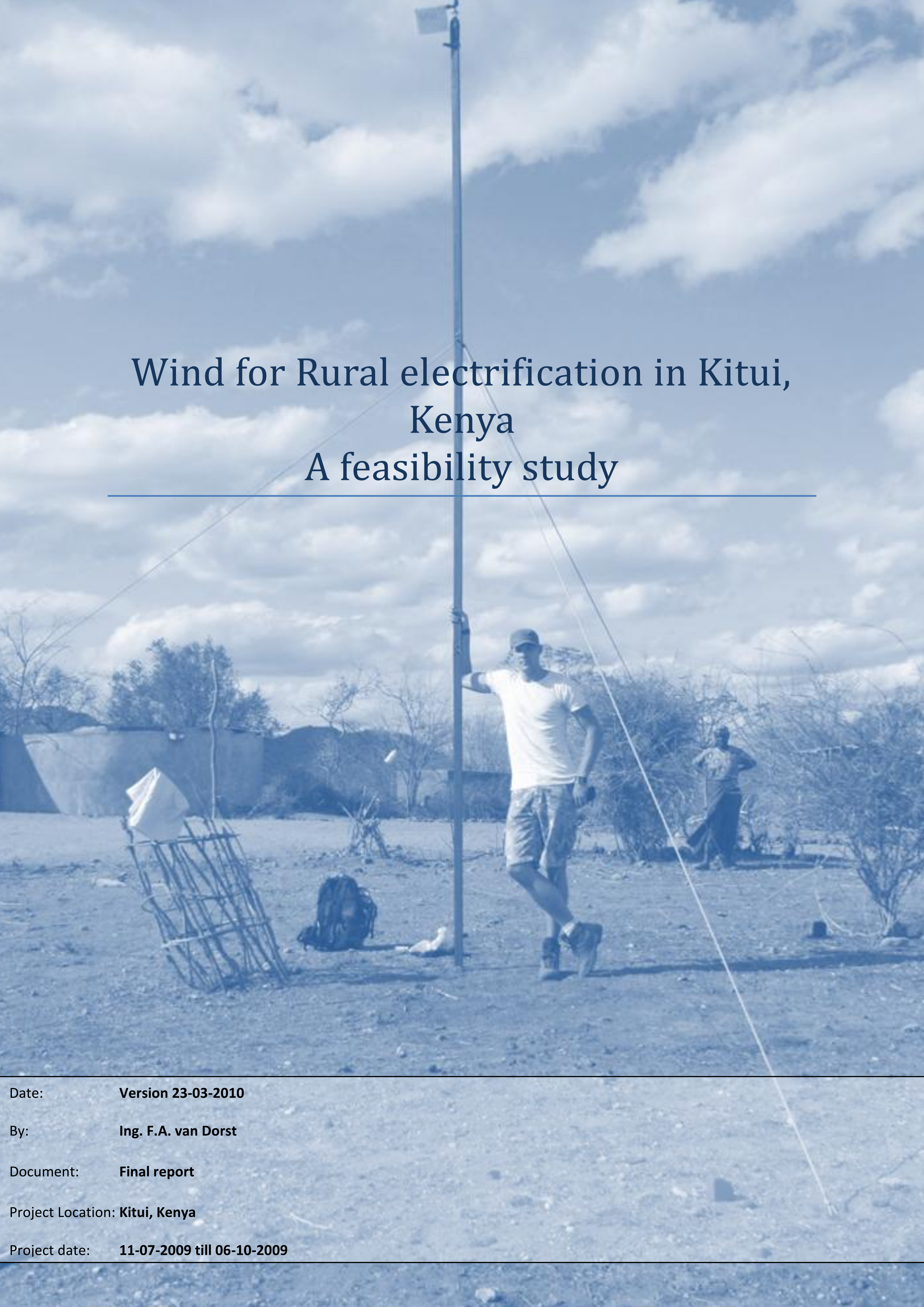

Wind for Rural electrification in Kitui, Kenya
A feasibility study

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“You must be the change you wish to see in the world”

Mahatma Gandhi

1 Preface

This report describes the feasibility study for small scale wind energy in Kitui district. This project is done for the Kenyan NGO SASOL, SAhelian SOLutions.

The report is part of the work that was done for the project course on Technology Development and Globalization and the System Integration Project II (cTDG and SIPII) at the Eindhoven University of Technology. This project is part of the second year of the MSc-program on Sustainable Energy Technology and a preparation for the MSc-final project on wind energy.

In 2005 I got to know Kenya as a great country to do projects. I did projects on pumping and other energy related issues. Contacts that were made in 2005 provided the opportunity to do a new project in Kenya. The SET study schedule allowed to combine this with the Wind Energy specialization. The new project which was executed from July 2009 till October 2009 was titled:"Wind for rural electrification in Kitui, Kenya: A feasibility study". This created an opportunity to return to the country where I have had a great experience and explore new things again.

This report is written for the supervisors of the Eindhoven University of Technology, Prof. dr. G.J.W. van Bussel (SET) and Dr. H.A. Romijn (cTDG), and for my supervisor of SASOL, J.M. Munguti MSc.

The stay in Kenya has been great. It was three months of hard work, of great moments and sharing of a lot of time with many old and new friends. The work in Kenya would not have been like it was without the help in the preparation from Paul Smulders, Henk Holtslag and Jan de Jongh, a word of thanks to their assistance and their guidance. The input of Mutinda Munguti, Kennedy Mutati, Prof. Mutiso, Onesmus Mwagangi (all of SASOL) and Prof. Luti of Nairobi University assisted in making this project succeed. To each of them a word of thanks. I would also like to take this opportunity to thank Sammy Mwa-gendi for all the work he has done.

Asante sana![1]

[1] Swahili for Thank you very much

[2] Measure Correlate Predict

2 Executive summary

This report describes a feasibility study done on small scale wind energy for three locations in Kitui district, Kenya:

- Kanyangi boys secondary school
- Kanziko secondary school
- Multipurpose center south.

These locations are selected to be potential locations for small scale wind turbine. The produced electricity will be used for lighting and run a computer. In this way the generated power is contributing to education in this part of Kenya.

Attention has been paid to work that has been done in history on wind energy in Kenya. That showed that there are some locations in Kenya with wind potential, but all of them are not in Kitui district. The expectations for wind energy in Kitui were low, but local variations could make it interesting.

Parts of site selection for small scale wind energy are local wind measurements. Measurements were done at all three locations. In Kanyangi two weeks of wind data were collected, in Kanziko three and at the multipurpose center one week of data. The data were extrapolated according to the linear regression MCP[2] technique to obtain a year of wind data. These yearly data were used to find Weibull distribution functions, which were used to predict the power output at the various locations. It turned out that the location of the secondary school in Kanziko offered the best wind conditions for power generation.

When comparing the use of a small scale wind turbine with other systems for power generation, a solar PV system or a diesel generator, the PV system financially turned out to be the best option, but based on a multi criteria analysis the diesel generator showed to have the best potential.

In order to make this feasibility study more reliable, longer term wind data have to be collected in the Kitui district, since three weeks, or a even one week, of measurements as a base of a feasibility study are not sufficient.

[2] Measure Correlate Predict

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5 Introduction

In the past seven years student teams of the Dutch NGO Edukans have been doing several water, energy, mechanical engineering and trade & marketing related projects in Kitui district, Kenya. I was one of those students working in a pump and energy team in 2005. I have worked for three months on making rope-pumps and doing an energy survey. I have stayed active for Edukans since then by guiding new student teams, and since 2008 I am a registered volunteer at Edukans. My job is to assist each Mechanical Engineering and Energy Technology team of Edukans that is going to do a three month project in a developing country. In that function Edukans asked me to go to Kitui and evaluate the past projects and investigate for new projects. This fits well within my MSc program Sustainable Energy Technology (SET) in combination with a certificate program in Technology, Development and Globalization (cTDG). Like this I can combine three projects in one three month period:

- Evaluating the past projects of Edukans (Edukans)
- Looking for new projects (Edukans)
- Do research on rural electrification by wind or solar power (MSc SET and cTDG)

In the first two projects a lot of knowledge is generated in informal conversations with rural communities, employees of the Kenyan partner, people at Kenyan universities and the student teams that have been working in Kenya from May till July.

The rural electrification project is the core of my research and thus this report plan is written for this project only. To be able to obtain credits for this project, the project should deal with one of the steps of the project cycle (cTDG) shown in Figure 1 and at the same time it has to contain work on my specialization within the MSc SET program. Since my specialization is on wind energy, the project will go into more depth on wind energy.

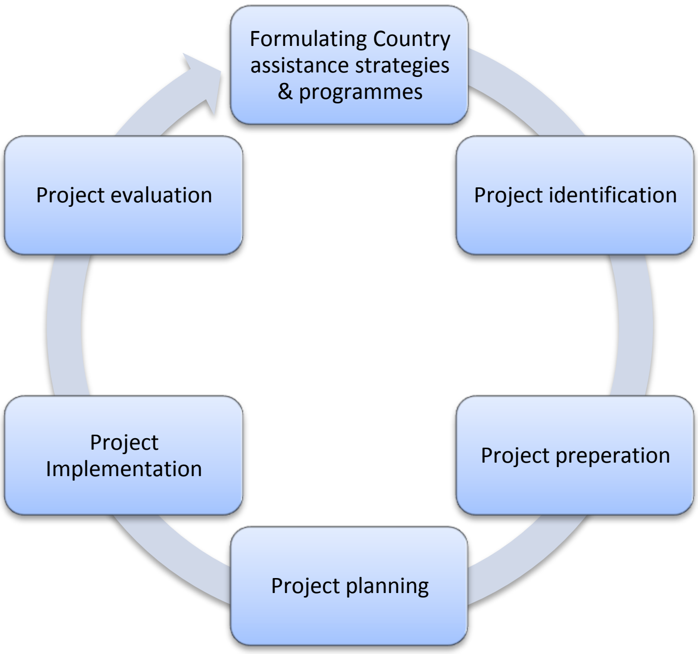


Figure 1: Project cycle

To let a project succeed, special attention has to be paid to each of the steps of the project cycle, Figure 1. During a training by the Technology, Development and Globalization group at Eindhoven

Technical University, these steps were dealt with. To this research the steps of project identification and project preparation apply. It is in fact in between these stages since the Kenyan partner has already determined that they want to work with wind energy, but I have to do a prefeasibility study in order to let a new student team work on actually building the wind generator. The project has to be developed, defined and designed. This phase is called the project opportunity phase, in which a needs assessment and a search for alternative solutions are done in combination with a preliminary Cost Benefit Analysis.

The project has been carried out in Kitui, Kenya in cooperation with the Kenyan NGO SASOL (SAhelian SOLutions). SASOL has been building sand storage dams in Kitui district for about 20 years now. More than 700 of them have been built by them in cooperation with the communities. SASOL provides the knowledge, material and food if the communities provide labor. Since 2003 SASOL is working together with Edukans and has widened its focus to water quality, pumping, energy, ICT and trade & marketing. Recently SASOL has been rewarded as being the best Kenyan NGO on capacity building, vocational education and community training. More on SASOL can be found in Attachment I: Capabilities of SASOL.

Kitui district is situated approximately 200km east of Nairobi. Kitui district is one of the poorest areas of Kenya inhabiting about 600,000 people on an area as big as The Netherlands. The main source of income is agriculture. Due to the lack of rains the harvests have been really poor since 2003 and the situation is becoming worse. This makes people move from the rural areas to the big city to find a job. The main city in Kitui district, Kitui town, sees its population grow yearly with 20%-40%. SASOL is aiming to reach these people to keep them in the rural areas and create opportunities for them there.

It is not just Kitui district that has problems with the lack of water, since this year the entire country is influenced by the lack of rains. The absence of rains results in low water levels in the rivers and the dams in the Rift Valley, where most of the country's electricity is produced by hydropower. To compensate for this, power cuts occur regularly, even in the capitol Nairobi.

This introductory chapter will go more into the context of this research and the detailed content of the research. Chapter 6 will explain the basics of wind energy and will discuss the possibilities for wind energy in Kenya. In the 7^{th} chapter the technical feasibility study will be done for the three locations, after which an economical feasibility study will be described in chapter 8.

5.1 Context

Energy plays a significant role in the development of a country or community. According to UNDP energy service can have strong influences on the social and the economic development. For more than 2 billion people all over the world without a reliable energy service, electricity can offer a reduction in the poverty, improve their health and increase their standards of living. Energy can support a nation to achieve their Millennium Development Goals (MDG's). Table 1 shows how energy can be linked to the MDG's (1).

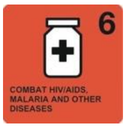
Extreme poverty and hunger		Electricity can enhance the development of enterprises and thus contribute to income generation. Lighting offers the possibility to generate income after the daylight hours.
Universal primary education		Energy can contribute to a more child friendly environment. Lighting at schools assists to retain teachers at schools. Electricity offers access to educational media, communication technologies and gives the possibility to use educational equipment (e.g. projectors, computers, printers)
Gender Equality and women's empowerment		Electricity gives women the possibility to study at home and/or follow evening classes. This means they can study without a reduction of income.
Child mortality		Energy allows communities to have access to cleaner pumped water, even purification.
Maternal health		With electricity medicines can be refrigerated at hospitals or health centers.
HIV/AIDS, malaria and other major diseases		Electricity gives health centers the possibility to be open at night hours, have their medicines refrigerated and dispose syringes in a safe way. Besides that, electricity enables access to health education media.
Environmental sustainability		Electrical irrigation can increase agricultural productivity, can help cultivation on bare lands. The time needed for fetching water can be reduced as well, with access to energy.
Global partnership		Large scale energy development requires countries to cooperate.

