accurate enough result to decide if a wind turbine with hub height from 50 to 70m would be feasible. Any mast bigger then 30m was not feasible nor technically appropriate. To extrapolate the wind conditions in a later stage up to a hub height of 50 m, an anemometer was mounted also in 20m, additional to the one in the top, as seen in Figure 18. In chapter 5.2.2 it is described how this enables to calculate wind speeds higher than the top anemometer.

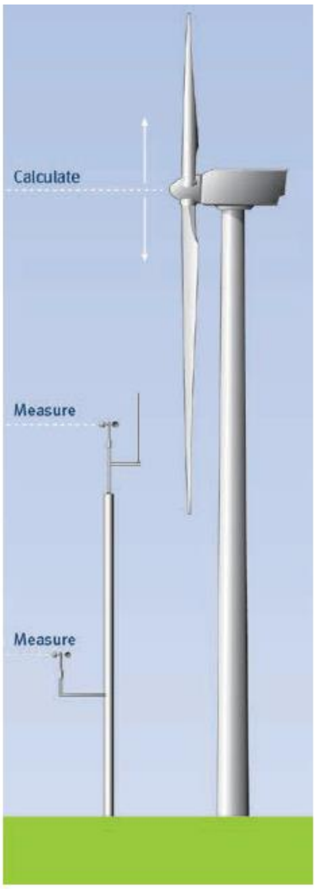


Figure 18: Measuring concept with an extrapolation of conditions in hub heights bigger than the mast. [18]

3.2.1 DEVELOPMENT OF A DATA LOGGER

Measuring wind characteristics e.g. speeds and variances need to be executed in a most accurate way. Measures for wind energy assessments are defined with the Measnet standard. It defines what and how these measures should be done. For this study, the following parameters were measured and seen as minimum required input parameters:

- Wind speed at height 1, 30m o.g.l.
- Wind speed at height 2, 20m o.g.l.
- Wind direction at height 1
- Mean temperature
- Solar irradiation (additionally to the wind characteristics for solar assessments)

A data logger has a key role in any measuring system. Especially when dealing with wind resources, long measuring periods are necessary to cover seasonal variations. Furthermore, a stable operation over this time is crucial for a valuable outcome. Any losses or outages are very expensive in this matter. Harsh weather conditions of the site are a further challenge for such a system.

Measuring systems in Europe are usually enclosed and sealed in a big sized control cabinet. They usually come with high energy demand, based on the fact that a lot of energy is necessarily for sensor heating anyway. A standard system in Austria uses for its supply beside a solar panel (PV) also a small wind turbine and a small fuel cell in case of no wind and snow covered PV cells. The given framework for a measuring system in Upper Egypt is different. A heating system of sensors isn´t necessary, even if low temperature levels (about 5 degrees Celsius) could occur, they don´t last for a long time nor would cause a disturbing or freezing effect on the measurements. Without a heating system, a big energy consumer falls off and the logger efficiency itself is crucial for the energy supply of the system. Instead of taking an energy intense existing logger, a new logger was designed on a micro controller basis.

In a first attempt a standard Arduino micro controller was used for some tests. Soon it was clear that the on-board memory is not sufficient to calculate the 10 minutes mean values, standard derivation, etc. out of 1 Hz samples of each parameter without any bad impact on the measuring. Furthermore the digital and analogue ports were limited at the Arduino. A STM32 is a slightly bigger chip and has all necessaries for such applications. This controller can also be programed very energy efficiently with sleeps between every 1Hz measuring routine. A battery therefore needs to supply the sensors (mostly digital) and the logger. That further leads to the outcome, that the logger and the battery system can be designed in a very small housing, which also has advantages in transportation and import issues.

Out of the input parameters following values are computed and stored every 10 minutes, with 1Hz samples and were transmitted online through a standard GSM module:

- 10 minutes mean wind speed of height 1
- 10 minutes mean wind speed of height 2
- 10 minutes mean wind direction
- Standard derivations for both speed parameters
- 10 minutes Min and Max values

- 10 minutes mean temperature
- 10 minutes mean solar irradiation

The anemometer values came through digital input and needed a conversion regarding to their specification and calibration, and further an averaging of the 10 minutes 1Hz (600) values. Additionally, the min and max value needed to be identified. A mathematical problem appeared with the standard derivation. Only through the use of the algebraic formula for the variance can the parameter be calculated with continual data input.
Another mathematical task appeared with the mean value of the wind direction. The output targeted is a mean value in degrees (0° - 360°) with north direction being 360° and also 0°. Imagine a measured angle of 315° and 45° where the average would be 180° (south), but the searched value would be 0° (north). Finding such a mean value of 600 values each 10 minutes made it necessary to convert the angle into a Cartesian coordinate system, doing vector calculus and convert it back to a polar coordinate system.

Besides the integration of all calculations, the energy supply was a major key component of the system, since it should be working isolated for at least one year. That made it necessary to implement a maximum power point tracker (MPPT) and a charge controller for the lithium polymer batteries. Additionally the PV panels (four times one Watt) were equipped with bypass diodes in between to avoid losses and cell damage in case of part shadow effect caused from mast wires. First tests and performance analyses of the system and its supply were carried out in Graz, Figure 19.

Figure 19: Testing of system supply and measuring data in Graz with electronic specialist Martin Mauernböck

Since the very first running systems, parallel tests in Cairo were put in place, shown in Figure 20 to check the power consumption and furthermore the GSM connection to the server.

Figure 20: Test station of a logger prototype in Cairo.

This thesis aim is not going into details regarding the completing of all electronic components and the coding of the micro controller since this should be content of another survey. The final logger on the mast, shown in Figure 21, was online for 13,5 months and collected the wind data without any losses.

Figure 21: The final data logger on the mast after its installation

3.2.2 LOCAL CONSTRUCTION OF A 30M WIND MAST

The 30m high wind measuring pole is an adopted system which allows measuring wind speed related to international Standard “Measnet”, written in “Evaluation of site specific wind conditions". [19] The mast and all its accessories are made in Egypt, together with local workshops. Materials came from local distributers.

The mast configuration was made due to requirements as shown in Figure 22: The mast set upFigure 22:

- Wind speed sensors (anemometers) in two different heights
    - Height 1 (top): 30m
    - Height 2: 20m
- Wind direction sensor (wind vane) in 30m
- Logger terminal out of reach for animals or people without a ladder
- Solar irradiation mount on logger
- Temperature mount in shadow, under logger

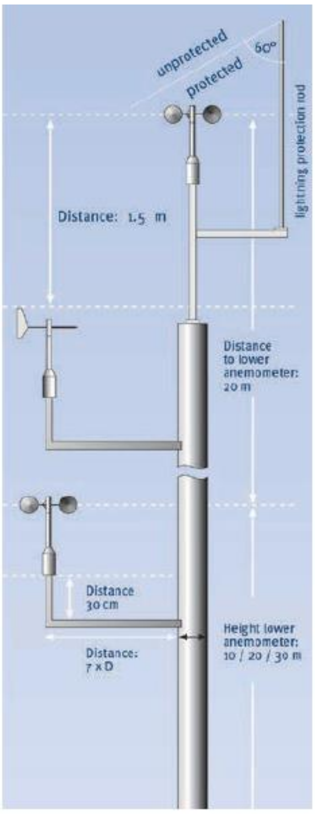


Figure 22: The mast set up [18]

Together with the Verein Energiewerkstatt, seen in Figure 23, a concept of how to manufacture the pole locally was created. The availability of quality goods in the Egyptian market constituted a challenge. Therefore, a local partner, Company Solarshams, was involved from the very beginning.

Figure 23: One of several meetings with Verein Energiewerkstatt. f.l.t.r.: Michael Puttinger BSc, DI Andreas Krenn, Mag. Johann Winkelmeier, Eng. Christoph Tiefgraber

After the technical plans were finalised in Austria the manufacturing phase started in Egypt with the selection of local welding workshops. Every district of Cairo has its specialities of workshops and handcraft, so the focus was near the region Heliopolis in the eastern part of Cairo where most of the industrial welders are based. A local workshop which is specialised on welding pipes, mainly for fluid transportation, was found and assigned to weld adapted flanges on the standard steel pipes. The main work happened outside as shown in Figure 24.

Figure 24: Welding the flanges for the mast, in eastern part of Cairo

A key part of this pole system is the bottom plate which enables the lifting from horizontal to vertical position at one pivot point. With a second pivot point the gin pole is mounted at the plate which is redirecting the lifting force of the grip hoist. The main force is then loaded onto two bolts as seen in Figure 25. In that case, four dowels keep the bottom plate on the concrete fundament and secure it from slipping sideways.

Figure 25: The heavy bottom plate which enables the lift (and lie down) of the mast

Following the construction of the wind mast with the heavy bottom plate, the traverses for the sensors were manufactured. The measures were taken from the Measnet given standard, that e.g. the anemometer needs to be seven mast diameters off the mast to minimize the turbulence and shadow effects on the measuring. Most of this works happened in the small workshop of Mohamed Eissa, shown in Figure 26, where it was very common that black outs appeared during the job.

Figure 26: Work on the sensor mounts and on necessary small parts

Besides the hardware parts of the mast, the anchors of the wirings were developed. The first concept doing a “dead man”, anchoring system with a tree trunk sideways to the pulled direction sideways into the soil had been revised because the owner of the area agreed on concrete fundaments. With the support of DI Manuel Lagger, from the Institute of Rock Mechanics and Tunnelling, the maximum wind loads were calculated and due to the soil profile shown in Figure 27 the enforced concrete anchors were designed.

Figure 27: A soil profile reveals: mainly sand, gravel, limestone and sedimentary rocks

With a plan of the site shown in Figure 28 the site owner, the local company Emisal, was asked to prepare the reinforced concrete fundaments.

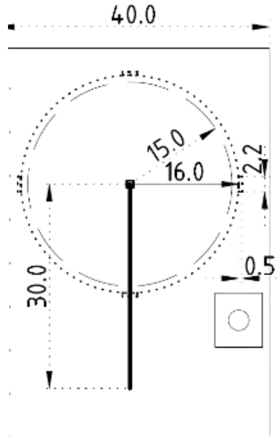


Figure 28: Site plan and positions of concrete anchors.

Having everything ready and transported to the site, the mast was assembled and erected. The 30 meter pole consists of five 6m segments. Following the assembling on ground level, it was erected with a 10m supporting mast which consists of two segments. 1000kg of iron is used for the whole system with 350 bolts and screws holding it together. To keep the mast straight up, 500m of steel cable is used to secure it with 12 side wires in 4 directions. All wires are connected to four concrete anchors. Two measuring levels are mounted with side structures to avoid shadow effects of the mast in the heights 20 and 30 meters. A key element was the calculation of the length of all 12 wires. To avoid having an uncontrollable mast at any occurring situation while erection, they were all connected to the anchors before the start of the lifting process. The lifting was tested once with the mast without sensors. After the successful test, it was lowered again and the traverses were mounted with the sensors and the cabelling through the mast was finalized as shown in Figure 29.

Figure 29: Assembling of the traverses with the sensors

The fully equipped pole is lifted up with a manual grip hoist as shown in Figure 30.

Figure 30: Hoisting the mast with a manual grip hoist

The gin pole was pulled until the main mast was in full upright position, mentioned in Figure 31. Then the wires were moved from the gin pole and fixed at the prepared anchor points, Figure 32. All pre-fixed wires from the mast to the anchors were adjusted until a perpendicular state was reached and finally locked with three screw terminals on each end. The gin pole was laid aground but stayed in place in case of a mast lay down following the measuring period.

The whole lifting process took one day with one day of site and mast preparation.

Figure 31: 30m wind pole during erection phase

Following the installation-phase the sensor cables which were guided through the mast were connected with the data logger. The logger was put three meters above ground level on a prepared plate attached to the mast, so that no animals could disturb the measuring.