Table 1: Millennium development goals and energy

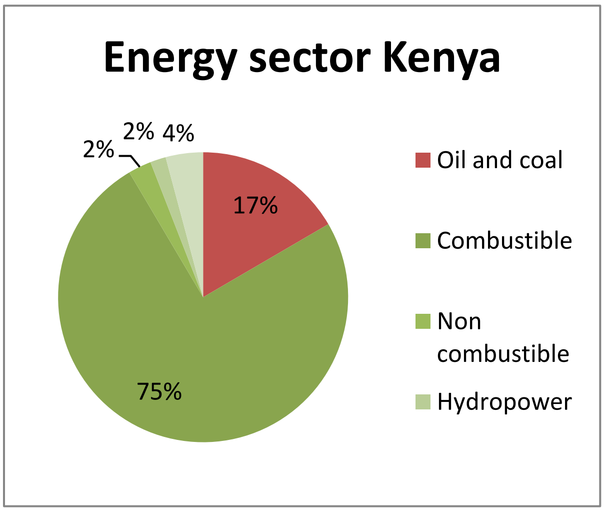
Core international (2) confirms that energy and development should go hand in hand and addresses the lack of energy as the main obstacle to development and growth.

The previous two sources confirm that the research done in Kitui district on energy will have a contribution to the development of the communities living there.

5.2 Energy in Kenya

Quite a big portion of the energy in Kenya is delivered by renewables, a bit over 80 percent; see Figure 2 (3). This includes combustible biomass, as charcoal and firewood, which is mainly used for cooking and heating. This type of energy source is leading to big amounts of deforestation in regions in Kenya, especially in the Kitui district. The trees in this district are very good for the production of charcoal because it is very dry; this is one of the reasons that there is a lot of trade of charcoal from Kitui to other regions of the country. Besides charcoal and firewood the biggest source of energy in the rural areas of Kenya, as Kitui district, is kerosene. The kerosene is used in the rural areas for lighting kerosene lamps, since the coverage of electricity in the rural areas is below 1% (4); only less than 0.5% of the people living in the rural areas are connected to the electricity grid. This has multiple reasons, the grid connection is quite expensive (80% of the Kenyans live below the $1/day poverty line), the grid is simply too far away and the grid supply is not reliable (3).

The Kenyan electricity market is controlled by one power company: the Kenyan Power and Lighting Company (KPLC). Most of the electricity is produced by large scale hydropower Figure 2.Besides that diesel generators deliver the power to the grid. The problem of the last couple of years is what is called the energy crisis, due to absence of heavy rainfall in the rain seasons, the levels in the dams and rivers in East-Africa are low, causing the hydropower stations to run on low capacity, to make sure they are able to supply the country throughout the year. To be able to do this KPLC has introduced power rationing, two or three days a week there will be no power delivered by the grid during daytime. To back up the power supply KPLC together with the Kenyan government have invested for $150million in diesel generators in 2009, to be able to supply sufficient power.



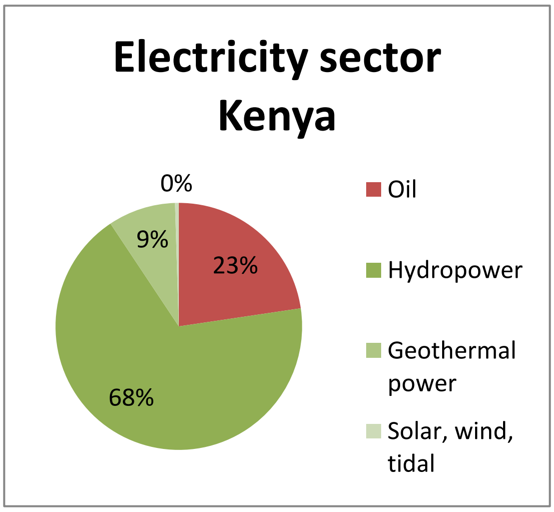


Figure 2: Energy in Kenya (3)

5.3 Rural electrification in Kitui district

The best option for rural electrification in Kenya should be solar or wind energy (5) (6) (7). There are various reasons why other alternatives are not among these two options: diesel generators will be too expensive, because of the diesel; the most common source of lighting, the kerosene lamps are harmful for people's health and are becoming more expensive as well, since the price of kerosene is rising; the main sources for cooking, the firewood, is causing too much deforestation. The Kenyan government is not focusing on the rural electricity by means of small scale solar or wind energy (5) (6) (8). Because of this there is an important role for Non Governmental Organizations (NGO's) working on energy related issues in Kenya, one of them is SASOL.

Sasol has been doing projects on pumping, wood saving cooking stoves, solar energy, solar water heaters, and some energy surveys. This research on small scale wind energy is in the line of these projects and should give an answer on the electrification questions.

The grid in Kitui district is limited to a small part of the district, Figure 3 shows Kenya with in red Kitui district and the green parts are grid connected. The locations where this research is focused on are at least 20 km from the nearest grid connection. To extend the grid to these locations a connection fee of 35.000 KSh (approx €300) has to be paid, with average fees of around 3000ksh (€28,-) per month. For this investment the people are still not sure of electricity since there has been severe and long term power cuts for the last decade.

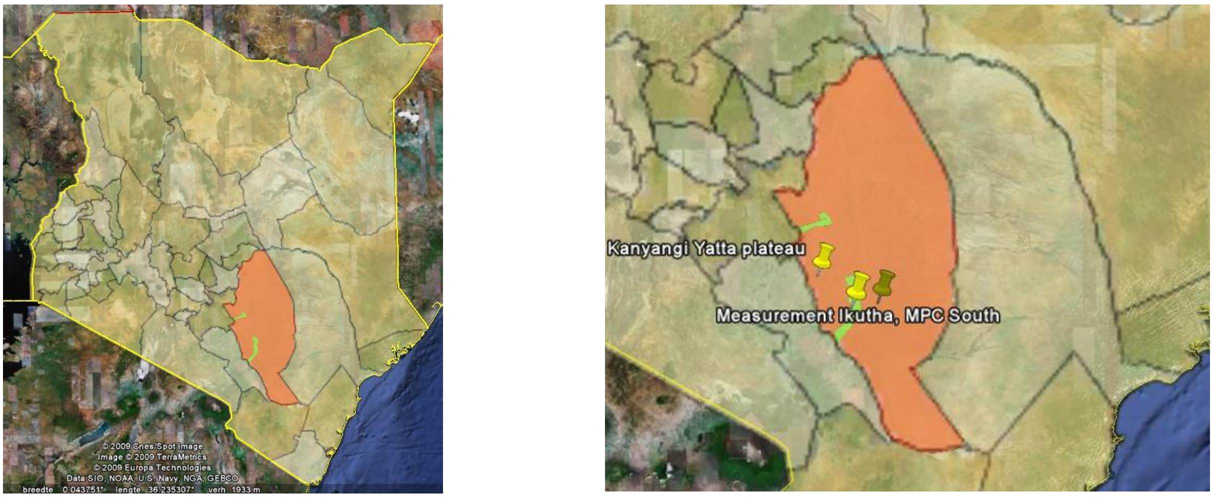


Figure 3: Electricity grid (green) in Kitui district (red) [Google earth and own experience]

SASOL is planning to build a field office in Ikutha (Figure 3, MPC south). At the same spot a demonstration farm is to be built, where they will expose the equipment SASOL has developed over the years and train the communities in the southern part of Kitui district on mainly agricultural technologies. The target group is the students that are leaving the secondary schools. They will train the students on how to create good terraces, what type of crops to grow, how to irrigate them, how to keep livestock etc. Besides there will be a smaller group of students that will be trained in some basic engineering skills as working metal sheets, sawing, welding, carpentry, masonry etc. These students will make rope-pumps, brick presses, wood saving cooking stoves, sand storage dams and vegetable dryers.

SASOL has been interested in different options to bring electricity to schools and the communities. The first energy survey was done in 2005, which recommended SASOL to use bio-digesters, solar energy or do more research on the wind potential. With the demonstration farm coming, it was an opportunity for SASOL to start a project on wind energy. If there is sufficient wind, a wind generator can be build at the demonstration farm by the students, so they can train their skills, take care of the maintenance and supply themselves with electricity.

This research focuses on three locations in Kitui district (Figure 3):

- Kanyangi boys secondary school
- Kanziko secondary school
- MPC south

The schools are included in the research since SASOL also want to equip some schools in Kitui district with clean energy sources, to offer them lighting and the use of some computers. As the previous paragraph 5.1 has shown, electricity contributes to the education of the students.

Together with SASOL the following research question was formulated:

"What contribution can low cost wind energy bring in supplying the rural areas of Kitui district with electricity for lighting and small appliances and how does this relate to the costs of other energy sources like photo voltaic energy?"

6 Wind Energy

This chapter will give some basic background on wind energy, how is it possible that energy can be generated by the use of wind. Besides that this chapter will give some historical background on wind energy development in Kenya. Finally the last paragraph will address why SASOL is interested specifically is interested in wind energy.

6.1 Energy from the wind

Wind energy is basically solar energy. Because of temperature difference over the globe, pressure fields are being created, causing the air to move from one part of the World to the other, this is what we experience as wind. Wind consists of moving particles, one of the basic laws in physics shows that moving particles are energy carriers, more specifically, carriers of kinetic energy:

$$E = \frac{1}{2} m U^2 \qquad \text{Equation 6.1}$$

When looking at the mass flow, the power available in the wind will be:

$$\dot{m} = \rho A U \qquad \text{Equation 6.2}$$

$$P_{available} = \frac{1}{2} \rho A U^3 \qquad \text{Equation 6.3}$$

Not all of this power can be captured, because the wind still has a velocity behind the rotor. If all the power available will be captured, there should be no wind behind the rotor. Physically this is impossible. This limitation is known as the Betz limit and can be explained with an actuator disc model

:

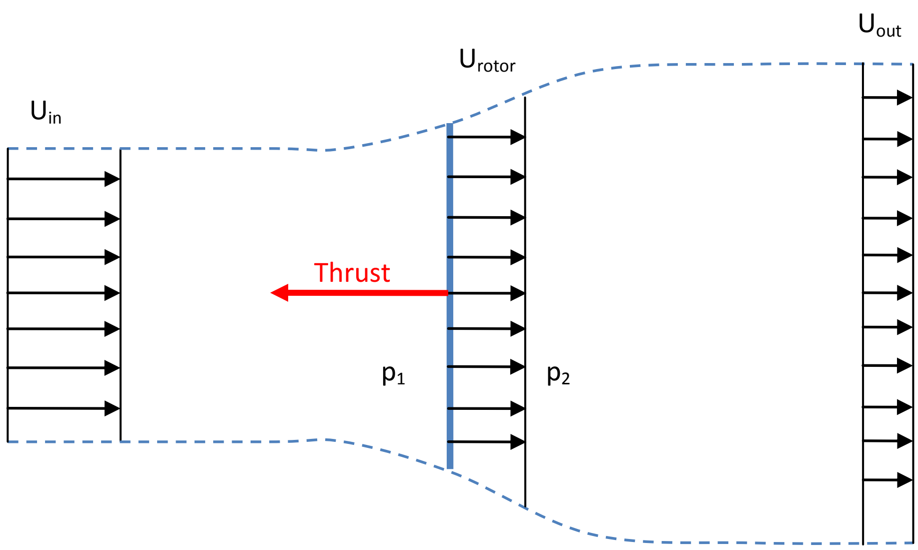


Figure 4: Actuator disc model

The power that the turbine actually takes out of the wind is equal to:

$$P_{captured} = (p_1 - p_2) A_{rotor} \, U_{rotor} \qquad \text{Equation 6.4}$$

With simple momentum theory it can be shown that the thrust exerted on the flow by the rotor is due to velocity and thus pressure difference. Assuming an incompressible flow, so that the following continuity equation holds (Equation 6.5) gives the thrust.

$$U_\infty A_\infty = U_{rotor} A_{rotor} = U_{out} A_{out} \qquad \text{Equation 6.5}$$

$$(p_1 - p_2)A_{rotor} = \rho A_\infty U_\infty (U_\infty - U_{out}) \qquad \text{Equation 6.6}$$

When applying Bernoulli in front and behind the rotor Equation 6.7 can be derived:

$$(p_1 - p_2) = \frac{1}{2}\rho(U_\infty^2 - U_{out}^2) \qquad \text{Equation 6.7}$$

Rewriting this in combination with Equation 6.5 and furthermore applying Equation 6.6, the following is obtained:

$$= \rho \frac{A_\infty}{A_{rotor}} U_\infty (U_\infty - U_{out}) = \rho U_{rotor} (U_\infty - U_{out}) \qquad \text{Equation 6.8}$$

Comparing this with Equation 6.7 gives:

$$U_{rotor} = \frac{1}{2}(U_\infty + U_{out}) \qquad \text{Equation 6.9}$$

When inserting the result of Equation 6.9 into the equation for efficiency, the quotient of Equation 6.3 and Equation 6.4

$$\eta = \frac{P_{captured}}{P_{available}} = \frac{1}{2}\left(1 - \frac{U_{out}}{U_\infty}\right)\left(1 + \frac{U_{out}}{U_\infty}\right)^2 \qquad \text{Equation 6.10}$$

The maximum efficiency will occur when the ratio $\frac{U_{rotor}}{U_\infty}$ is equal to $\frac{1}{3}$. The efficiency is then $\frac{16}{27} =$ 59%. This is known as the Betz limit of a wind turbine. It is the theoretical maximum efficiency of a horizontal axis wind turbine.

What just has been calculated is the maximum power that can be captured by the blades of the wind turbine and will make the blades rotate. The blades are connected to a shaft that is (in-) directly connected to a rotor of a generator, where the electricity is being produced. It is out of the scope of this report to go into more detail about this.

6.2 Experience with wind energy in Kenya

In the past some projects have been done on wind energy conversion systems in Kenya. This paragraph gives a small overview of these projects based upon the work of Ogana (9) and Van Lierop and Van Veldhuizen (10).

In the colonial times, many types of water pumping wind turbines were used in Kenya. These were often produced in Europe and then shipped to Kenya. With the coming of the diesel pumps and the low diesel prices, these wind pumps were abandoned. When in the 1970's diesel became more expensive due to the oil crisis and the Kenyans wanted to use the wind pumps again, they often found them broken down. Spare parts were not available, because either they were not produced anymore, or due to the import regulation of the Kenyan government, the spare parts could not be imported. The old designs had been replaced by new designs. This lead to several projects done in Kenya, ran by different development organizations. Most of the time the projects did not lead to successes, this was due to:

- Lack of local know-how. Basically ex-pats were working on these kinds of projects, without taking knowledge transfer into account.
- Poor project supervision. Often projects were started without looking at what kind of work predecessors had done and learn from their experiences. Bad project planning is also called as one of the reasons why projects often failed in the mid 1980's.
- Lack of knowledge of the wind regimes. Often the same data were used for feasibility studies, which were inaccurate. An example is that in one of the feasibility studies no height variations were taken into account.[3] Because of the lack of knowledge of the wind regimes, wind turbines were not designed for the right regime and their performance was worse than expected.

In the early 1980's the first major feasibility study was done by Van Lierop and Van Veldhuizen (10), working for the CWD group, by order of the Kenyan Ministry of Energy. They stayed in Kenya for 10 weeks and visited a lot of meteorological stations. Out of the 126 visited stations, only 26 stations gave reliable data. With these data Van Lierop and Van Veldhuizen indicated some potential sites for wind energy in Kenya. See Figure 11.

There has been one company that did some thorough testing with wind pumps. An agricultural company, Bob's Harries Engineering Ltd (BHEL), faced trouble during the droughts in the mid 1970's. In order to be able to assure themselves of a good harvest irrigation was required. The price of diesel was too high, so they had to look for a different solution: wind pumping. Importing parts or complete turbines was not possible, so they had to design their own turbine. In cooperation with IT-DG from the United Kingdom, they developed their wind pump, a very robust machine. At that moment there was a big demand for the wind pumps, so BHEL started a new company: Kijito. Up till today Kijito is producing and selling these wind pumps.

In the 1980's the University of Nairobi made some designs of wind turbines, but they never came out of the development stage. Besides that, Ogana did some work on resource assessment.

[3] Wind speed increases with an increase in height.

With a dropping oil price, the interested in wind energy dropped as well in Kenya, so in the 1990's hardly any work on wind energy was done in the country, besides the work of Kijito.

In the last decade some more work was done on wind energy because of a rising oil price and attention to climate change. By order of the Kenyan government the German consultants of GTZ performed a detailed resource assessment of the country and made a wind map of Kenya, based on average wind speed estimations.

As a new development Kijito has done some research on small scale electricity production in 2007. On a primary school in Central province they installed a 1kW wind turbine of Chinese make. It showed that the turbine produced sufficient power to supply the school and charge batteries with the surplus of power. Recently Kijito is planning to work together with the Australian wind turbine producer Aerogenesis to produce their turbine in Kenya. The turbine is a result of 25 year of research at the Newcastle University in Australia (4) (11) (12).

In 2002 a new company was founded: Craftskills enterprises. They have a totally different approach then the former company: as cheap as possible is their motto. At Craftskills all the parts of their turbines are produced in their own Jua Kali (open air workshop) in one of the slums of Nairobi. Since their start in 2002 they have been installing several of their turbines throughout Kenya. It is hardly possible to compare the windcharger of Craftskills with the Aerogenesis turbine. The Aerogenesis turbine is designed to produce maximum power with minimal losses, maximum lifetime, no compromises on quality, whereas Craftskills accepts a trade off of performance for cost reduction (13).

That there is renewed interest in wind energy in Kenya is shown by the development of the small scale wind energy market and the large scale wind energy market. The distinction is based upon the power generated by a wind turbine. Small scale turbines produce a maximum power of 2kW, whereas the large turbines start at 100kW up to MW's. In 2008 six large turbines have been installed at Ngong Hills, just outside of Nairobi with a total capacity of 5.1MW. A recent plan is to install 300 MW at Lake Turkana in the North West of Kenya, which should be installed by July 2012. The renewed interest in small scale wind was shown on the conference: Small Scale Wind Energy for Developing Countries, hosted in Nairobi on September 14-16 2009. Half of the people involved were Kenyan lecturers, Kenyan retailers and Kenyan employees of NGO's (14).

6.3 Wind energy in Kitui district

The SASOL project is about bringing electricity to the schools located in the rural areas of Kitui district. As shown before a grid connection is not an option, since it will be most of the times too expensive. With excluding the grid connection, two main options are remaining, solar and wind energy. SASOL has already done some projects powered by solar energy. The costs of the installed power are approximately €10,-/Watt installed capacity (15). Electricity from a generator running on biogas is not taken into account. A student team from Edukans has built a biogas digester in 2006. It performed well, but was faced with a lot of social resistance from the communities. For the schools and the test farm, SASOL wants to know whether wind turbines can be used for electricity production. Besides possible cost benefits, another benefit of wind energy should be the learning aspect. According to SASOL more can be learned from a wind turbine than from a solar PV installation. Especially if basic mechanical engineering skills are being trained, wind turbines can be of assistance in training manufacturing skills and flow dynamics and mechanics.

7 Technical Feasibility of Wind Energy in Kitui district

The technical feasibility of small scale wind energy depends strongly on the wind speeds in Kitui district, as seen in Equation 6.3. The produced power is dependable on the cube of the wind speed. The higher the wind speeds, the more viable a wind energy project will be. Important as well are the system requirements. This chapter will discuss the expected wind speeds in Kitui district, based upon previous research, the local wind speeds at three locations in Kitui district, the technical requirements and the estimated output of a wind turbine.

7.1 Expected wind

To understand the expected wind speeds it is necessary to have some background knowledge on the different winds and how they are caused since the wind speed distribution is highly dependable on time and geographical location. In this chapter extensive use is made of Burton et al (16).

7.1.1 Geographical variation

Wind energy can be seen as a form of solar energy, since the solar radiation causes differential surface heating over the globe. The greatest heating occurs close to the equator during day time. As the earth spins around its axis, the heated air follows this motion, causing warm air to rise, circulate in the atmosphere and sink back to the earth's surface in cooler areas. This large scale motion is influenced by coriolis forces due to the rotation of the earth and cause a large scale global circulation pattern, also referred to as doldrums and trade winds Figure 5.

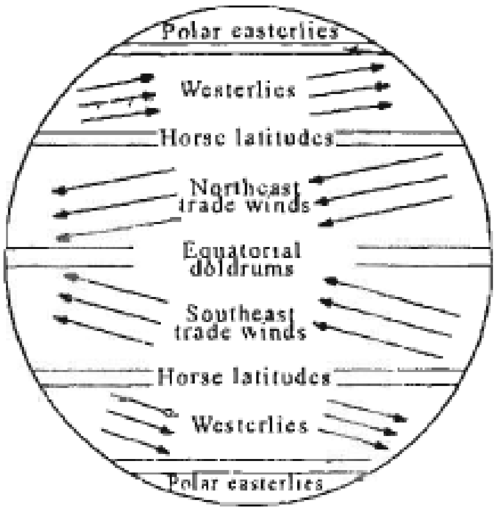


Figure 5: Geographical variability of winds (17)

The non-uniformity of the earth's surface influences these global patterns on smaller scale (continental scale). Hills and mountains lead most of the time to different wind speeds. The wind speed generally increases with altitude, thus higher wind speeds can be expected on mountains. Besides that hills and mountains can cause accelerations of wind flow. Together with funneling effects through passes and along valleys that are aligned with the flow, this can cause high local wind speeds. This means as well that reduced speeds can be found in sheltered valleys; Figure 6.

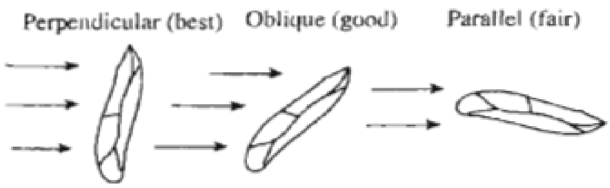


Figure 6: flow around ridges (17)

When looking on smaller scale, local variations can be seen due to thermal effects. That is why at coastal areas mainly high winds can be witnessed; there is differential heating between the land and the sea. Let's assume the Kenya case, where the air of the land is warmer then the sea air, which causes the air from the sea, flow to the land, rise and drop over the sea again, causing local circulation. Besides that, air will flow down mountains and create circulation on the slopes and at the foot of the mountain, because of daily heating and cooling at local differences in altitude. This kind of variation occurs on a daily basis and is called diurnal variations, Figure 7. Thermal effects are caused as well by the absorption and reflection of solar radiation by the vegetation, influencing the local winds.

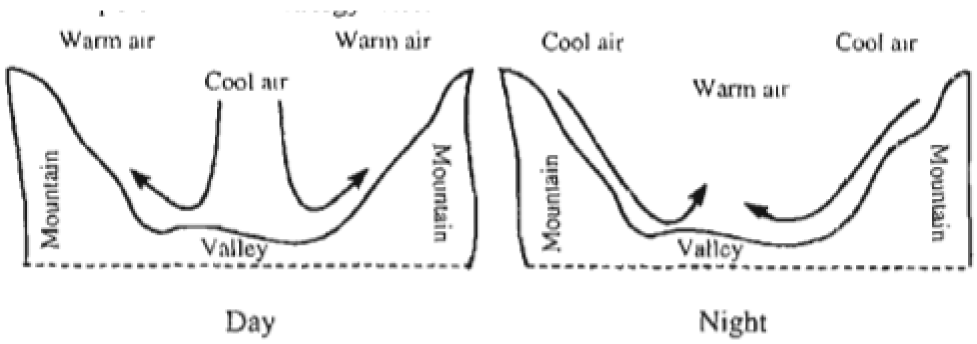


Figure 7: Diurnal variation (17)

Local variation is also caused by obstructions in the earth's boundary layer. As Figure 8 shows, obstructions as a forest, but also buildings, crops and grasslands influence the wind speeds. This is called wind shear. Wind shear has to be taken into account when using wind data from a certain reference height (z_r) for calculations at another height (z). It is important to use the right so-called roughness lengths (z_0) by up-or downscaling the data. This is done with the log-law:

$$\frac{U(z)}{U(z_r)} = \frac{ln\left(\frac{z}{z_0}\right)}{ln\left(\frac{z_r}{z_0}\right)}$$

Equation 7.1

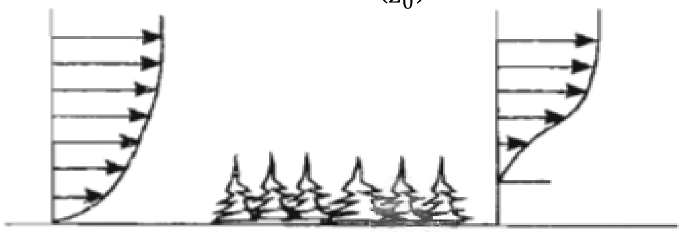


Figure 8: Boundary layer obstruction (17)

7.1.2 Variations in time

Long term variations are variations between decades and years. These variations are still not well understood and make it hard to predict energy output through the life time of a wind turbine at a specific location. There is a link between the temperature variation and the wind speed variation, what is used to do some predictions on the long term.

Yearly variations are mainly due to global climatic phenomena, change in atmospheric particulates (volcanic eruption) and sunspot activity.

Seasonal variations are easier to predict, with a probability density function. When wind data is clustered in bins, it has been found that almost always a fit with a certain Weibull function can be made. Seasonal variations are driven by insolation during the year, which changes over the year due to the tilt of the earth's axis. This is why the winter months are windier then the summer months. Besides this variation, tropical regions have monsoons accompanied with strong tropical storms.

Synoptic variations have a pattern with a recurrence of approximately 4 days, and are influenced by large scale weather patterns such as areas of high and low pressure and associated weather fronts as they move across the earth's surface. It mostly takes a few days till these patterns pass over a certain location. The synoptic variations are hard to predict.

Depending on the location there is a considerable variation between the different times of the day, diurnal variations, mainly driven by local thermal effects. As already indicated in paragraph 7.1.1, diurnal variations are caused by the heating of the air during day time and cooling down at night time.