Figure 32: The wires from the gin pole were fixed at the anchor, when the mast was fully upright

Local mast managers were introduced to the systems to do regular checks and to clean the PV panel once a month. After three months the mast was checked, including tension of all wires, screw terminals and anchors. The logger was in operation for about 13 months without any losses. Following this period, the local flash memory was analysed. Figure 33 shows the mast in final operation mode.

Figure 33: The final wind mast position in operation

3.2.3 SENSORS

The used sensors at 30m and at 20m height of the measuring system are highly sensitive and durable wind sensors from the company Adolf Thies GmbH & Co. KG which is based in Germany. The two anemometers for the wind speed, shown in Figure 34, are made of a durable three cup aluminium rotor and offer a high accuracy rate of 2%. Especially for cold conditions, like central Europe winters, also a sensor heating would be included. Due to the frost-free conditions in the Fayoum region, the heating system was not connected.

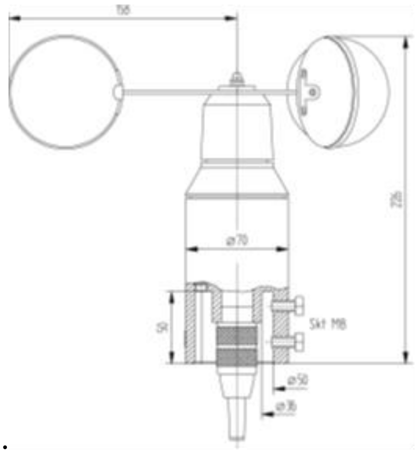


Figure 34: The "Thies classic" anemometer [18]

The wind vane, shown in Figure 35, for the wind direction, is packed in a durable aluminium chassis and offers a maximum accuracy of 2%. This type, "Thies compact" works with an inside potentiometer which varies the electrical resistance depending on the direction from 0 to 2000 Ohm.

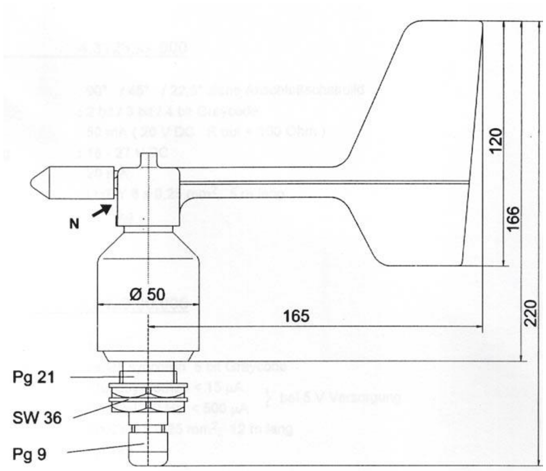


Figure 35: The wind fane „Thies compact" [18]

Beside measuring wind characteristics also a global radiation sensor was mounted near the photovoltaic supply for the logger and an external digital temperature sensor was integrated to log the outside temperature of the site.

4 Site assessment

4.1 The Fayoum Region

The greater Region of Fayoum is also called the breadbasket of the capital Cairo. Pharaons started with the cultivation of this land due to it´s orographic situation and wide flat lands. They dug channels of the Nile to irrigate the area which is slightly smaller than the Austrian federal state Salzburg, shown in Figure 36. The expression “Fayoum oasis” alludes to it being surrounded by deserts but is not correct since it´s water-supply does not come from the ground but directly from the Nile channels. [20]

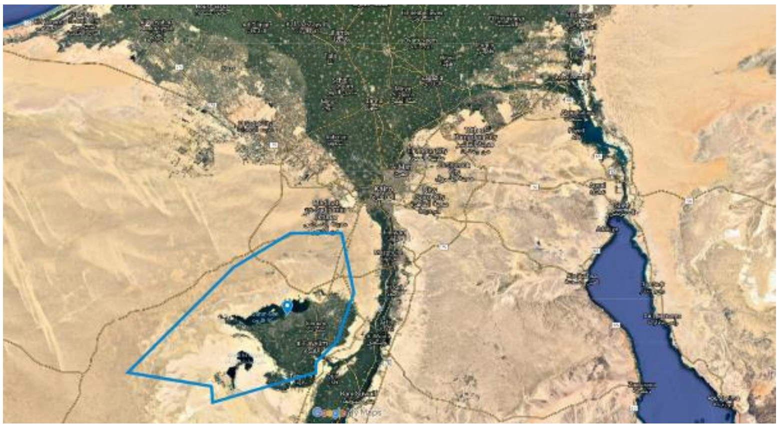


Figure 36: The Fayoum region[4]

The climate is a compromise between the colder north (Lower Egypt) and the hot south (Upper Egypt). Relatively warm winters and mild summers are present, not as hot as in Upper Egypt but warmer than colder Mediterranean region. Due to the fact, that Egypt´s north coast is close to the 30 latitude, all southern areas are effected by the northerly trade winds, which also shows the outcome in chapter 4.3 Measured Wind Resources. The dominant trade winds are not only the architect, but also the cause of the Sahara desert. The air mass heats up during its descend with a constant absolute humidity, what follows in a decrease of the relative humidity. The northerly dry breeze is then drying the soil as the Sahara region. [20] Very rare are the other wind directions, such as the hot southerly

[4] Online google my maps, © 2019 Google, ORION-ME Bilder © 2019 TerraMetrics

Khamsin winds, which always raises sand and dust and causes poor views. They can appear between March and May.

The biggest source of income in the area is agriculture and agriculture related businesses, the cotton crop therefore presents the cash crop and is usually planted in the center of the Fayoum area. Beside cotton also tomatoes, sugarcanes and herbs are very common. On the south west coast of the lake Qarun small potteries with handcrafted porcelain tableware are found beside the gravel roads. The few industries are mainly linked to agriculture and e.g. food-processor companies or are also producing porcelain goods. On the lake the far biggest industry is the Egyptian Mineral and Salt Company, Emisal.

4.2 MEASURING SITE "EMISAL COMPANY"

Based at the south side of the lake Qarun, the "Egyptian Mineral and Salt Company" (Emisal) takes responsibility to desalinate the stressed waters of the lake, which are caused by a high flow of minerals and salt content of the soil combined with an intense conventional agriculture in the Fayoum region and its water evaporation.

Emisal was established to balance the salt content of the lake on sea level. Its products (salt and minerals) are used for the market, for industries and agriculture purposes. It extracts sodium chloride, sodium sulphate, sodium sulphide, magnesium oxid and potassium for both local use and export. [20]

Figure 37: Emisal Anlage Sept. 2018

Figure 37 shows one of several industrial buildings of EMISAL. Since desalination needs a huge amount of energy, Emisal itself has a huge energy balance. It´s thermal energy is mostly provided by gas fired steam boilers. Beside the thermal, also electric loads are high, mainly for pumps and other electric drives.

4.3 MEASURED WIND RESOURCES

Following graphs show sample daily profiles of measured parameters on a windy day during September 2017:

Figure 38 shows a typical graph of the data logger interface. Dark blue coloured are the 10 minutes maximum level of the upper height wind speed. Slightly below, in lighter blue are the other measured wind parameters namely maximum wind speed of height 2 (below), then two lines of the upper and lower mean value and minimum and standard derivation.

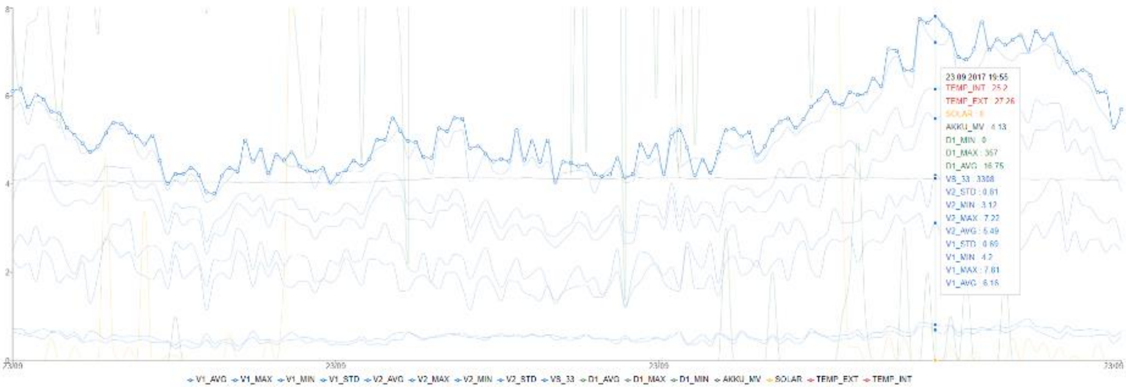


Figure 38: Day profile of maximum wind speeds. 30m o.g.l. measured on September, 23rd,2017

Figure 39 shows the measured wind direction in the logger interface from 0 to 360 degrees. It clearly points out, that the usual wind direction on this day was always close to north (360° or 0°).

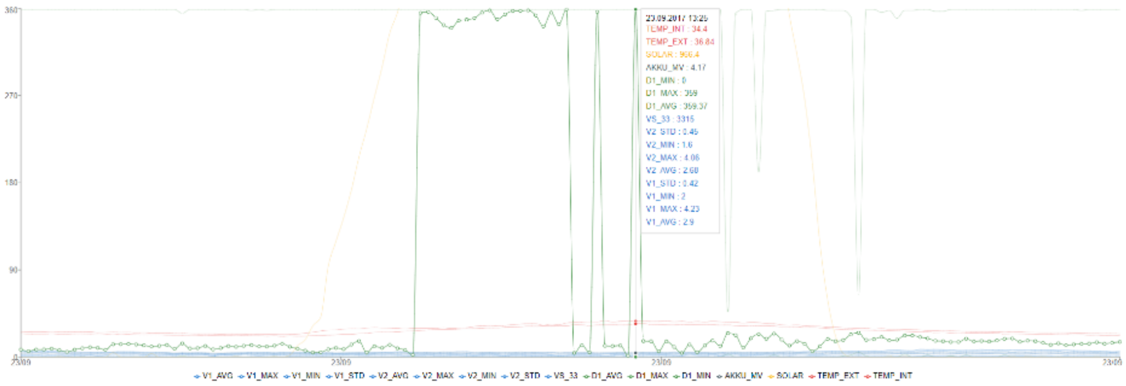


Figure 39: Measured wind direction Figure 30m o.g.l. on September, 23rd,2017

Figure 40 shows the 10 minutes mean sun radiation of September 23rd, 2017. The small buckle at the maximum is caused by the shadow of the mast wiring holding the mast in south direction.

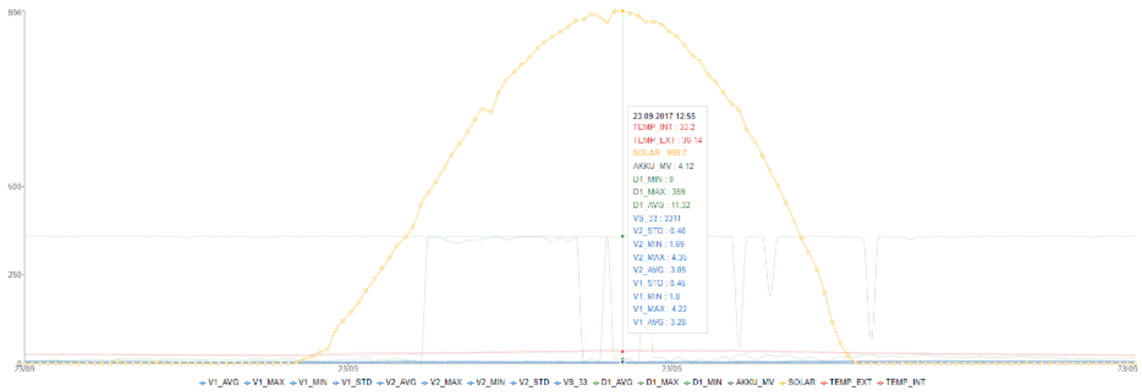


Figure 40: Day profile of solar radiation. Measured in September 2017

Figure 41 shows the measured external temperature. It´s increase at morning with a decrease again is because of some northerly winds bringing fresh cold air from the lake to the southerly shores (as seen in the mean wind values in Figure 38). The light red coloured curve is the internal temperature, measured near the processor, its smooth characteristic is mainly because of the damping of the logger housing.