Variations with a frequency of smaller then 10 minutes are called turbulence. Turbulence is caused by friction with the earth's surface and by thermal effects. It is quite difficult to explain it physically, and that is why it is mostly described statistically with the turbulence intensity:

$$I = \frac{\sigma}{\overline{U}} \qquad \text{Equation 7.2}$$

In which σ is the standard deviation of the wind speed data, and $\overline{U}$ is the mean wind speed.

The different variations are shown in Figure 9. This is called the "van der Hoven spectrum"[4]. A clear gap in the spectrum, the spectral gap, can be seen. Between frequencies of 2hours and 10minutes there is little energy in this spectrum.

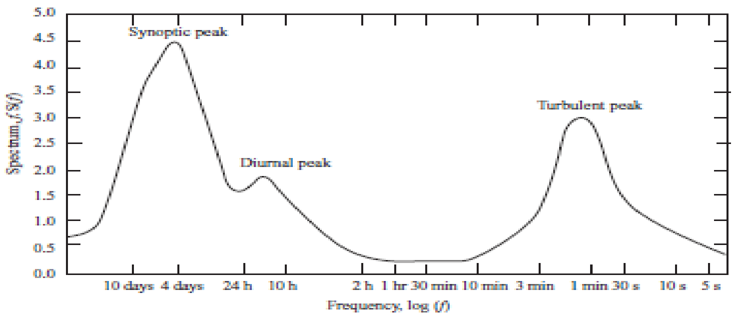


Figure 9: van der Hoven spectrum

[4] Applicable for different latitudes

7.1.3 Expected winds in Kenya

This paragraph is highly based on the work of Gatebe et al (18), Van Lierop and van Veldhuizen (10) and the Kenyan Windatlas (19). These sources give insight in what kind of wind speeds can be expected in Kenya.

Information about the type of phenomena that are influencing the Kenyan winds was given in (18). The article mentions that the winds in Kenya are mainly influenced by local influences (diurnal changes, based on thermal effects) and larger scale monsoon circulations (trade winds). The most influential trade winds are the North-Easterlies, coming from the Arabian Peninsula and crossing the Indian Ocean and the South-Easterlies, coming from the Indian Ocean. The other two minor dominant trade winds are some Atlantic Westerlies and Equatorial Easterlies. Table 2 gives an overview of when the different trade winds are predominant.

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
NEF	90.3	85.8	54.8	4.7	0.0	0.0	0.6	0.0	0.0	0.0	34.7	72.9
EEF	6.4	10.6	25.1	24.7	0.6	0.7	0.6	1.9	2.0	11.6	35.3	23.9
SEF	2.6	2.1	20.0	70.7	99.4	99.3	98.7	98.1	98.0	88.4	28.7	3.2
WF	0.6	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0

NEF, northeasterly flow; EF, equatorial easterly flow; SEF, southeasterly flow; WF, westerly flow.

Table 2: Monthly percentage frequency of synoptic circulation in Kenya

Because of Kenya's complex topography and the varying nature of the surface and the existence of large inland lakes, locally the horizontal and vertical wind speed profiles are heavily influenced (19). This makes many locations posses' substantial wind energy potential. The land-sea breezes influence the wind flows and weather patterns heavily in the country. Besides these water bodies, there are some high mountains (Mt. Kenya, Mt. Elgon, and Mt. Kilimanjaro), hills and plateau's (Yatta and Nyika Plateau) influencing the wind speeds. Marsabit is good example, where the winds are significantly influenced by the high venturi effects over the plains in valleys between mountains.

The work of Van Lierop and Van Veldhuizen is the oldest and was in the 1980's the most thorough research on wind speed data collection. From the almost 40 meteorological stations put up in Kenya, only 20 were able to deliver reliable data, according to (10). This because of several problems, most of the anemometers were poorly sited, broken, wind shear was not taken into account or the beaufort scale was used instead of metric scales. According to (10) this lead to deviation of up to 30%.

Figure 10 and Figure 11 are obtained from (10). They give a general view into the Kenyan winds. Both figures show that the wind speeds should not be expected to be too high in Kitui district, based on measurements done between 1960 and 1980 (10). Overall the wind speeds are quite low, with some exceptions at the coast and two inland locations. It shows as well that there are not any detailed data available for Kitui or even close by Kitui, since these data are the only data available from this period, according to (10) and (9).

Station number	Station	Remarks	Conversion factor 8) 2 m → 10 m	Average wind speed at 10 m height [m/s] J	F	M	A	M	J	J	A	S	O	N	D
2	Amolem	7)	2.00	2.6	2.6	2.0	3.6	2.6	2.6	2.0	2.2	2.2	2.0	2.2	[illegible]
5	Bungoma Hydromet 1st order station	3)	1.67	3.0	3.3	3.2	2.9	2.8	2.3	2.4	2.8	2.8	3.2	3.3	[illegible]
12	Embu Mwea Experimental station	2)	1.5	2.6	2.9	3.0	2.5	1.9	1.7	1.9	2.4	2.7	2.9	2.2	2.4
16	Calole Irrigation Scheme	2)	1.5	1.9	1.8	1.9	2.2	3.2	3.5	3.7	3.9	3.8	3.4	1.9	1.6
17	Garissa Meteorological station	1)	1	1.8	2.0	2.0	2.4	3.6	4.2	4.6	4.5	3.9	3.0	1.8	1.6
23	Kadenge Hydromet 1st order station	3)	1.67	2.7	2.8	2.8	2.1	1.9	2.2	2.0	2.4	2.9	2.2	2.3	2.4
26	Kakuma Mission	4)	1	5.8	5.1	-	-	-	-	-	-	5.1	6.9	6.7	7.1
30	Katilu small scale irrigation project	7)	1.67	3.2	3.3	3.3	3.0	3.3	3.2	2.8	3.2	3.5	3.5	3.2	3.2
31	Katumani experimental station	2)	1.7 *	4.2	4.2	4.7	3.9	3.1	2.7	3.0	3.2	4.0	4.6	4.6	4.3
33	Keekorok Hydromet 1st order station	3)	1.8	3.3	3.5	3.4	2.9	3.8	3.1	3.8	4.3	4.0	5.0	4.0	3.3
47	Kisii Hydromet 1st order station	3)	2.0	2.3	2.3	2.4	2.0	2.3	2.2	2.6	2.6	2.3	2.3	1.9	2.0
48	Kisumu Meteorological station	2)	1.4	3.3	3.3	3.4	3.0	2.3	2.3	2.3	2.5	2.5	2.7	2.8	3.1
62	Magarini G.I.S.	6)	1.38	4.1	4.0	2.9	3.2	4.0	4.0	4.1	4.1	3.9	3.6	3.1	3.4
79	Mombasa Airport met. station	2)	1.4	3.6	3.7	3.6	4.6	4.1	4.3	4.0	3.9	4.0	3.8	3.0	3.2
84	Mtwapa Mtwempi settlement scheme	4)	1	3.7	-	-	-	-	-	-	-	3.7	3.5	2.8	3.2
86	Muhoro Bay Hydromet 1st order station	3)	1.4	3.5	3.4	3.6	3.1	3.1	3.1	3.1	3.8	3.7	3.7	3.3	3.3
88	Nairobi Dagoretti Corner	1)	1	3.6	3.4	3.4	2.5	1.7	2.5	1.5	1.7	2.0	2.9	2.9	3.2
90	Nairobi Embakasi Airport Met. Station	2)	1.4	4.6	4.6	5.2	4.2	2.9	2.6	2.6	3.1	3.3	4.2	4.8	4.8
92	Nairobi Wilson Airport Met. Station	1)	1	3.4	3.6	3.6	3.0	1.9	1.8	1.9	2.0	2.4	3.0	3.2	3.3
95	Nakuru D.C. Office	1)	1	2.3	2.1	2.2	1.7	1.7	1.9	1.9	1.8	1.6	1.7	2.8	2.1
96	Nakuru Showground Meteorological Station	2)	1.5	2.8	3.3	3.3	2.5	2.1	2.0	2.0	1.8	1.9	1.8	1.9	2.2
101	Narok Meteorological station	1)	1	1.9	1.7	1.8	1.7	2.7	1.5	1.7	2.0	2.0	2.2	1.8	1.6
111	Rumuruti M.O.W.	2)	1.5	1.1	3.3	3.6	3.4	3.2	2.9	2.8	2.6	2.8	3.1	3.2	3.1
112	Rusinga Island Hydromet 1st order station	3)	1.4	3.9	4.0	4.2	3.3	3.2	3.0	3.4	3.5	3.5	3.6	3.4	3.6
116	Tana Irrigation Scheme (Hola)	5)	1.45	2.1	2.2	2.5	3.0	3.7	4.2	4.3	4.7	4.2	3.7	1.9	1.7
122	Turkwell small scale irrigation project	7)	1.67	4.2	4.5	5.0	4.5	4.5	4.2	3.8	4.5	5.0	5.2	4.5	3.8

Figure 10: Meteo stations with monthly mean wind speeds at 10m

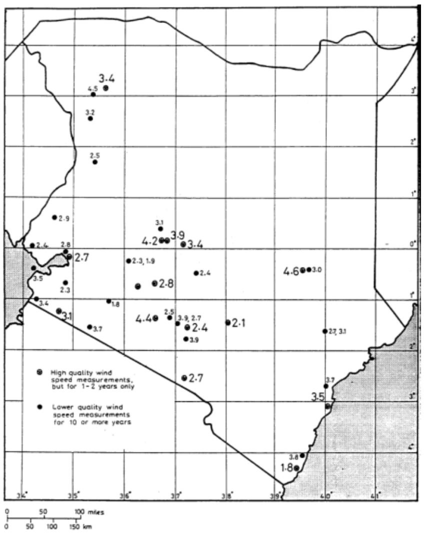


Figure 11: Yearly mean wind speeds

The latest work on wind potential was done by the Kenyan Ministry of Energy in cooperation with the SWERA project[5] of the UNEP[6] (19). They developed a wind atlas for Kenya, based on modern mapping techniques of Remote Sensing, GIS, GPS, surveying, digital data capture, database design, cartography and spatial and geo-statistical modeling. This means it is more based upon estimations than actual measurements. Besides it is not possible to obtain detailed local wind data from this wind atlas. Only the data as shown in Figure 12 are available, so local variations are not taken into account. When looking at the area of Kitui the mean winds speeds seem quite low.

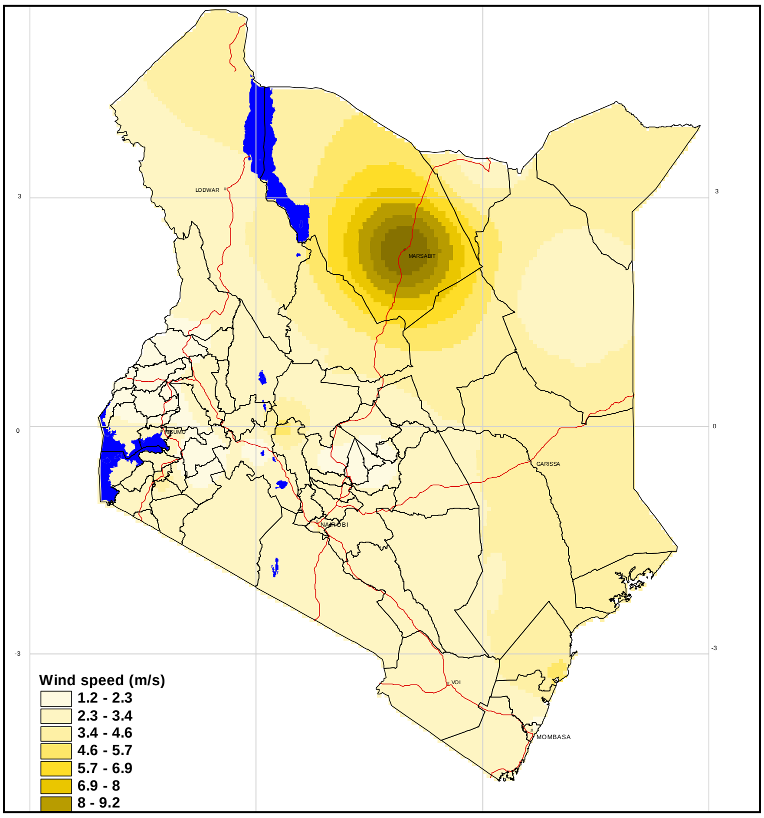


Figure 12: Mean wind speeds in Kenya (19)

[5] Solar and Wind Energy Resource Assessment, UNEP in cooperation with DLR, IEA, NASA, NREL and Risoe
[6] United Nations Environment Program

Besides the quantitative data of the wind resource atlas, data was found for Makindu, a town approximately 100km from Kitui, Figure 13. Data from 1976 up to 2000 were available (20; 21), through the internet.

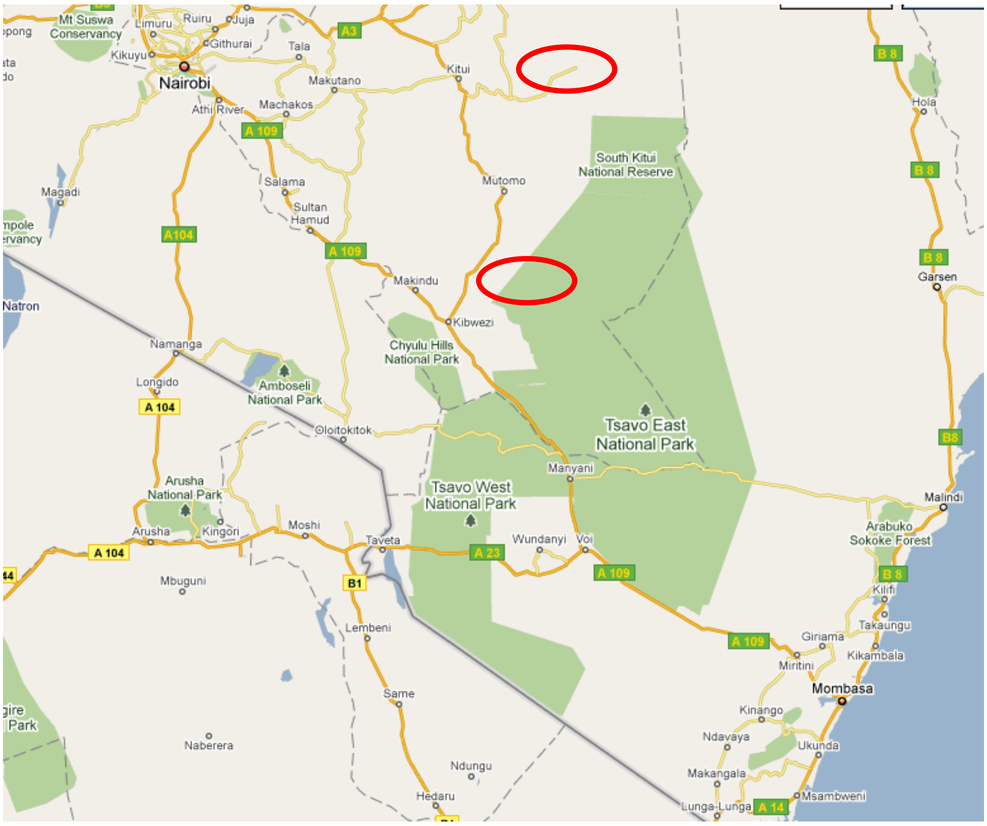
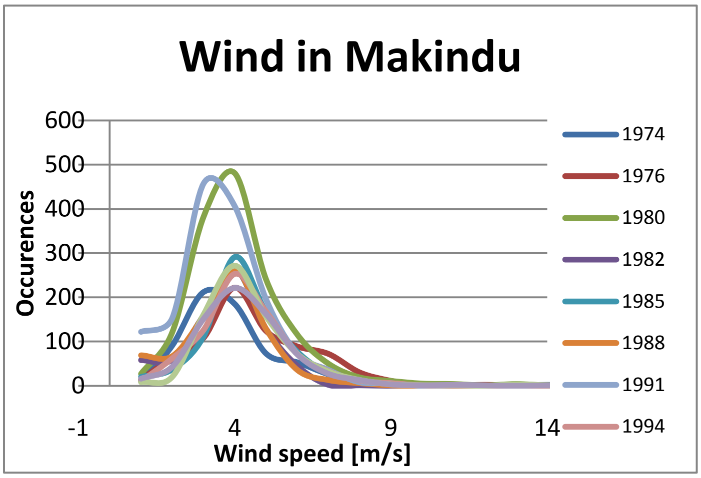


Figure 13: Kitui and Makindu

The winds in Makindu are shown in Figure 14 for some periods between 1976 and 2000. The graphs are showing the wind speed distribution and the wind direction. Remarkable is that the wind direction is almost always between 90 and 150 degrees, when binned in 30 degrees bins. For the wind speeds can be concluded that they are quite low: the maximum annual mean wind speed is 3.35m/s and the minimum 2.15m/s at 2 meters ASL.



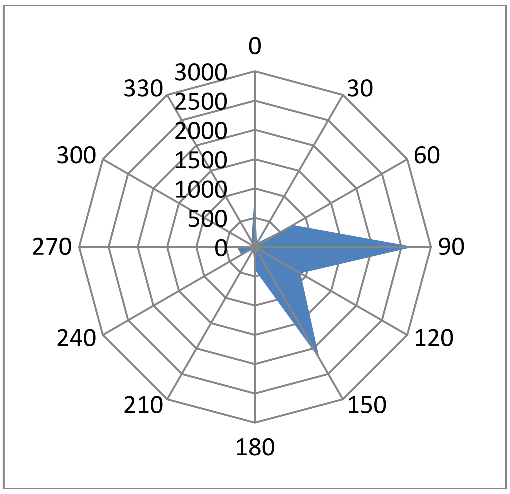


Figure 14: Wind speeds and wind direction for Makindu '76-2000

The wind data from Makindu will be used to extrapolate the data obtained in Kitui district for over a longer period. Unfortunately only three months of data can be obtained from the location in Kitui district.

Kitui town has its own meteorological station, but after paying a visit to the location, it showed that the data from this station could not be used for this research. The two main reasons were that the anemometer was placed at 1.5m from the ground level and that the anemometer was surrounded with trees, bushes and buildings, Figure 15. Another option for obtaining wind data are normally airports or airstrips, but unfortunately the airstrips in the neighborhood only measure wind direction. The only option remaining is using the data from Makindu. The station of Makindu is located at the airport of Makindu. Quite an open field, and the wind speeds are recorded at a height of 2m ASL.

Figure 15: Anemometer in Kitui, Kalawaroad, Ministry of Water

7.2 Wind in Kitui district

In order to get reliable wind data for the locations where SASOL is interested in installing wind turbines local measurements had to be taken. As shown in paragraph 7.1.3, there are wind data available from Makindu, a town 46km from the nearest location of interest. Since this project only lasts for a bit more than two months, the found data have to be extrapolated with the data from Makindu. This paragraph will deal with that.

7.2.1 Wind measuring equipment

The wind measurements are done at 6meters height. This to decrease influences from the surroundings at the measurement locations and at the same time make it possible to transport the measurement equipment by public transport. Three tubes of each two meters were bolted together and supported by guy wires, attached to the tubes at 4 meters height. On top of this a bicycle front wheel axis is fixed with two small metal strips welded on it. These strips are welded perpendicular on each other. On one of them the wind meter is attached, on the other a wind vane is fixed. This makes sure that the wind meter is always perpendicular to the incoming wind. Figure 17 and § 11.1 show a sketch. Figure 16 shows a picture of the installation.

Figure 16: Wind measurement installation

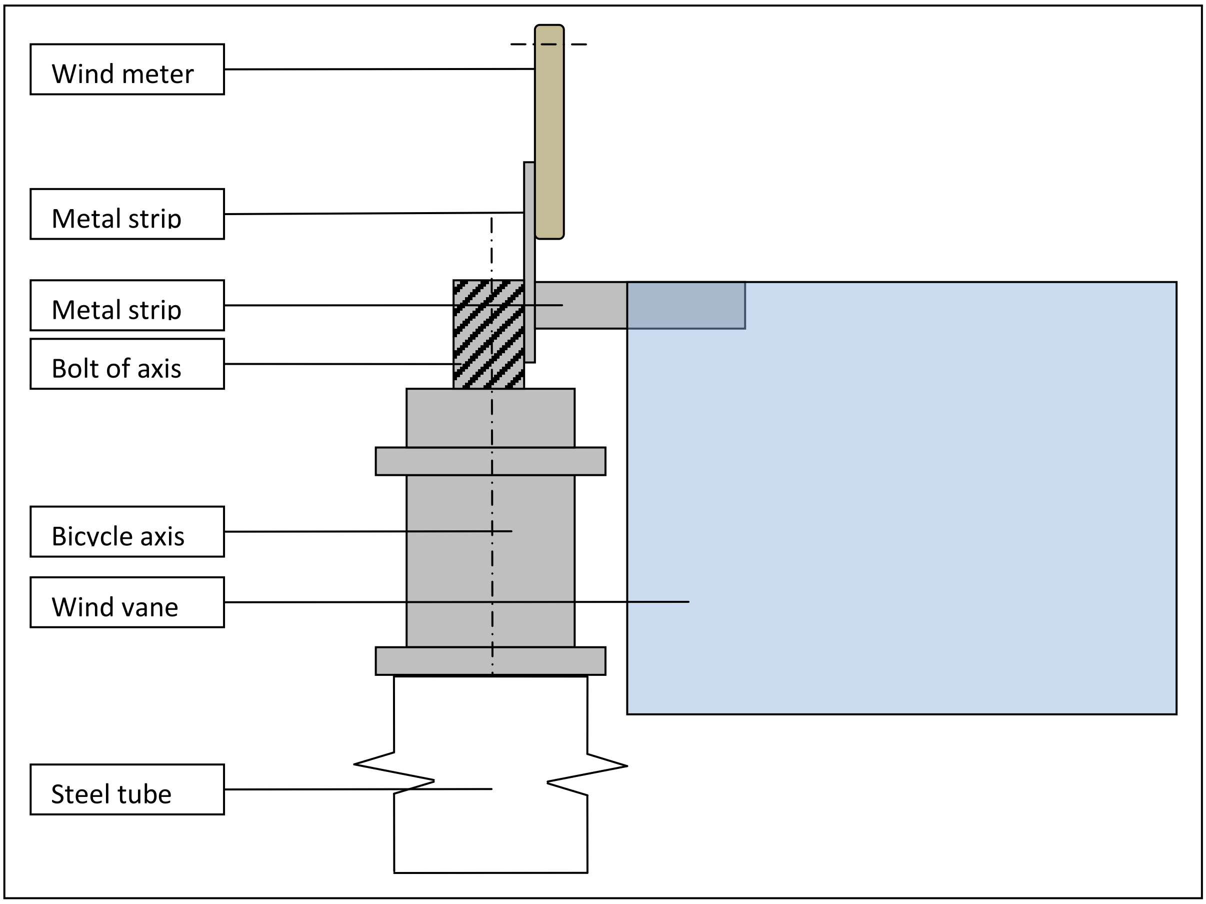


Figure 17: Sketch of wind measurement equipment

The used wind meter is a SILVA ADC (Atmospheric Data Centre) PRO. It is able to log up to 2000 records and record in those records, the ambient pressure, the altitude, the temperature and the wind speed. So if each 10 minute data is recorded, the wind meter can be up and running for 13 days

In order to know whether the collected data from the wind meter are reliable the wind meter was calibrated in the low speed wind tunnel at Delft Technical University, Figure 18 and Figure 19 showstwo pictures from the test.

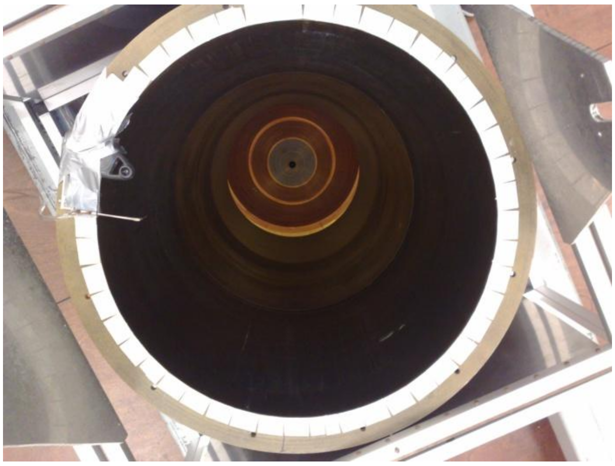


Figure 18: Calibration in wind tunnel

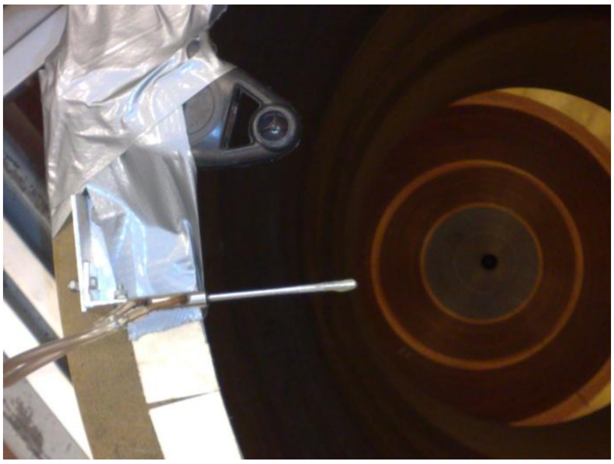


Figure 19: Wind meter and Pitot tube

Intervals of 0.5m/s were used. It was striking to see the difference between the measured wind speed with the wind meter and the pitot tube of the wind tunnel.