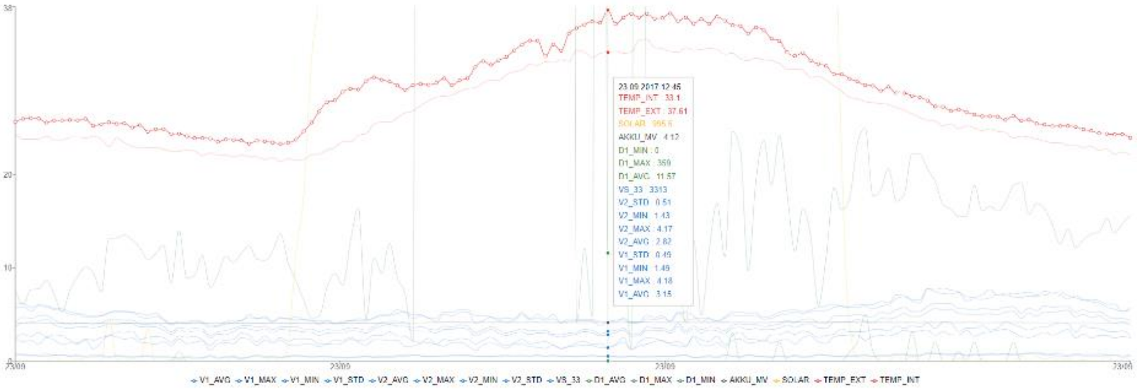


Figure 41: The mean external temperature over a day during September 2017

The Figure 42 is showing a main vital data of the logger which is the supply voltage. It shows that the logger has a voltage level more than 4V, which means that batteries have in this case a very high spare capacity. (Used batteries are lithium polymer type with 3,7V nominal voltage). The slight increase in the morning shows the loading process, which after reaching a voltage level of 4,2V stops it´s process. Usually a maximum of two charging processes per day were necessary to keep the logger on full power. The aim when developing this supply was to minimize charging procedures to maximize battery lifetime.

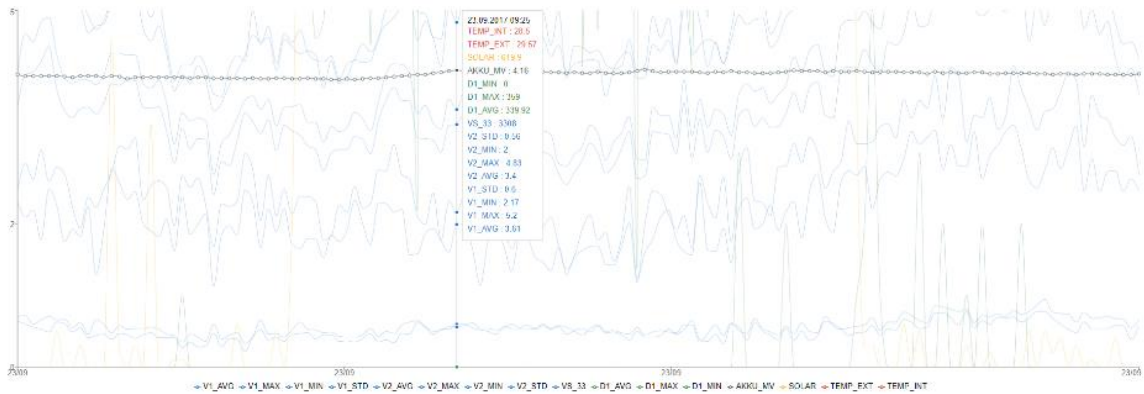


Figure 42: Supply voltage of data logger

After 13 months of data collection the logger data was taken and loaded into a database. The constant ten minutes interval of data flow logged nearly sixty thousand data rows during the measuring period. Following several data analyses and calculations, assessment figures and values were calculated.

Figure 43 shows the mean windspeed during the measuring period. For a later energy output calculation the speed values of height one and height two is extrapolated to 50m o.g.l., since that would also be a potential height for a suitable wind turbine hub. The extrapolation is possible with the orographic roughness factor calculated out of the difference of the two measuring heights and further described in the chapter 5.2.2.. However, it´s maximum mean windspeeds about 3,5m/s occur in September and slightly below in the late spring/early summer months of May and June. It´s minimum is February, since also the sun (as driver for thermal winds) reduce its intensity in that time and is moving towards the southern turning circle.

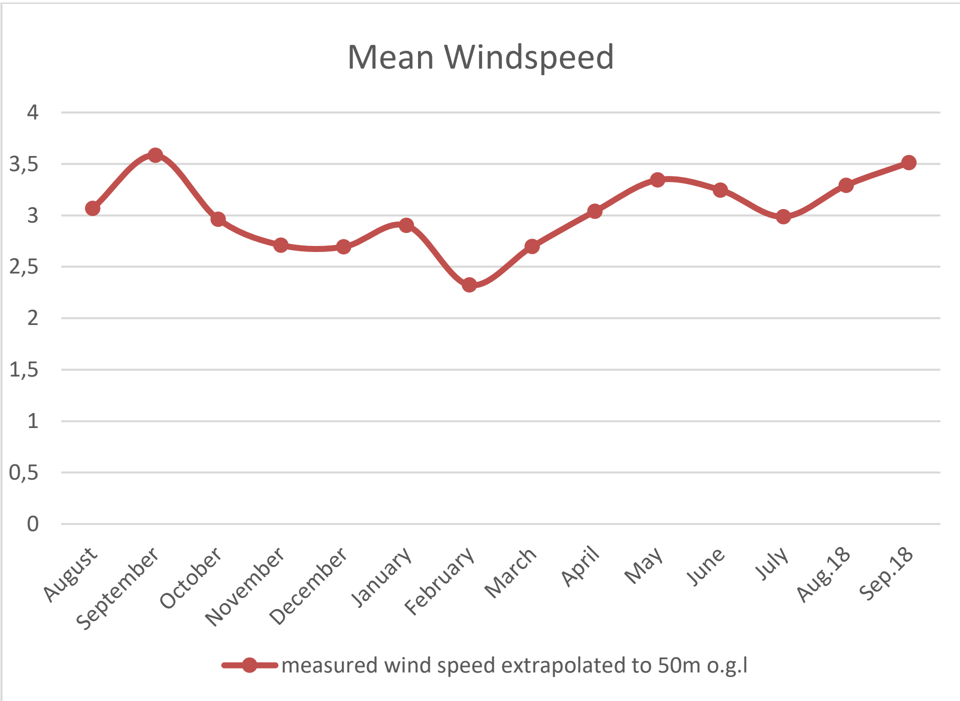


Figure 43: Monthly mean values at project site. extrapolated to 50m o.g.l.

As mentioned in the chapter 3.1 Available Wind Data, the expected main wind direction is north. The measured wind rose in Figure 44 shows that this also is clearly the case at the measuring site. It´s typical that under the 30th latitude are northerly winds dominant, the rare, mostly during spring, happening Khamsin weather comes from south-east direction and is also shown in the wind rose, with a low percentage of time being there.

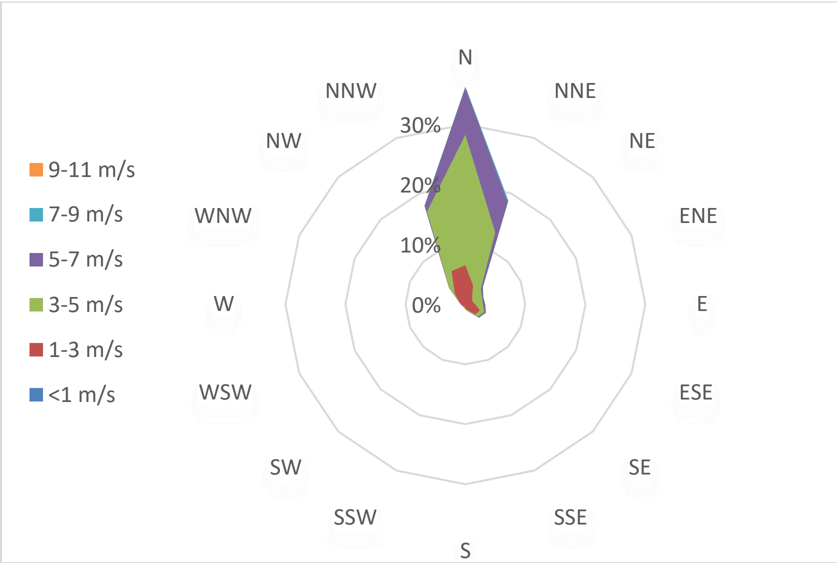


Figure 44: Wind rose of measuring period

For the most accurate calculation of a potential energy output, which is generated by a wind turbine, it´s necessary to calculate a histogram, showing the percentage of time over the different wind speeds, as shown in Figure 45.

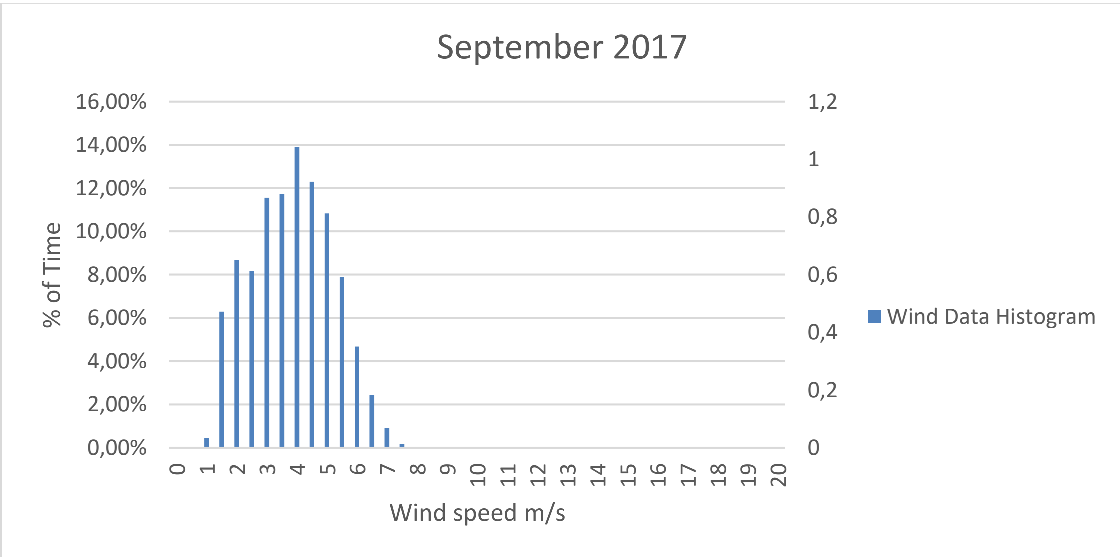


Figure 45: Generated wind speed histogram of the month September

4.3.1 MEASURED OUTCOMES WITH WINDPRO

Beside doing the calculations and data processing with own calculations, several tools and software programs exist. A very common software is the Danish tool WindPro, which is modular and covers all belongings of project design and planning. With the Verein

Energiewerkstatt the tool was used to have also a deeper look into long term data analyses. Therefore, measured data and characteristics was fed into the tool and several figures had been generated and compared to the own calculation.