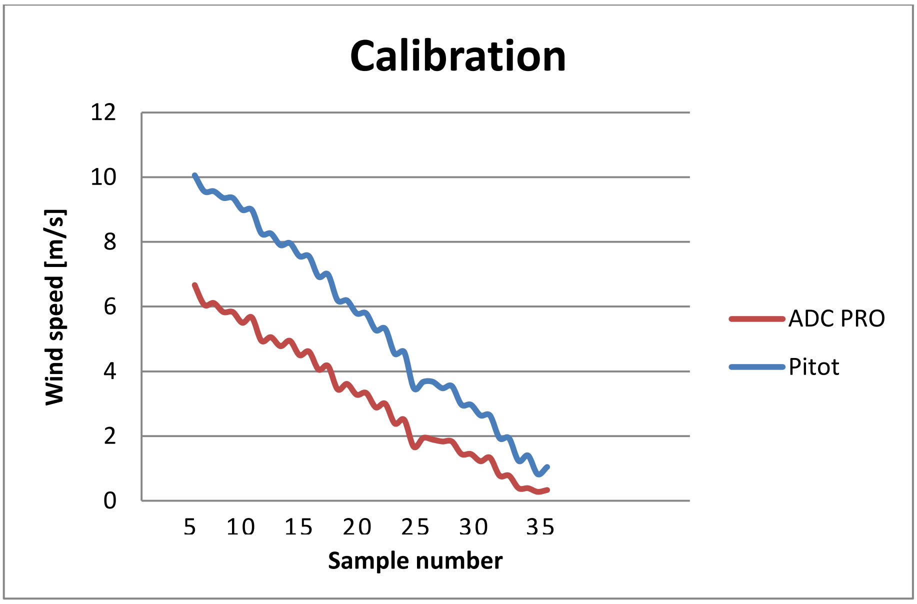


Figure 20: Calibration of wind meter

When plotting the results of the pitot tube against the measurements of the ADC PRO an interesting results shows:

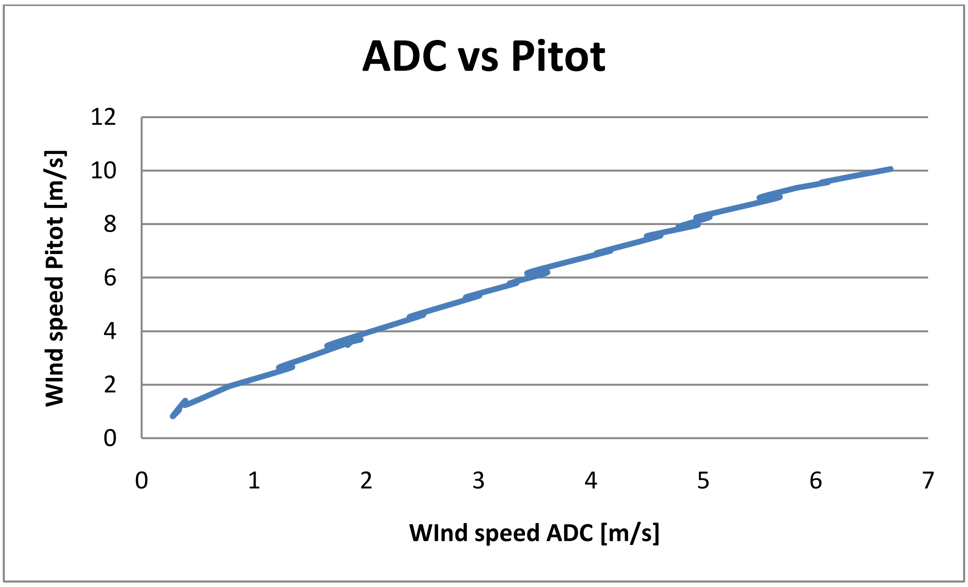


Figure 21: ADC Pro vs. Pitot

It shows that there is almost a linear relation between the measured wind speed and the actual wind speed. That relation is the function that matches with the graph in Figure 21. This function can be used to upscale the done measurements in Kitui district. The relationship used is:

$$U = 1.4633U_{ADC} + 0.8382$$ Equation 7.3

7.2.2 Locations

The locations are chosen after consulting employees of SASOL who have a lot of field experience in Kitui and Mutomo district, and are the ones that know where most of the wind will be. Besides that a criterion was that the measurements are done on a location where a wind turbine can be installed for power generation. In these cases the power will be used to supply the schools with electricity.

The three locations where the measurements were done are (see Figure 22):

- Kanyangi Boys Secondary school
- Kanziko Secondary school
- SASOL MultiPurpose Centre South (MPC)

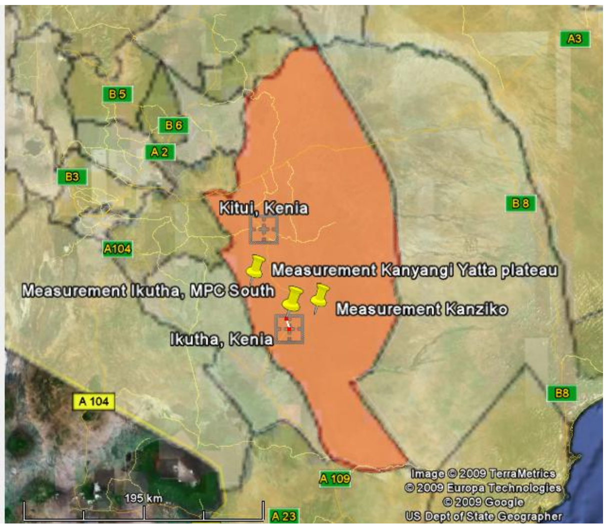


Figure 22: Measurement locations

The initial plan was to get wind data for just the two secondary schools. But when the measurements at Kanyangi secondary turned out to give low wind speeds, in consultation with SASOL it was decided to skip the last measurement there and do extra measurements at the location of the new MPC of SASOL near Ikutha (MPC South). At the Kanyangi Secondary two weeks of data are collected, at Kanziko three weeks of data and at MPC south one week of data. The following figure shows the time line with the data collection moments.

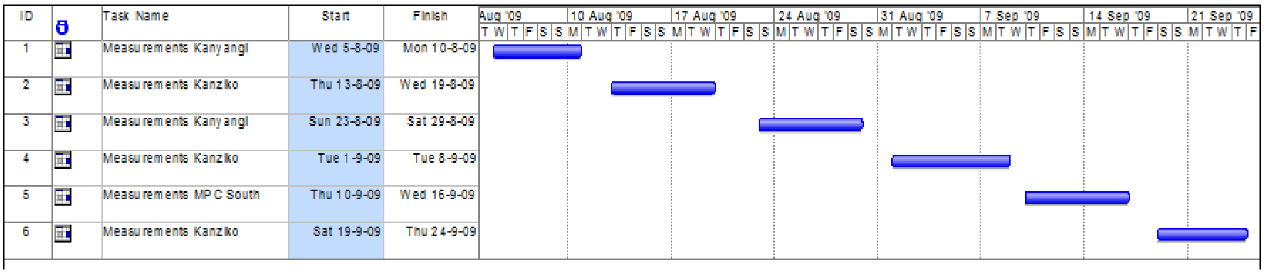


Figure 23: Data collection moments

Kanyangi boys' secondary school

GPS coordinates: 1,7526° S; 37,9058° E.

The school is located on the Yatta Plateau, which is a part of the district that is up higher than the surroundings. That is why it was chosen for the measurements. Kanyangi is at an altitude of approximately 1400m above sea level (ASL), compared to Kitui town 1100m ASL and the surroundings of 800m ASL. Since the school is on top of the plateau the wind speeds can be expected to be quite high. Unfortunately the wind speeds turned out to be on the low side. This can be explained that the accelerated wind has been slowed down over the plateau when it reaches Kanyangi. The most prevailing wind direction is South-East, and the orientation of the plateau is from South-East to North-West, with Kanyangi on the North-West side of the plateau.

Detailed pictures of the location where the measurements were taken and the surroundings are shown in Figure 24. Looking at the surroundings of the measurement equipment, which is most likely to be the location of the wind turbine, it can be concluded that the obstructions can be characterized with a roughness length of 100mm[7], which is used for taking wind shear into account, when comparing the data with the Makindu data. The school building is at the west of the wind meter, but since most of the wind is coming from the south east, it should not be that a big problem.

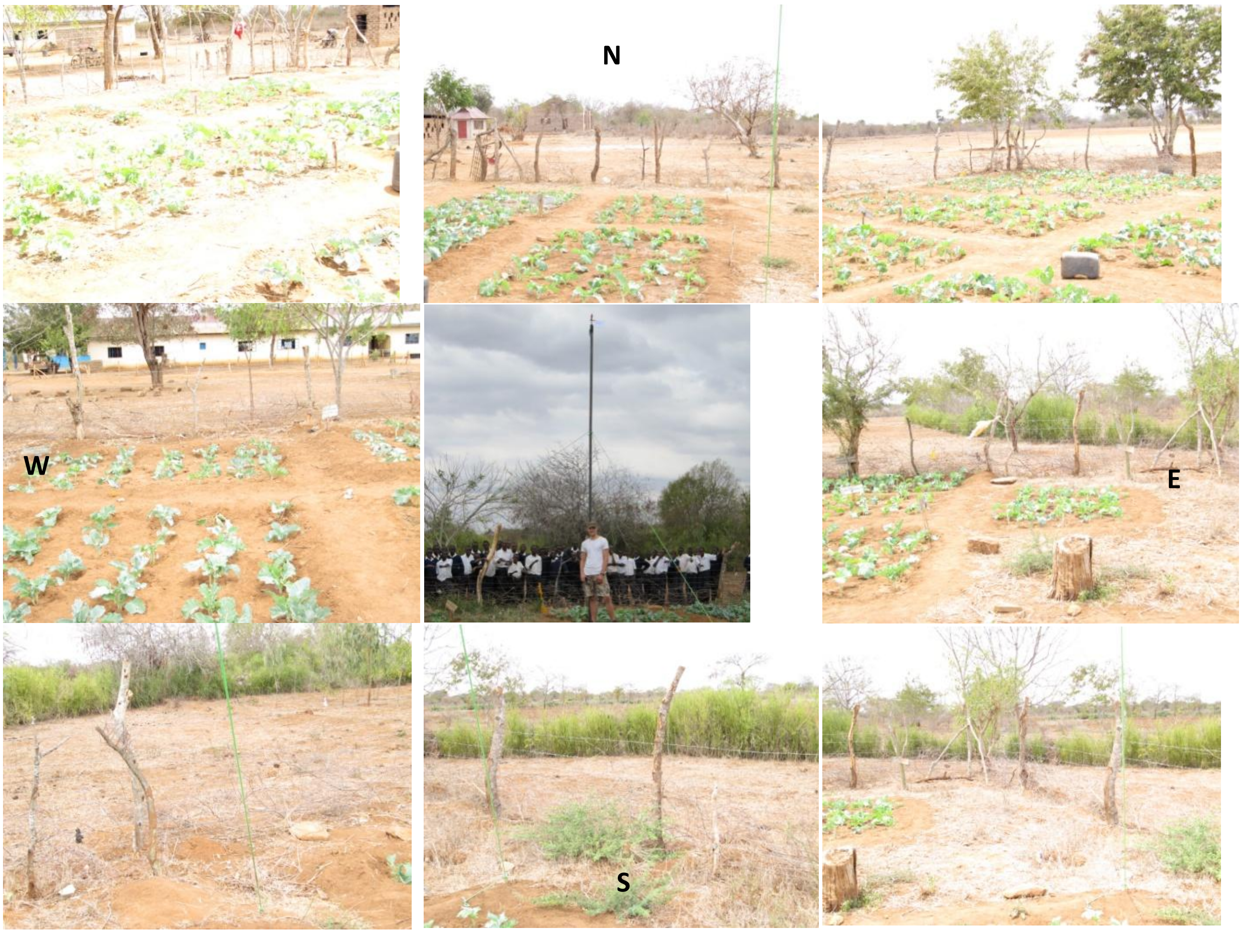


Figure 24: Surroundings Kanyangi Measurement location

[7] See Table for roughness lengths in Attachment III

The raw data obtained from Kanyangi are shown in Figure 25.

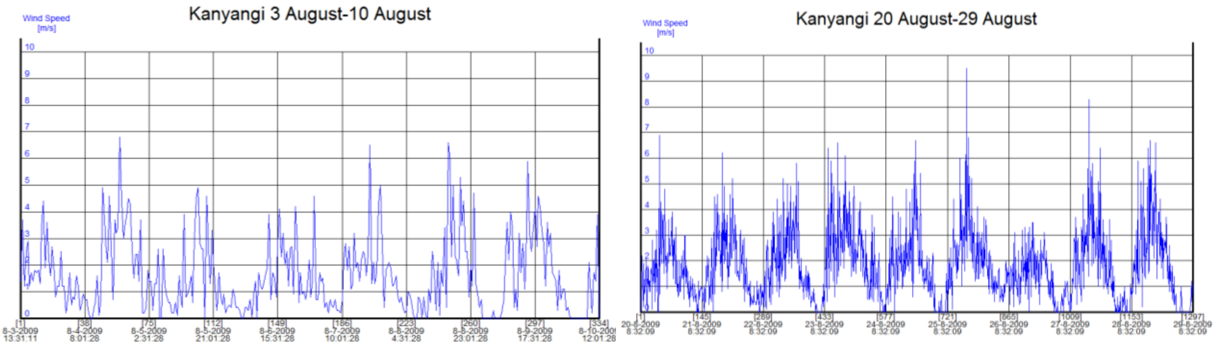


Figure 25: Raw data Kanyangi

Clearly some high variations during a day can be seen. The peaks are almost always between 14.00 and 15.00 hours, whereas the minima are during the night, 03.00 and 05.00 hours.

Kanziko secondary school

GPS coordinates: $1,9578^{0}$ S; $38,3631^{0}$ E.

Kanziko is located in the driest parts of Kitui district and lies close to the district boundaries with Tsavo-West national park. There is a mountain range in between, which can be seen in the Figure 26. The school is located just out of the main town on the slope of a hill. The altitude in Kanziko is approximately 800m ASL. The school was included in an energy survey in 2005, that is why this school is in this research as well (22).

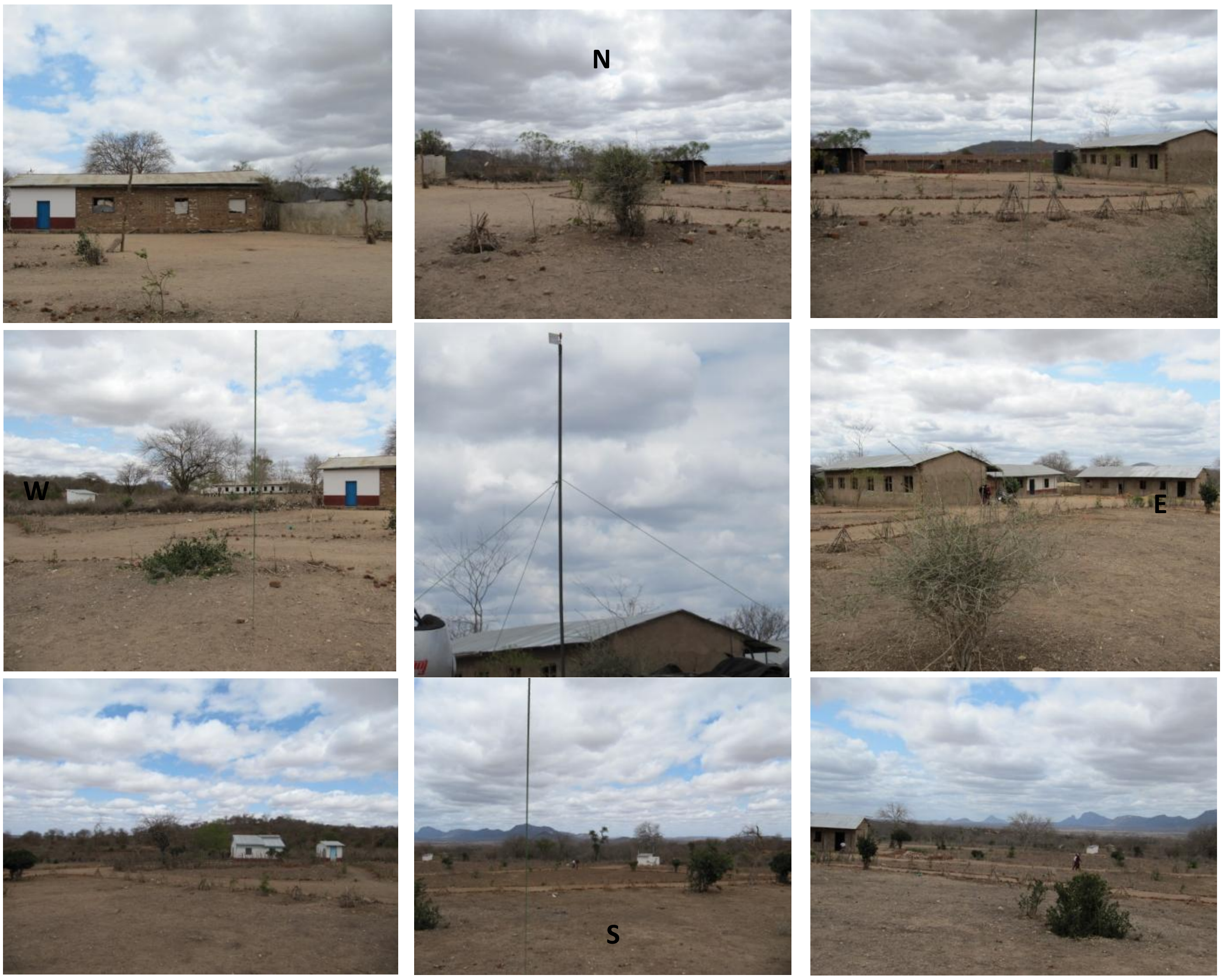


Figure 26: Surroundings Kanziko Measurement location

As Figure 26 shows this measurement location has more buildings around it. Fortunately most of the winds are coming from the southern directions (23). This is also the direction of the slope of the hill. The roughness length taken for this location is 50mm. The location is just on the edge of a valley, as the following sketch shows.

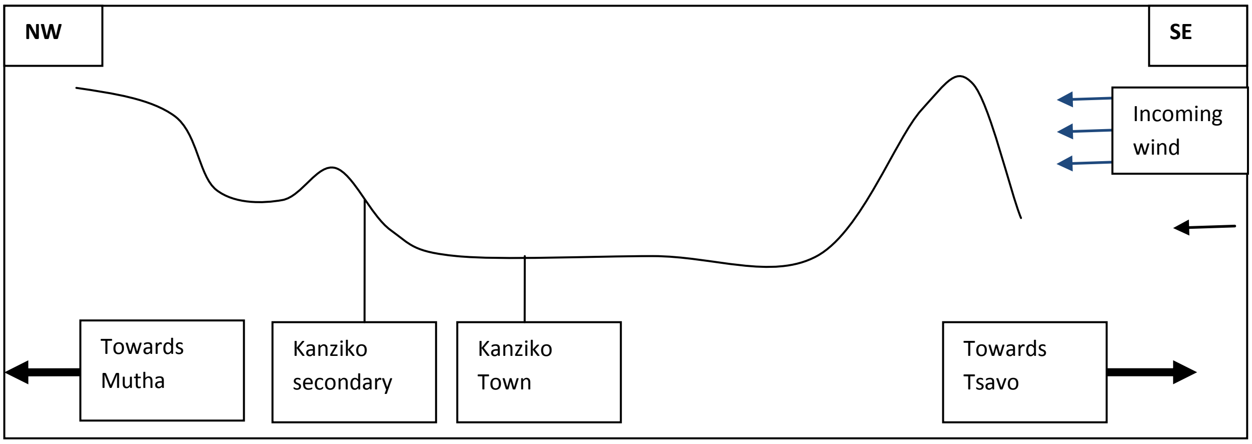


Figure 27: Sketch of location Kanziko secondary

This could result in accelerated wind at the measurement locations. The first measurements at Kanziko looked promising, but later on these data seemed to follow the trend of Kanyangi as well. The raw data are available in Figure 28.

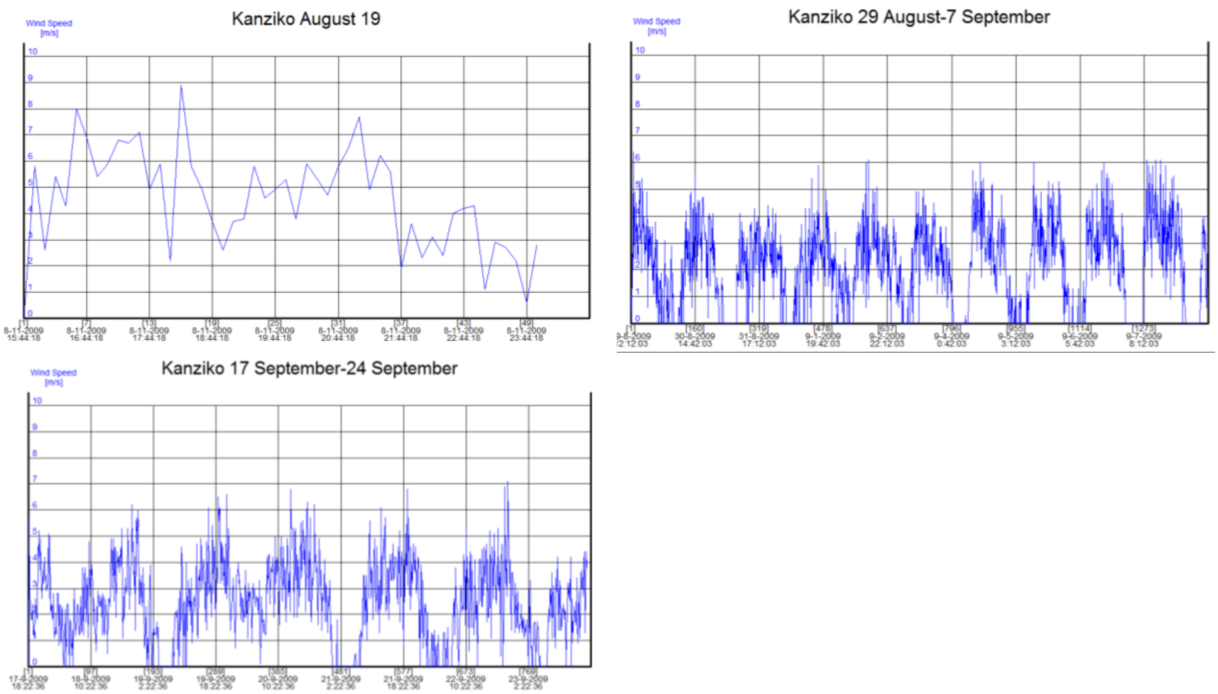


Figure 28: Raw data Kanziko

Again a clear diurnal pattern is shown with high peaks and minima during the night hours.

MPC South

GPS coordinates: 1,9948^0 S; 38,1639^0 E.

The MPC will be located 8km from Ikutha, one of the bigger places in the Kitui district, and is placed on the land owned by SASOL in this area. On the land SASOL will be building an MPC, in which people will be trained. Also a test farm and a field office will be built there. This makes this location an interesting location in this feasibility study. The measurements were done on the compound of a family living close to the location of the MPC. This had to do with safety issues. Figure 29 gives an impression of the location. The picture shows quite some trees, what has to be taken into account for the done measurements. Since at the location where the MPC will be built, and thus the potential location for a turbine, there will be fewer obstructions. In this case the obstructions are on the north and north-west side of the wind meter.

Figure 29: Measurement MPC South

The raw data of MPC south are shown in Figure 30.

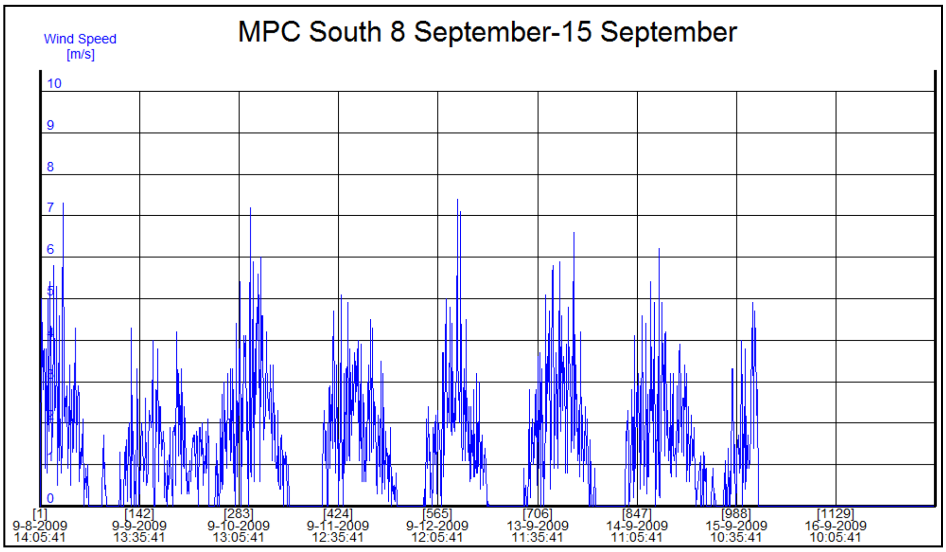


Figure 30: Raw data MPC south

Again a clear diurnal pattern can be seen, and at night times there are even bigger gaps, where there is almost no wind. Besides that the density of the wind speed distribution seems lower compared to the data from Kanziko.

7.3 Wind data Analysis

The required wind measurements are done. There are some steps that need to be done to make the data applicable for analysis (17):

- Upscaling data with Equation 7.3 (calibration)
- Scaling data to 10m. height from 6m. with Equation 7.1 (wind shear)
- Extrapolating data with measure-correlate-predict (MCP) technique (16)
- Put the wind speeds into bins of 0,5m/s
- Find a Weibull distribution for each location
- Energy production estimate

MCP is a way of extrapolating the short term data obtained from the three locations over a longer term with the use of the data from Makindu. One of the simplest approaches of MPC is the linear regression technique:

$$U_{site} = a + bU_{long\ term}$$ Equation 7.4

The factors *a* and *b* are found by comparing the obtained data with the data from Makindu at the same time of the year, as an example, the mean wind speed at August 11 2009 in Kanziko will be compared with the mean wind speed in Makindu on August 11 2009 (24)[8]. This will be done for all the data of one of the three locations, and a relation might be found. With this relation the longer term data can be used to extrapolate the data in one of the locations for over a year. This has to be done for each of the three locations.