Figure 46 shows the daily profile of the mean values. In red are the values of 30m measure height and in green are values of ther lower 20 meters. It clearly shows that the most wind (over a one-year period) appears during the evening between 6 and 7 pm. With that measured, it also confirms the expectation what a local fisherman of lake Qarun was telling in a personal interview before the installation of the mast.

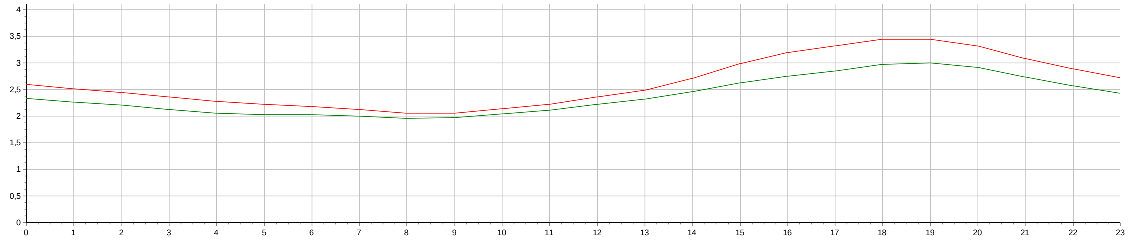


Figure 46: Mean wind speeds, daily profile, one year, red: 30m, green: 20m

The turbulence intensity, shown in Figure 47, usually gives output about the continuasly measures of the site. It demonstrates, that the higher mounted sensor in 30m (red line) shows less turbulences than the greener lower sensor. It also shows that the sun caused thermal winds during the day are less turbulence intense than the winds during night. This is a sign that the sun thermal effects during day have an smothing affect to the wind speed. At noon and afternoon, when the land and soil is heated up by the sun, less turbulences appear. It stays low until sunset when the land again cools down and wind gets gusty.

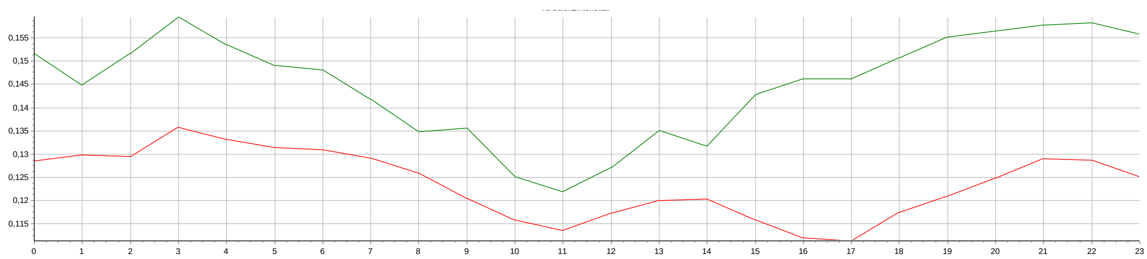


Figure 47: Daily turbulence intensity, red: 30m, green: 20m

A major parameter to understand the wind at a site is given by the mean direction, shown in Figure 48. It also points out that the present northerly trade wind is affected thermally by the sun. During night it is close to perfect north and without direction change. In the morning after sunrise it starts turning towards east direction, where higher desert regions are heated up by the rising sun and vacuuming the air until noon, when the absorbed sun heat is again decreasing and the deflection of the wind is decreasing again.

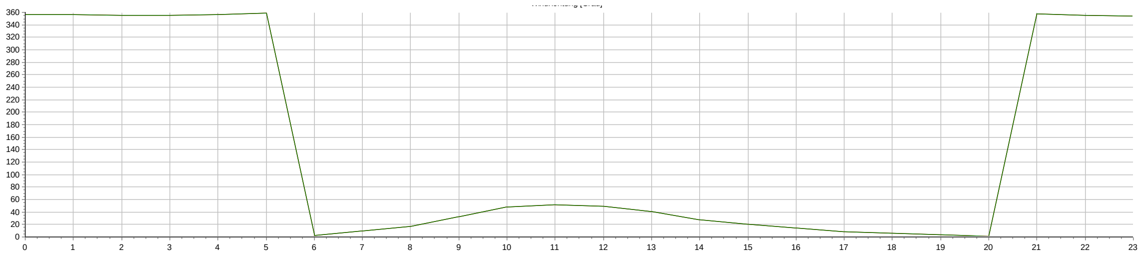


Figure 48:Mean daily wind direction in 30m

4.3.2 MEMORABLE ENVIRONMENTAL EVENTS

Table 4 shows some memorable events which are characteristic for the desert region. The top temperatures can exceed 50° Celsius as it appeared end of May during noon with a light Khamsin wind coming from southeast. This was supplemented by the mean temperature of 5,5° Celsius what appeared on the 20.th of January 2018 at 4am. The maximum wind speed occurred during end of March with an easterly direction during evening.

Table 4: Memorable environmental events

Maximum Windspeed 30m o.g.l.	12,85 m /s
Maximum Temperature	53,11°C
Minimum Temperature	5,5 °C

4.3.3 CHALLENGES ON ENVIRONMENTAL MEASURING IN EGYPT

Egypt’s Wind Energy sector is developing with up and downs but continuously growing. The ambitious targets (20% Renewable Energy capacity in 2022) are in place and at least show the governmental willingness to bring the sector forward. The main region where the top speeds are expected are on the Red Sea coast at the Gulf of Suez/ Zafarana. That’s also the area where most projects (large scale grid connected) are implemented. Like in nearly every wind project are also feasibility analyses with measurements necessary.

But following the strict import regulations, it is especially for high tech measuring instruments challenging to bring it to Egypt. It´s known, that also Egyptian companies failed importing a Data Logger, because of customs decision. It´s obvious that also the military has influence on the imported goods. A lot of standard data loggers use radio frequencies which are forbidden to use in Egypt and also the transmission of GPS data is forbidden. Importing a logger with such abilities (even if it´s deactivated) can fail and could furthermore follow to a declaration as a military-dangerous good. To reimport such Logger back to Europe with these declaration to Austria again can then cause even more troubles. An alternative possibility could be loggers which use only local storage and GSM connection. The mobile connection is in most region of Egypt well covered and usually very stable.

The environmental framework in Egypt for any outdoor operated system is harsh. Temperatures during summer can exceed 50 degrees but can drop in winter to zero. The temperature differences between day and night are usually very steep including a UV radiation much higher than in Europe. In combination with the present dust and salt loaded air can this furthermore cause a corrosive mix which can damage metal screws, pipes, plastic surfaces, solarpannels, or block any moving parts like bearings etc.

Due to an exposed position of the logger a local regular maintenance would require a technician with tools. The logger system itself is dust and waterproof anyway, but the energy supply like Solarpannels is exposed to the environment. Figure 49 shows what a data logger can look like after one year of operation. Using a back up capacity of three times of it measured demand, this logger was still in full operation. But in any case a sufficient back up power supply for any logger system in this region is hardly recommended.

Figure 49: Data logger after a one-year measuring period. (at this time still in full operation)

4.3.4 POTENTIAL IMPROVEMENTS FOR FURTHER WIND ASSESSMENTS

A site assessment always comes with uncertainties. Every sensor comes with a limited accuracy and the system itself can only be as accurate as its components. For this survey the sensors “Thies classic” were used, which are known for a high durability and good accuracy over long periods with ± 0,3 m/s or ± 2 % of measured value. To reach higher accuracies at the sensors also other anemometers, such as “Thies First Class” could be used which reach accuracies of ± 0,2 m/s or ± 1 %.

To calculate the energy content in the wind the air pressure and humidity is necessary. In this case it was taken from the calculated yearly mean value of the site and furthermore seen as constant due to the desert climate with less variations than in Europe. Including both of the sensors (Barometer and humidity sensor) would follow in an increases precision of calculated potential energy yield.

Beside the components itself a wind site assessment is most valuable if the wind speed is measured at the hub height of a potential turbine or above. If it´s below the hub height it is extrapolated later on, as described in chapter 5.2, The amount of energy in the wind.

In the international standard IEC 61400 – 12 – 1, Wind energy generation systems – Part 12-1: “Power performance measurements of electricity producing turbines“, the whole process is described, how a standardized wind assessment should look like. From the measuring systems through the analyses to the extensive outcome. A part of this standard also targets the calibration of the sensors, what was in this survey not conducted with an external institution. Furthermore it is based on own test ranges and analyses with function and frequency generators. The system itself was designed with the Measnet standard that is public available and also known as short summary of the IEC 61400 – 12 – 1.

What aroused as a major topic in the long time measuring periods is the stable operation of the logging system without any data losses. Figure 50 shows the gapless data read of the last version of the logging system from the measuring period start at August 01st 2017 until September 13th 2018. In each day of the measuring period, 6 values per hour times 24 hours were stored.

WM-Daten_MichaelP.30,00m -	%	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
08.2017	100,0	89	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144
09.2017	100,0	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	
10.2017	100,0	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144
11.2017	100,0	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	
12.2017	100,0	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144
01.2018	100,0	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144
02.2018	100,0	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144			
03.2018	100,0	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144
04.2018	100,0	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	
05.2018	100,0	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144
06.2018	100,0	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	
07.2018	100,0	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144
08.2018	100,0	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144	144
09.2018	100,0	144	144	144	144	144	144	144	144	144	144	144	144	144	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
All	100,0																															

Figure 50: Complete data collection of the logging system showing 144 data rows per day

5 Economic and financial analyses

5.1 Costs of wind energy

The costs of wind energy are dependent on several parts. Figure 51 gives an overview what have to be consider to calculate the costs for each energy unit out of the wind.

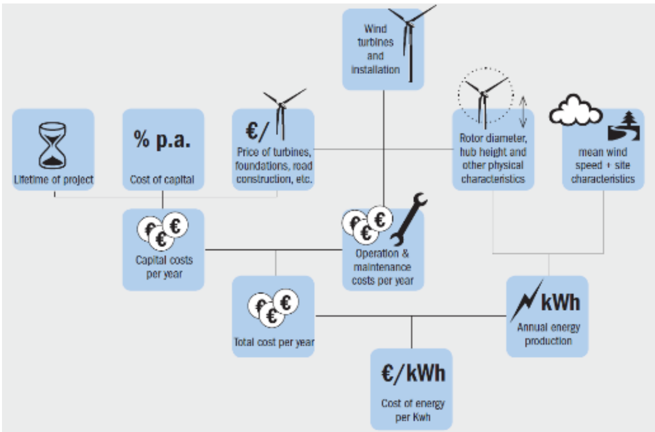


Figure 51: Costs of Wind energy [21]

One major cost input parameter is related to the turbine itself, its installation, the operation and maintenance and the cost of the financing, as shown in Figure 51. The second input parameter is more related to the technical and climate site characteristics, as wind speed. Both input parameters are dependent on the size and physical characteristics of the used turbine.

5.2 The amount of energy in the wind

Before installing a wind turbine in an area, a site assessment is necessary and usually done with a wind measurement in a certain height. Such a measurement logs wind speeds in one or several heights and logs other characteristic parameters like wind direction, temperature and solar irradiation. Figure 31 shows the pilot measurement pole that was used for the data collection in this paper.

Mean values of 10 minutes have shown a sufficient accuracy and are defined by the Measnet Standard as described. So far, data rows of 13 months were collected. Calculated monthly mean values are shown in Figure 43. Such monthly values are often available through retrospective analyses and weather data but always diverge from measured data. Therefore a previous chapter was about the topic of site data input such as MERRA (Modern Era Retrospective –analyses for Research and Application) or the available country specific Wind Atlas data. No matter where the data is coming from, to calculate an energy output, the turbine characteristics must be known.

5.2.1 THE CHOICE OF A SUITABLE WINDTURBINE

Since ancient times utilizing wind energy was part of human being. Not only for transportation of goods and trade with sailing boats like it also happened in ancient Egypt along the Nile. Furthermore it was utilized to convert the flow of air into a mechanical rotation like a windmill does. Systems like mechanical wind water pumps, on which cross- American settlement is based, are still present. Generating electricity from the wind resources was just a logical consequence, but especially with modern materials and processing developments there is still a lot of development happening. The trend of previous years development was mainly in the size of the blades and further the increase of the nominal power. Shown in Figure 52 the capacity, by now, increased more than ten times compared to available wind turbines 20 years ago. Beside developing the turbine itself also the capability utilizing harsh areas like offshore sites received a huge increase.

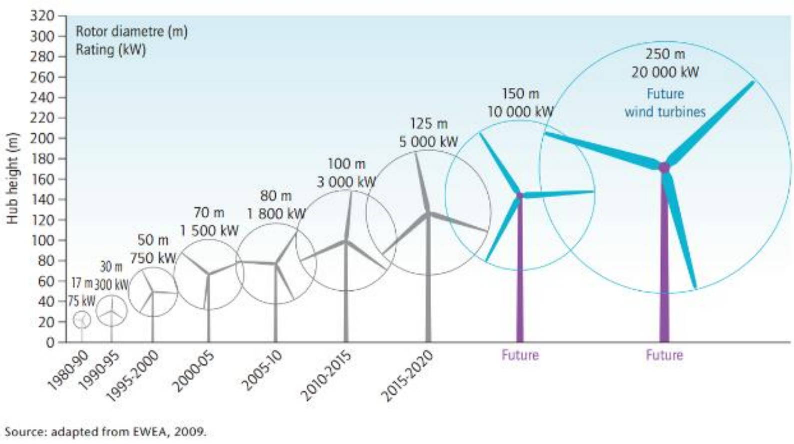


Figure 52: The evolution of wind turbines since 1980.

Wind turbines for electricity generation are now available in all different sizes and types for varying purposes. For power production a three-blade horizontal rotor imposed for most cases. Its advantage is a good proportion of tip speed ratio (is related to the rotor and wind speed) to the power coefficient (describes the ratio of harvested mechanical power to the energy of the airflow) as shown in Figure 53. [22]

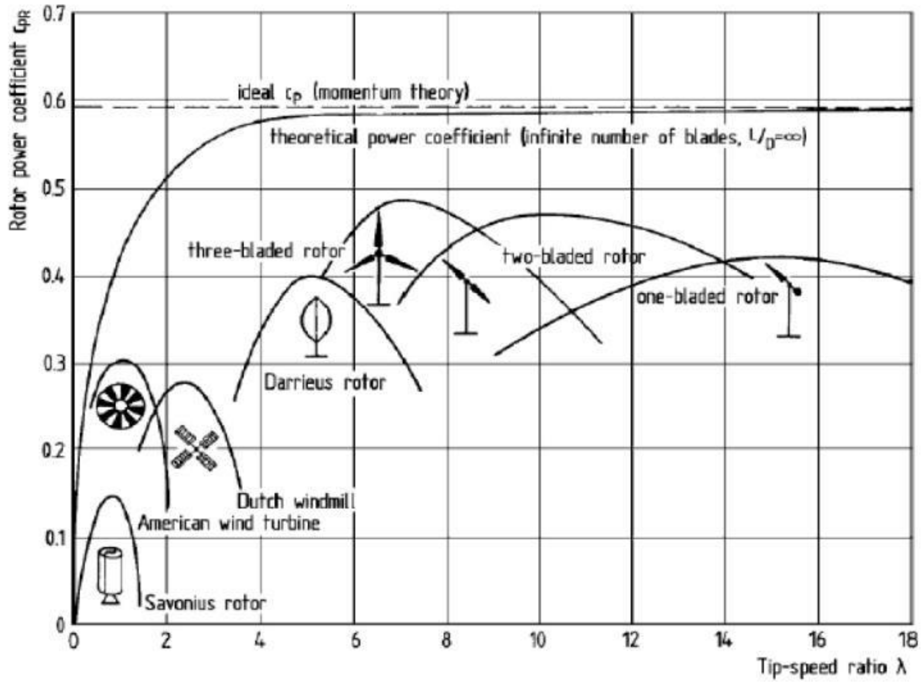


Figure 53: Power coefficient to speed ratio of different rotor types [22]

In the question of finding a potential wind turbine for this site several issues were considered. Beside the technical framework which is a height limit to 120 meters also issues of transportation and erection appeared In personal interviews with local constructors came out that the bottleneck in the turbine size is this height limit by law and not the lack of a crane or a big truck. On the other hand the amount of investment was a very sensitive part and important to consider. As mentioned in previous chapters all imports became very expensive since the devaluation happened. The state of the currency is still challenging for foreign investors to provide financing. To reduce investment costs, more affordable systems are needed that also domestic investors would be more able to penetrate the market.

In Europe, most of the running turbines under a FIT scheme are reaching the end of their funding period after 12 to 14 years. After this funding period, the price of produced energy is not fixed and a positive return for an investor no longer guaranteed. Following it happens that the owner then decides to repower the turbine, deconstruct it and replace it with a bigger new turbine, where fixed tariffs are again guaranteed for an increased energy yield.

The used wind turbines are then sold for different market regions, where high long term investments are not desirable at a small fraction of the initial price. Refurbishing such turbines and e.g. installing them in eastern Europe is already common practice. Therefore several online platforms are offering a huge variety of different types.

To find a potential refurbished turbine on such platform following characteristics had to be fulfilled:

- Height limit 120m (wing tip)
- Easy maintenance, -no gearbox
- Good availability of turbine
- Availability of maintenance parts
- Failure proof on weak electricity grids and small voltage fluctuations
- Heat- and dust secure

The type Enercon E-40-6.44 with a 50m hub height seemed to be the most suitable one. Its high availability and the gearless synchronous generator have advantages from a maintenance point of view. The grid guided inverter is less likely to fail with present grid fluctuations.

A refurbished wind turbine from this type would be a potential suitable option for this site and therefore was chosen for the following feasibility analyses.

5.2.2 EXTRAPOLATING MEASURED WIND SPEED TO HUB HEIGHT

The extrapolation to 50m height is calculated with the Hellmann exponent α [22]

$$\alpha = \frac{\ln \frac{v_{Z1}}{v_{Z2}}}{\ln \frac{z_1}{z_2}} \qquad 5.1$$

v_{Z1} …windspeed at height 1 (upper anemometer)

v_{Z2} …windspeeed at height 2 (lower anemometer)

z_1 …height 1

z_2 …height 2

And the Hellmann equation [22]

$$v_H = v_{Href} \cdot \left(\frac{H}{H_{ref}}\right)^{\alpha} \quad 5.2$$

v_H …windspeed at height of turbine nacel

v_{Href} …windspeed at reference height

H …height of turbine hub

H_{ref} …reference height

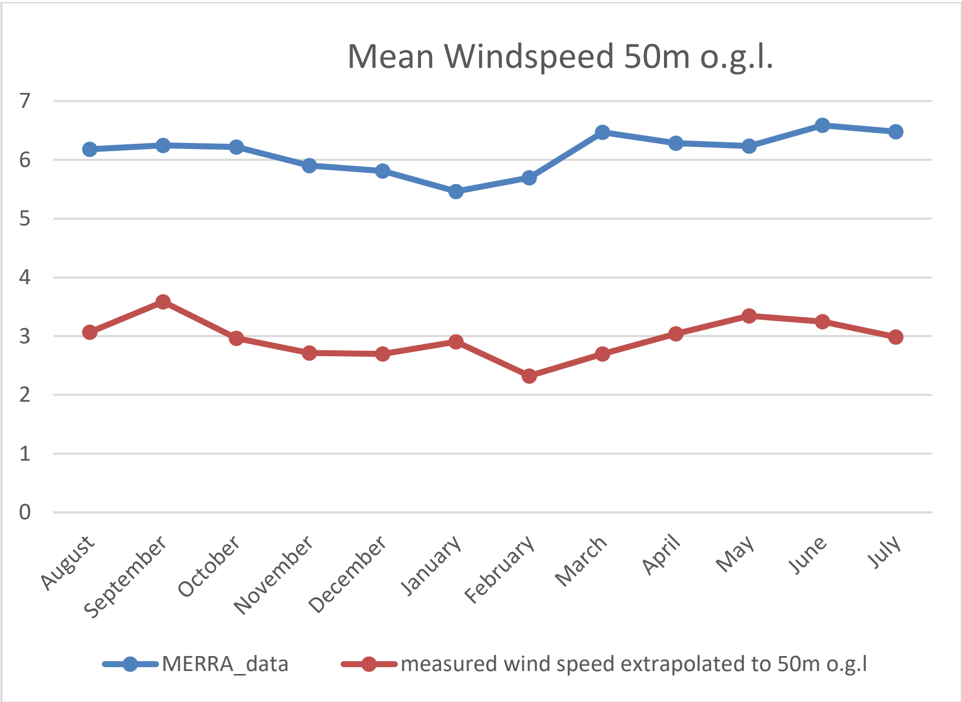


Figure 54: Monthly mean values at project site. -Measured- vs. retrospective data

The figure below shows how the measured wind diverges from the given dataset. The test area for this research was chosen, because of the poor available data. The most accurate available data (blue line) looked very promising in points of mean wind speeds. The reality is far below the expectations as shown in Figure 54. Since it is a scientific approach without commercial purposes, this data was used for further calculations even with low expectations a feasible wind power potential at this specific site.

5.2.3 CALCULATION OF THE ENERGY OUTPUT

To calculate the energy output of a turbine its necessary to sum up the hours with certain wind speeds and generate a histogram, where the wind speed is at the x axes and the number of hours in the y axes like shown in Figure 55. The data of the month September is chosen for demo purpose of this thesis. It showed the most promising wind speed. A full year analyses has to be prepared before a valuable economic analyses anyway. The shape of the produced histogram can be analyzed with the so-called Weibull distribution. This factor allows a comparison between several wind sites (monthly datasets, different sites) and typically comes with few shapes and scale factors, which enables a mathematical description of the measured curve and an easy handling for further calculations. [23]

The Weibull function is defined as following:

$$f(V) = \frac{k}{A} \cdot \left(\frac{V}{A}\right)^{k-1} \cdot e^{-\left(\frac{V}{A}\right)^k} \qquad 5.3$$

k … Shape parameter of the Weibull function, which defines the curve most suitable to the measured wind distribution

A … Scale parameter of the Weibull function

V … Wind speed

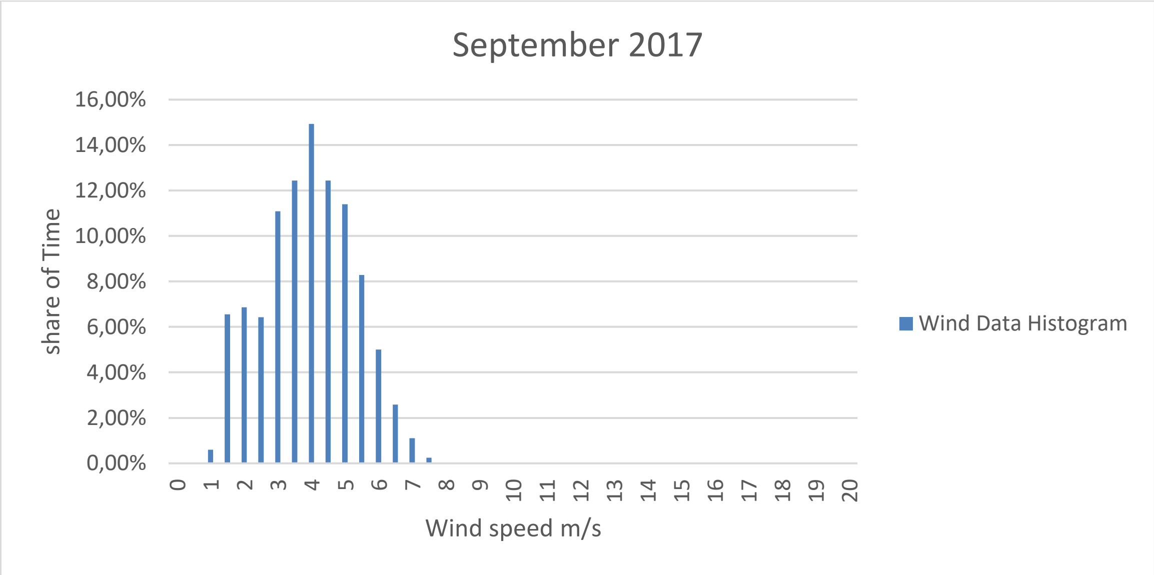


Figure 55: Wind data histogram for one test month

To match a Weibull function to the given wind data histogram the scale parameter "A" has to be calculated out of following equation:

$$v_w = A \cdot \Gamma\left(1 + \frac{1}{k}\right) \qquad 5.4$$

v_w … mean windspeed

Γ … Gamma function

To get the Weibull distribution for a dataset it is the best way to start with a fixed shape parameter of k = 2 and calculate the shape factor A with k fixed and the mean value from the raw data. Figure 56 shows a Weibull function with the calculated shape factor A out of the Gamma function and k = 2. It clearly shows that it does not match the original input function (blue colour).

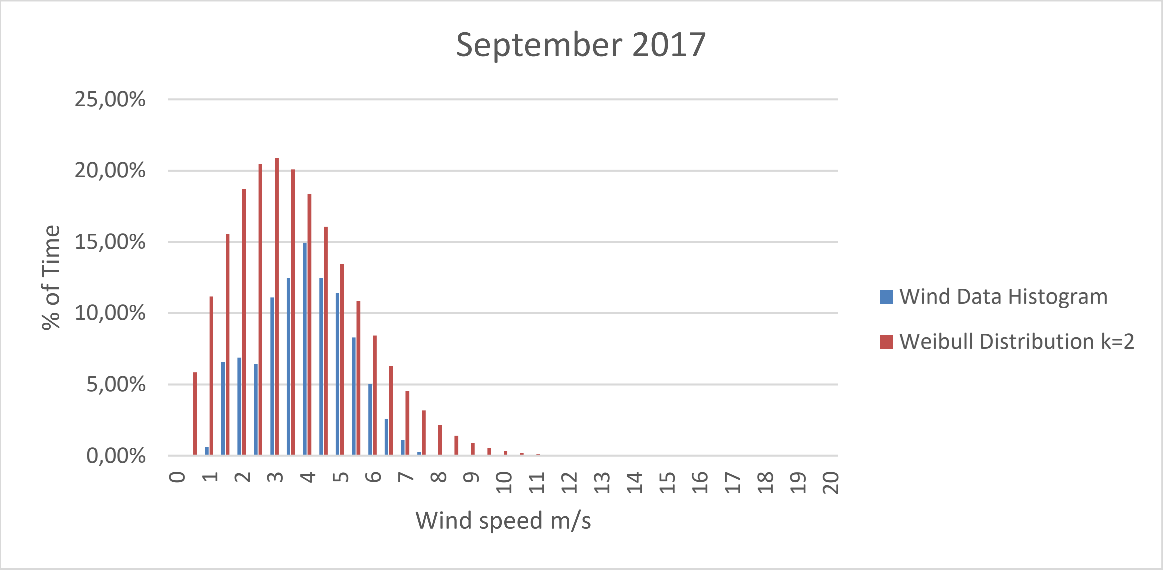


Figure 56: Wind data with Weibull distribution k=2

Once the Weibull function is generated it has to be matched with the given function. One possibility to do so is to compare the calculated wind power density of the original data set with a calculated wind power density from a produced Weibull function.

The power density, in some sources called specific energy flux E_{spec} is defined by the following equation:

$$E_{spec} = \frac{1}{2}\rho \, . \, v_w{}^3 \quad \frac{W}{m^2} \tag{5.5}$$

ρ … air density

The variable, what needs to be changed until the same power density is reached, is the shape factor k. Using a solver e.g. in the program MS Excel saves your time to find the most accurate curve. In this case our optimised k was found at 3.01226 as shown in Figure 57.

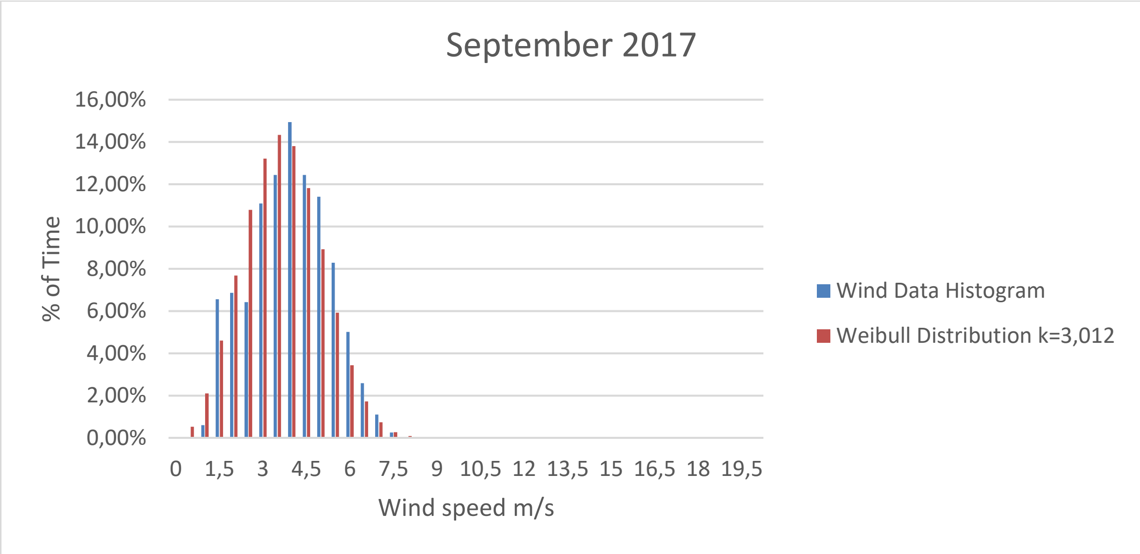


Figure 57: Matched Weibull distribution to wind data with k=3,012

The matched Weibull distribution allows, to describe with a few numbers thousands datasets of the month September in a very accurate way. Furthermore it makes it easy, to calculate the electrical power output of a turbine with the following equation:

$$P_{el} = \int_{v\_min}^{v\_max} \frac{1}{2}\, \rho \cdot S_{rotor} \cdot c_p(V) \cdot V^3 \cdot f(V) dV \qquad 5.6$$

S_{rotor} … circular area of the rotor

$c_p(V)$ … power coefficient of a specific wind turbine

The mentioned cp value is given by a turbine manufacturer.[5] An example for this calculation was the wind turbine Enercon E40/6.44 used as mentioned in chapter 5.2.1. It´s energy production characteristics are seen in Figure 58.

[5] Source: Internet: https://www.wind-turbine-models.com/turbines/68-enercon-e-40-6.44#marketplace

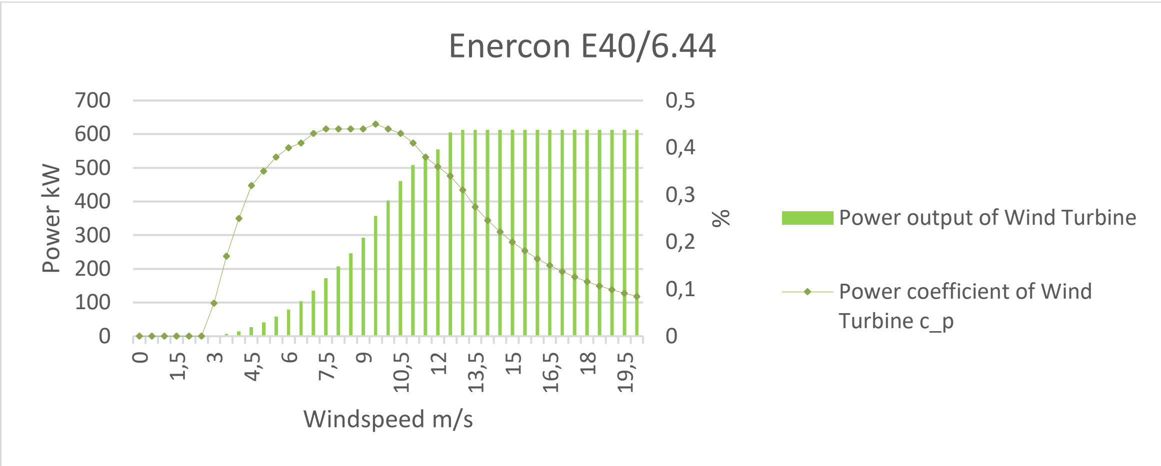


Figure 58: Wind turbine characteristics Enercon E40/6.44

Since we are in possession of the full wind resource datasets and the power output curve of the wind turbine, we are able to calculate the integral of the power output manually with the curve overlay. For the power output the measured share at each wind speed bin is multiplied with the related turbine output. Multiplied this number again with the hours of the months gives us the produced energy of this months.

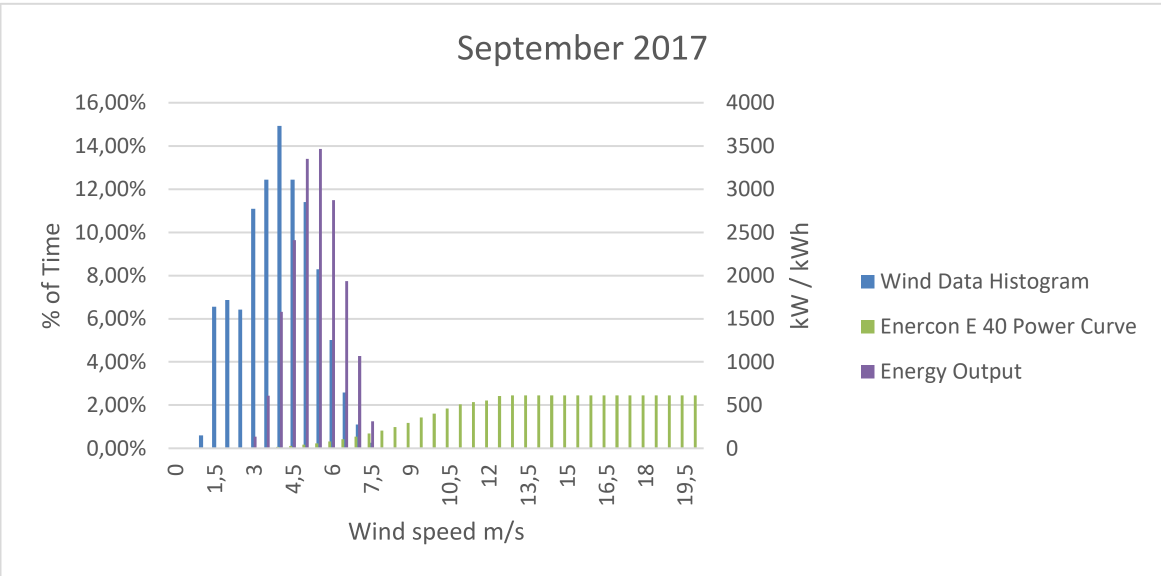


Figure 59: Energy output of wind turbine

Figure 59 shows the energy output of the turbine. To get the monthly energy output needed for financial and economic analyses we need to sum up the energy output at each wind speed bin.

This method seems the most accurate possibility to calculate the power and energy output and is used in the most common software tools for wind assignments, namely Ret Screen, WindPro and Wasp as long that they have the resources like measured data. Other approaches e.g. using only one yearly or monthly mean values come with much higher uncertainties.

5.2.4 CALCULATIONS WITH WINDPRO

The software tool includes energy output curves from several turbines and therefore enables a good comparison about different types of wind turbines. In theory it should do the same as mentioned in the previous chapter and just summarize monthly values.

The weak wind situation also aroused the idea of installing a weak-wind turbine. Therefore the Vestas V136 was compared to the other types as seen in Table 5. The capacity factor increased massively to 10,1% but still is not a game changer. Because of the present height regulation it wouldn´t be a realistic scenario anyway.

Table 5: Comparison of different wind turbines

Manufacturer	Turbine	Nominal Capacity [kW]	Rotordiameter [m]	Hubheight [m]	Energy output [MWh/a]	Capacity factor [%]
Enercon	E-40/6.4	600	44,0	50,0	119,9	2,3
Vestas	V112-3.45	3.450	112,0	94,0	1.638,0	5,4
Enercon	E-82 E4	3.000	82,0	84,0	919,5	3,5
Vestas	V136	3.450	136,0	112,0	3.041,7	10,1

Figure 60 as well shows the comparison and the immense energy yield increase of special weak-wind turbines.

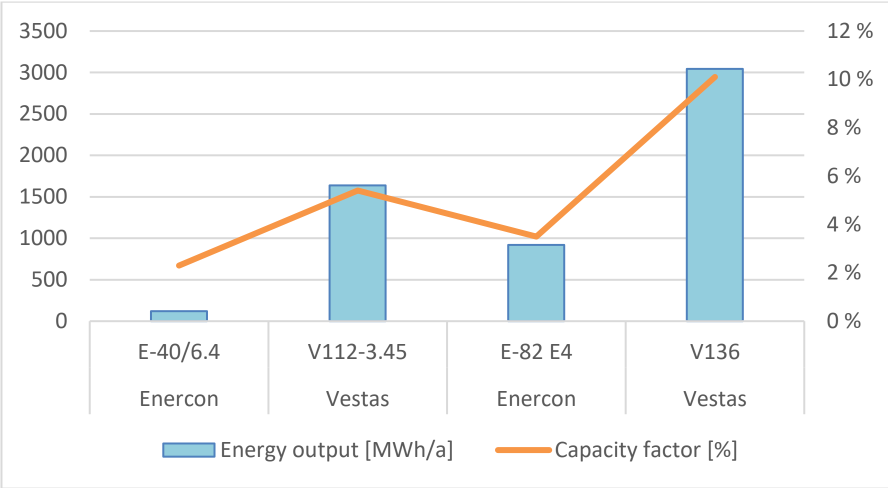


Figure 60: Comparison of different wind turbines

5.3 FINANCIAL ANALYSIS METHODS FOR WIND TURBINES

Financial analyses should help to see if an investment makes sense from an economical point of view or if it produces losses for an investor. It allows the comparison in terms of benefit and other economic characteristics. Figure 61 shows possible calculation methods.

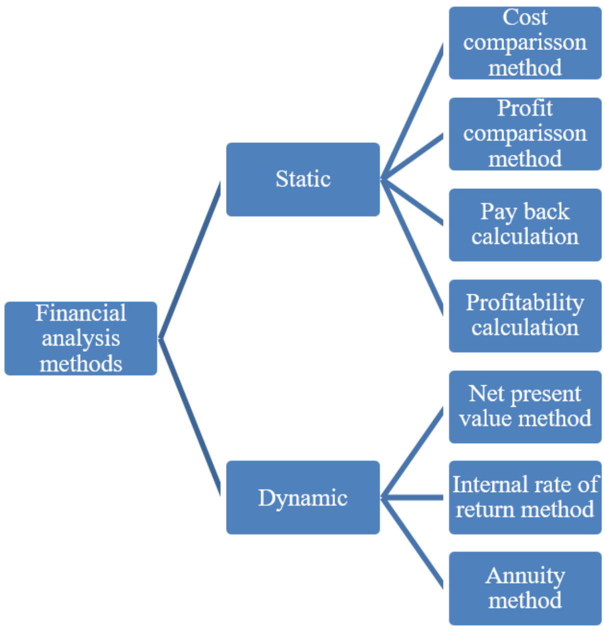


Figure 61: Financial analysis methods [21]

Before calculating the feasibility of a project, valuable information about the cost of the plant, construction and maintenance are necessary. In this case, numbers were used in collaboration with a planning office in Austria, institutions in Egypt and as well from real turbine offers online. The numbers are not mandatory valid and should mainly demonstrate how many cost positions to have to be considered in such a calculation and should provide a good estimation of a feasibility study.

Table 6: Turbine parameters [6]

Manufacturer		ENERCON
Ammount of turbines	[Stk]	1
Type		E40/6.44
Nominal power	[kW]	600,0
Diameter	[m]	43,7
Rotor surface	[m²]	1.500
Height of nacel	[m]	50,0
Height of blade tip	[m]	71,9
Annual energy yield	[kWh]	119.900
Availability	[%]	97
Distribution and transmission losses	[%]	3
Safety losses	[%]	5
Energy yield	[kWh]	106.711
Total Energy yield	[kWh]	106.711

Table 7: Turbine and site-specific costs [7]

Manufacturer		Enercon
Type		E40/6.44
Amount of turbines	[Stk]	1
Cost per turbine	[€]	30.000
Cost per transformator	[€]	10.000
Transport and deconstruction	[€]	200.000

[6] Source online https://www.wind-turbine-models.com/ and supplier homepage www.enercon.de
[7] Mentioned numbers found online at https://www.wind-turbine-models.com/ and were outcome from personal expert interviews and should show a realistic scenario but could vary according to project framework

Subtotal per turbine	[€]	240.000
Costs all turbines	[€]	240.000
Plant cost total	[€]	240.000
Foundation costs	[€]	15.000
Piece of land	[€]	3.000
Subtotal per turbine	[€]	18.000
Costs all turbines	[€]	18.000
Road access	[€]	1.000
Construction total	[€]	19.000
Cabeling	[€]	12.000
Grid transfer	[€]	5.000
30 kV-Erthcable	[€]	4.500
Grid integration	[€]	3.500
Control cables, others	[€]	6.500
Electro total	[€]	31.500
Windmeasurments and precosts	[€]	15.000
Planing and construction management	[€]	35.000
Evaluations and contracts	[€]	10.000
Planings, Evaluations total	[€]	60.000
Unexpected	[€]	20.000
Total	[€]	370.500

The determination of the value of an investment or a project is challenging because of different ways to measure the value of future cash flows. One Euro earned now is more valuable than one Euro earned in the future because of alternative investments, that could have been done with it, and because of inflation. Therefore, the Net Present Value, NPV, method can help to account for this through the NPV-discount rate. In Egypt a very high inflation rate makes its consideration even more necessary. Therefore, the discount rate in the following example was set as high as 12%. The tariff set for the selling of power represents actual energy costs of an isolated operator generated from a diesel generator with current diesel prices and furthermore represents the price for an industrial customer in Egypt connected to the grid. The energy prices are split in several categories, the bigger the consumer, the higher the tariff he or she has to pay. The actual price for the largest consumer was about seven cents and according to the Minister of Electricity the next increase will happen in July 2019. The ministry of electricity is following the plans to fade out the subsidies until the year 2021. [8]

5.3.1 Scenario 1, Measured on site situation

Table 8 shows the NPV table for the mentioned turbine in previous chapters with the determined energy yield. As expected, the NPV is negative because of the little output. Already mentioned, the cost positions for these graphs represent the result of personal interviews with Austrians and Egyptians, but do not provide a bankable financial survey of a specified project.

The turbine was chosen due to chapter 5.2.1. The used price was taken from used wind turbine online suppliers.[9]

[8] Source online article: https://ww.egyptindependent.com/electricity-prices-to-increase-july-2019-electricity-min/

[9] Source: online: ; https://www.wind-turbine-models.com/

Table 8: Economic analyses of the given turbine with the NPV method

Economic analysis — Enercon E40/6.44

Investcosts	EURO
Windturbine with Tower incl. Transformators	**240.000**
Foundation, Piece of Land, Grounding system	**18.000**
Cabeling	**12.000**
Substation, Grid transfer	**5.000**
30 kV-Earthcable	**4.500**
Grid integration	**3.500**
Others electro	**6.500**
Access road	**1.000**
Planing, Contruction- and project Management	**60.000**
Unexpected	**20.000**
Total investment	**370.500**

Revenues		EURO
Energyyield (kWh/a)		**106.711**
Tarif 1-12. Year (€/kWh)		**0,050**
Tarif 12.-15. Year (€/kWh)		**0,050**
		EURO
Financing		
Equity	100,0%	370.500
Subsidization 1	0,0%	0
Subsidization 2	0,0%	0
Subsidization 3	0,0%	0

Operation costs	EURO
Rent	**1.000**
Insurance WKA	**1.440**
Maintenance contract	**1.680**
Savings	**7.263**
Operating equipment	**600**
Operation Management	**1.000**
Excess insurance	**5.000**
Operating cost total	**17.983**
OC in % of total investment	**4,85**

WPT-Type	E40/6.44	
Ammount of Turbines	[Stk]	1
Diameter	[m]	43,7
Rotor surface	[m²]	1.500
Nominal power	[kW]	600
Annual Energy yield	[kWh]	119.900
Annual total energy yield	[kWh]	106.711
Specific revenues	[kWh/m²]	71
Specific costs	[EUR/m²]	247

Other parameters

annual operational cost increase	**0,0%**	
annual revenue increase	**0,0%**	
Warranty period	**1**	Year
Within warranty period	**3.000**	per year less operating costs
Depreciation period	**5**	Years

NPV disc. rate	p	0,12
	q	1,12

NPV **-463973,1 €**

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Sum revenue	5.336	5.336	5.336	5.336	5.336	5.336	5.336	5.336	5.336	5.336	5.336	5.336	5.336	5.336	5.336
Operating costs	14.983	17.983	17.983	17.983	17.983	17.983	17.983	17.983	17.983	17.983	17.983	17.983	17.983	17.983	17.983
Cashflow	-9.647	-12.647	-12.647	-12.647	-12.647	-12.647	-12.647	-12.647	-12.647	-12.647	-12.647	-12.647	-12.647	-12.647	-12.647
	-9.647	-11.292	-10.082	-9.002	-8.037	-7.176	-6.407	-5.721	-5.108	-4.561	-4.072	-3.636	-3.246	-2.898	-2.588
Depreciation	74.100	74.100	74.100	74.100	74.100	0	0	0	0	0	0	0	0	0	0
Earnings	-83.747	-86.747	-86.747	-86.747	-86.747	-12.647	-12.647	-12.647	-12.647	-12.647	-12.647	-12.647	-12.647	-12.647	-12.647
Spent equity	370.500	296.400	222.300	148.200	74.100	0	0	0	0	0	0	0	0	0	0
Via NPV	-370.500	-380.147	-391.439	-401.521	-410.523	-418.560	-425.736	-432.144	-437.865	-442.972	-447.533	-451.605	-455.241	-458.487	-461.385

Figure 62 shows the graphical outcome of the financial analyses. In this case the cash flow is never positive, because operational costs exceed the earnings (or savings) from the generated energy. Consequently the NPV gets more negative.

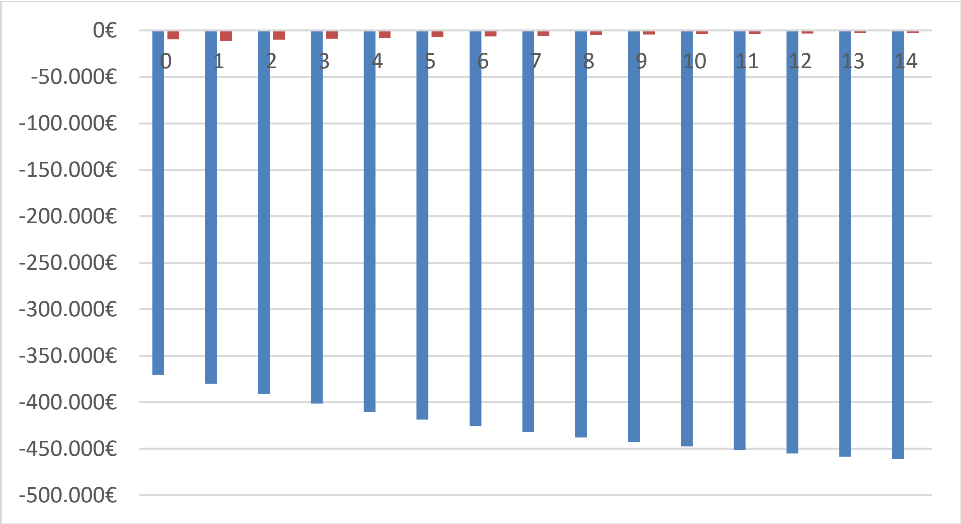


Figure 62: Negative NPV with measured values and 5 €cents per kWh, Euros and years

5.3.2 SCENARIO 2, BETTER WIND SITE

Following the fact that this site does not show feasibility another case was calculated with the same turbine and cost set up shown in Figure 63. The energy yield of the turbine was adjusted so that a capacity factor of 30% is reached, which represents a good wind site and what is very likely to exist in many places in Egypt. The price for the energy was still the same at 5 €cents per kWh like all other cost positions.

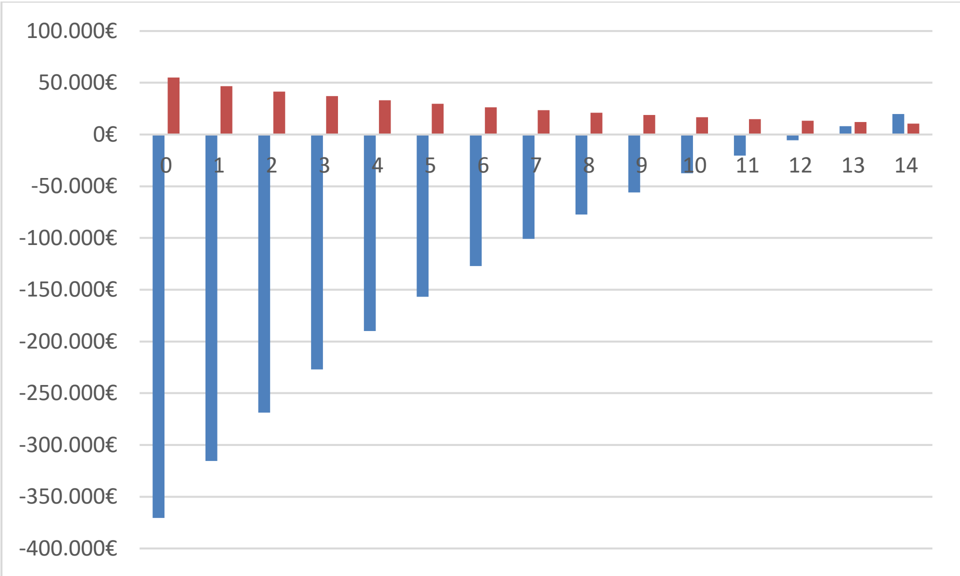


Figure 63: Slightly positive NPV with 30% capacity factor and 5€cents per kWh

The calculated Net Present Value is 30.576,7 € after fifteen years, which means that the project would be positive for an investor. The low NPV within a period of 15 years for a refurbished turbine still remains challenging. Typically for the NPV it shows that earnings (positive cash flows) are at the beginning more valuable than at the end. Following the subtraction of these yearly flows from an initial investment the positive NPV can be found.

5.3.3 Scenario 3, Better wind site and increasing electricity price

In a third scenario, Figure 64, the capacity factor of the turbine was still left at 30% with an increase of the energy price from 5 €cents to 10 €cents due to the mentioned electricity rates increases mentioned in previous chapters.

This, by far, represents the most feasible case with a NPV of 565.827,0 €.

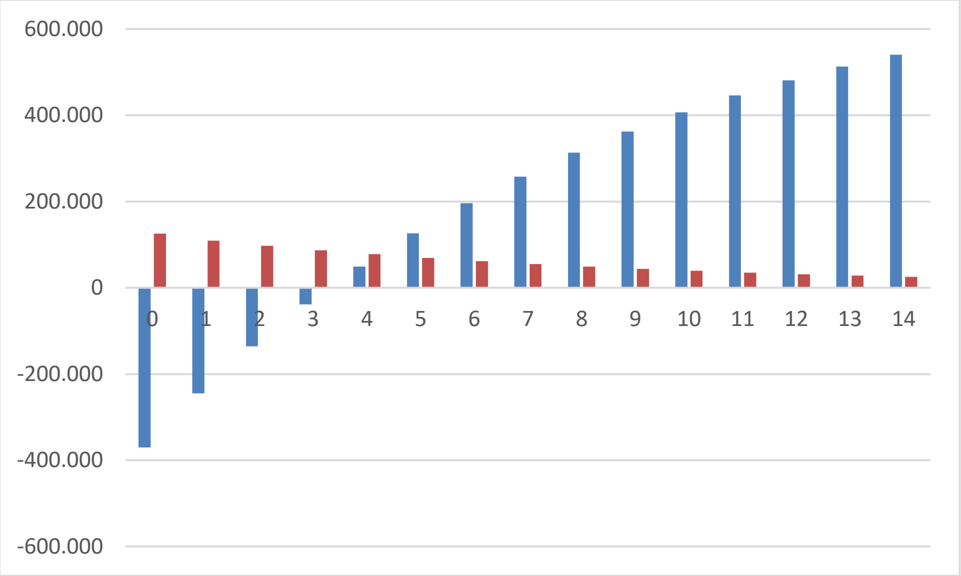


Figure 64: Positive NPV with a capacity factor of 30% and 10 €cents /kWh

6 CONCLUSION

Available wind data

The available wind data in Egypt comes with uncertainties, the Egyptian wind atlas shows low resolutions, especially in rural areas, and thus works with data rows which are at least 20 years old. Nevertheless, it provides an overview of potential good wind areas of Egypt. Modern available tools like the global wind atlas or the MERRA data discover in most cases the same areas as potential sites, but are more conservative in terms of absolute wind speeds. They seem to display higher accuracy due to longer data rows and better input data, but still are not as good as e.g. in Europe where the basic input data is much better.

Measuring wind in Egypt

Because of the identified uncertainties of available wind data, it seems obvious that a wind measurement is crucial for proper assessment analyses. This especially gains relevance for areas, away from the well-known coastal regions around Zafarana region. Several Project efforts in previous time also are approving that this is happening in the southern Nile areas were new site assessment were put in place.
The output of a measurement is always as good as the quality of the system itself. In this case many challenges appeared at the beginning, not only from a technical point of view, but furthermore from an administrative point of view. To end up without any imported goods except the sensors and the logger, was a big advantage. With the training of local technical staff, while manufacturing a 30 meter measuring system, a new local companies division was integrated into a Cairo venture, which creates urgently needed green jobs. The socio economic direct impact remains only as a drop in the ocean, but thus demonstrates that local production is feasible.

To have a stable running data logger, not bigger than a carton of cigarettes and adapted to Egyptian conditions contributed a lot to the measuring success and even paves the way for further installations.

Measuring wind in Fayoum is a groundbreaking endeavour, because it is an untouched region in terms of wind and weather assessment but has promising orographic specialities like the huge flat green cultivated land and the little desert coloured mountains and dunes what all meet at the shores of lake Qarun. The output of the measuring was unknown with chances to find out that the site is much better than it is mentioned in available wind data. The opposite happened. It turned out that the potential local wind system is less positive than the negative effect of the wind lee site depression region. On the contrary it seems likely that for this area the available wind data, both the wind atlas and MERRA data, is overestimating this site, while still being aware that this was a one year sounding measurement with possibilities to improve the accuracy and significance of its output.

Econmomical analyses

For wind energy site assessment, a most accurate description of the measured data is essential. Every conversion and minimization of parameters would decrease the value of the output at the end. Calculating energy outputs with monthly mean values is nothing more than a rough estimation. The Weibull distribution offers a good possibility to compress the big data sets gained from the measurement (more than 4000 rows per month) to only one distribution function, which can be compared with different sites and time periods. If given, a sum of the real power outputs at each wind speed bin is accurate enough to have a good comparison between sites and turbine types. The resolution for the wind speed bins are mostly given by the turbine data, which was resolved in this example at 0,5m/s.

Once the energy output is calculated the next bunch of input parameters appears. The number of variables and cost positions needed for the feasibility calculation is high. The risks of any uncertainties in the sources is present, why the need of experienced specialists is necessary. In an African country like Egypt always remain unknown input values which is a reason for a cost position named “Unexpected”.

Static calculations methods are mostly used to get a first estimation of the profitability and very often show a promising case with high uncertainties, while the dynamic analyses need much more input parameters with a higher accuracy at the end. Especially the net present value method considers very important at financial aspects, which is necessary at

such big investments. It therefore seems most suitable for wind energy and energy economy in general.
Filling this economical tool with the measured and analysed wind and turbine parameters leads to the conclusion that for this specific site any wind power plant is not feasible. Scenario 1 from chapter 5.3.1 furthermore showed that this case is even not sensitive on the energy price but caused by the very less energy yield as a result from the low wind speed. When comparing a calculated standard turbine with a top weak-wind turbine it still shows that capacity factors are not exceeding 10,1%.

Good wind sites can reach up to a capacity factor of 40%. In Austria the average capacity factor of wind power plants was 24% in the year 2014 . [24] To compare different cases for the same turbine set up, the capacity factor was set to 30% in scenario two and three. It shows that in a good wind site it is more sensitive on the energy costs what lead to scenario three (chapter 5.3.3) where the price of the energy tariff was set to 10€cents per kWh. This case does not only show a feasible case but furthermore is also the most obvious for the next two years when considering the sharply rising fuel and electricity prices.

The only question remaining to show a positive feasibility of Wind power in rural areas of Egypt is to find the right spot. This answer is blowing in the wind.

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10 LIST OF ABBREVIATIONS

BP	British Petrol
CIA	Central Intelligence Agency
CPI	Consumer Price Index
EEAA	Egyptian Environmental Affairs Agency
EgyptERA	Egyptian Electric Utility for Consumer Protection and Regulatory Agency
EIA	Energy Information Administration
EMISAL	Egyptian Mineral and Salts
FIT	Feed In Tariff
GW	Giga Watt
Hz	Hertz (frequency)
IMF	International Monetary Fund
kW	kilo Watt
kWh	kilo Watt hour
LNG	Liquefied Natural Gas
m	meter (length)
MERRA	Modern-Era Retrospective analysis for Research and Applications
NCEP	National Centers for Environmental Prediction
NPV	Net Present Value
o.g.l.	Over ground level
OPEC	Organisation of the Petroleum Exporting Countries
PPA	Power Purchase Agreement
PV	Photovoltaic
RCREEE	Regional Center for Renewable Energy and Energy Efficiency
RE	Renewable Energy
SME	Small and Medium-sized Enterprises
USD	United States Dollar

11 APPENDIX

SANKEY DIAGRAM: EGYPT ENERGY BALANCE