Next thing is to put all the wind data into bins of each 0.5 m/s (25). A so-called wind frequency distribution is then obtained. These figures will be shown for each of the locations. When the frequency distribution is known, a Weibull fit can be made with this distribution. When put into bins for all locations Weibull distributions can be obtained. A Weibull distribution consists of two factors, the shape factor, *k*, and the scale factor, *A*. The relation is:

$$U_{mean} = A\Gamma\left(1 + \frac{1}{k}\right)$$ Equation 7.5

$$\frac{\sigma_U^2}{U_{mean}^2} = \frac{\Gamma\left(1 + \frac{2}{k}\right)}{\Gamma^2\left(1 + \frac{1}{k}\right)}$$ Equation 7.6

When Equation 7.6 is solved for *k*, then Equation 7.5 can be used to calculated *A*. When both factors are known, the Weibull distribution can be calculated:

$$f = \frac{k}{A}\left(\frac{U}{A}\right)^{k-1} \exp\left(-\left(\frac{U}{A}\right)^{k}\right)$$ Equation 7.7

[8] With taking the wind shear into account (from 2m to 6m ASL)

With Equation 7.7 the distribution of wind speeds can be calculated for over a full year for each of the locations, and predictions can be made on the power output of wind generators at these locations.

7.3.1 Kanyangi

Figure 31 shows the wind data measured in Kanyangi and the data obtained from Makindu (24). There is not a strong similarity between the two graphs. In order to get some feeling about the similarity the data of both locations are plotted against each other in Figure 32. Remarkable is that

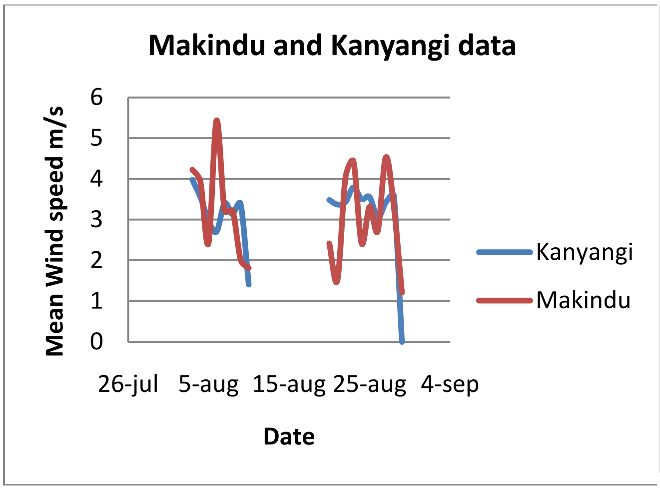


Figure 31: Data Makindu and Kanyangi

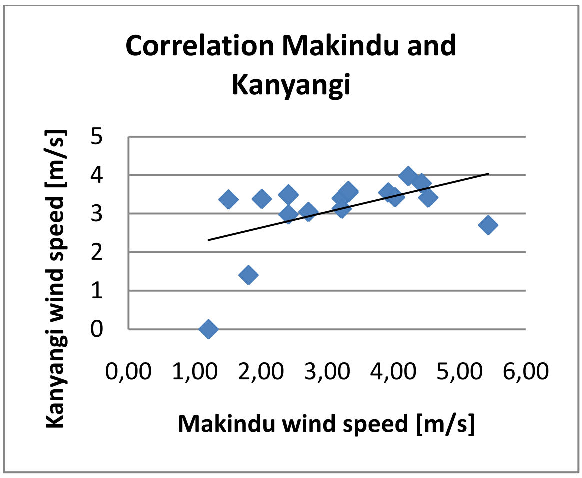


Figure 32: Correlation Makindu and Kanyangi

most data points are located along one line. When drawing a straight line through these points, Equation 7.4 can be solved for the wind data in Kanyangi, giving Equation 7.8.

$$U_{Kanyangi} = 1.8238 + 0{,}4075 U_{Makindu}$$ Equation 7.8

With this equation the available data of Makindu (21) are used to predict yearly data in Kanyangi. This gives the bar-graph in Figure 33.

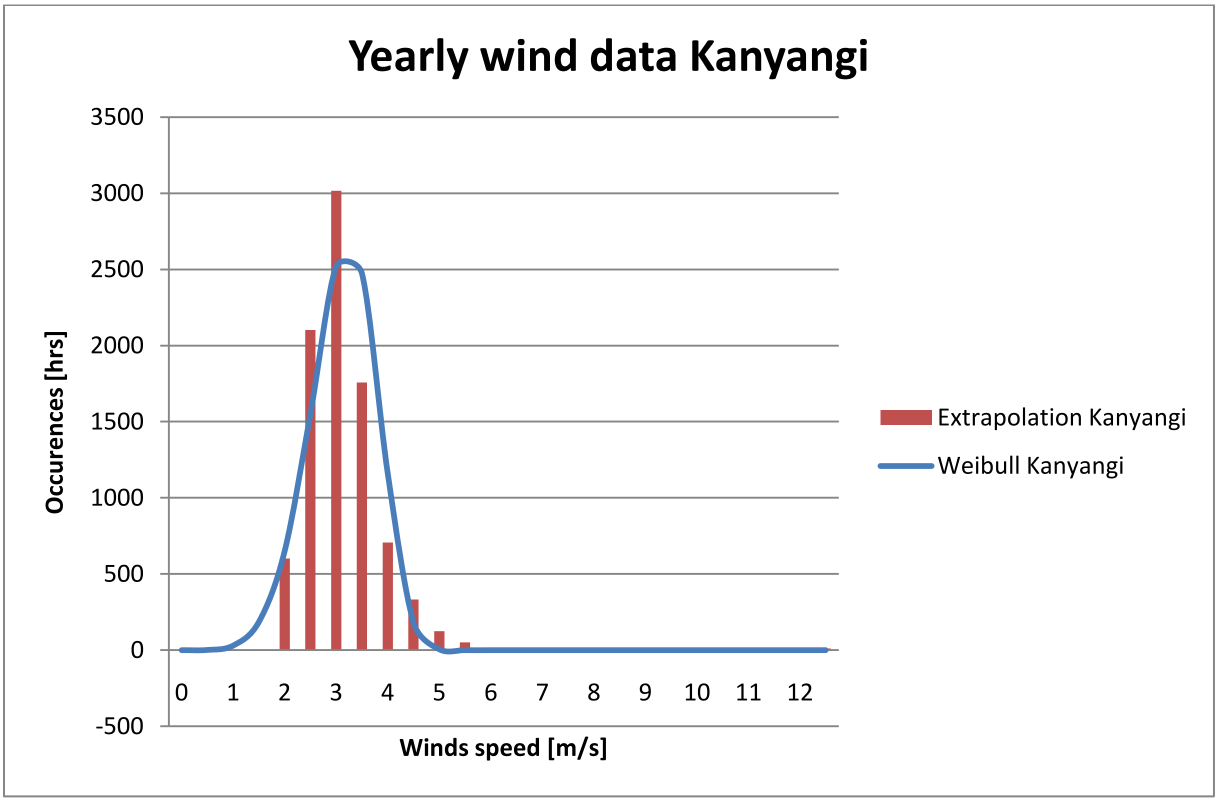


Figure 33: Yearly wind data Kanyangi

The bar graph is used to fit a Weibull distribution function for the yearly wind data in Kanyangi, the blue line. This is a Weibull function with a shape factor, *k*, of 5.51 and a scale factor, *A*, of 3.36. The yearly mean wind speed in Kanyangi will be about 3.1m/s.

7.3.2 Kanziko

Correlating the data of Kanziko and Makindu with each other gives Figure 34.To be able to find a

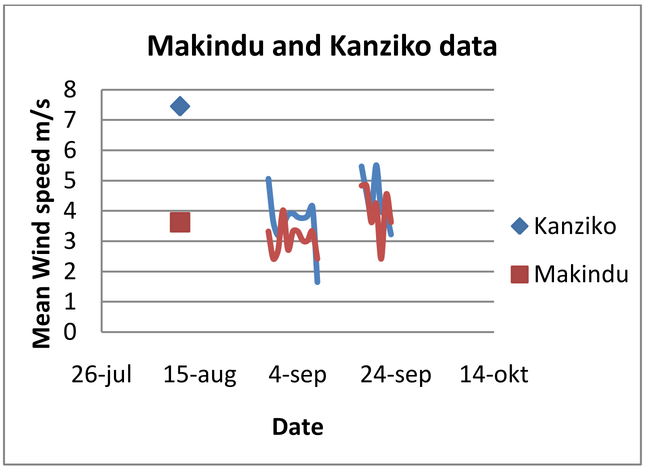


Figure 34: Data Kanziko and Makindu

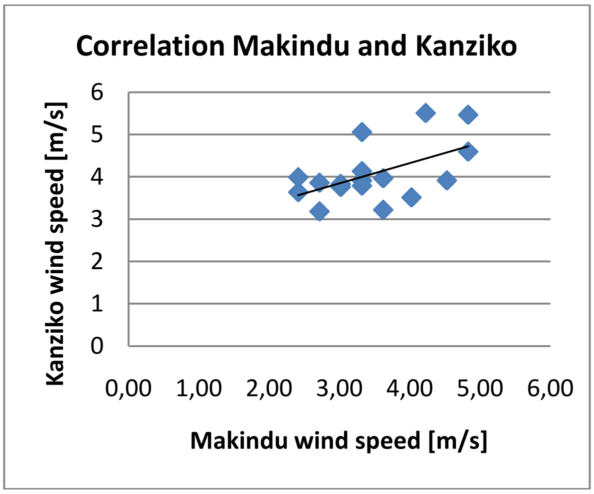


Figure 35: Correlation Kanziko vs. Makindu

relation between the data the biggest differences are taken out and both the wind speed distributions are plotted against each other, Figure 35. The relationship can between the data of Makindu and Kanziko can be put in the form of Equation 7.4, as shown in Equation 7.9

$$U_{Kanziko} = 2.4048 + 0{,}4797 U_{Makin\ du} \quad \text{Equation 7.9}$$

With this relation a yearly wind distribution can be made for the data in Kanziko and with that a Weibull distribution can be made as well for Kanziko, the red and the blue lines in Figure 36 respectively:

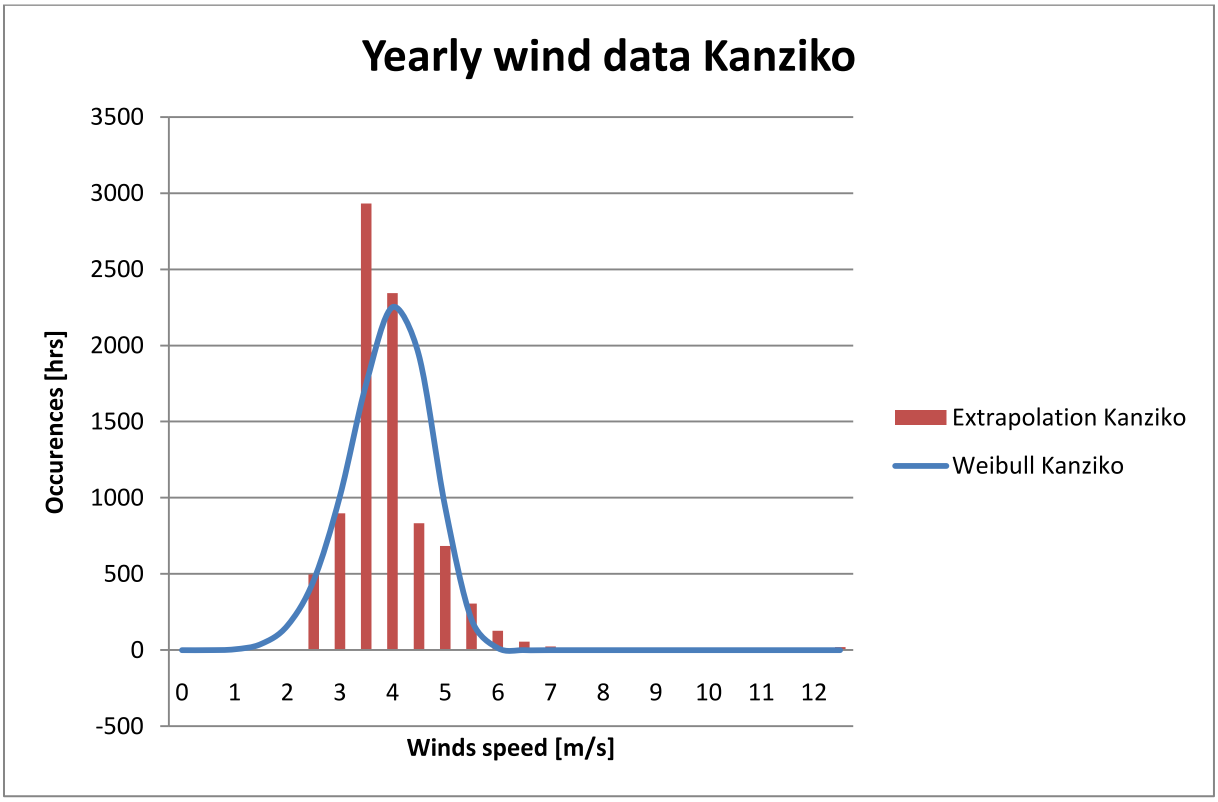


Figure 36: Yearly wind data Kanziko

The Weibull distribution as shown in Figure 36 has a shape and scale factor of 5.85 and 4.22 respectively. The yearly mean wind speed in Kanziko is predicted to be 3.9 m/s.

7.3.3 MPC South

When comparing the wind data from MPC South with the data from Makindu, Figure 37 is obtained. There is some strong resemblance between these data as well. This might be explained by the fact that MPC South is the location closest to Makindu. This can be seen as well by finding the relationship between the data by plotting MPC South vs. Makindu, Figure 38.

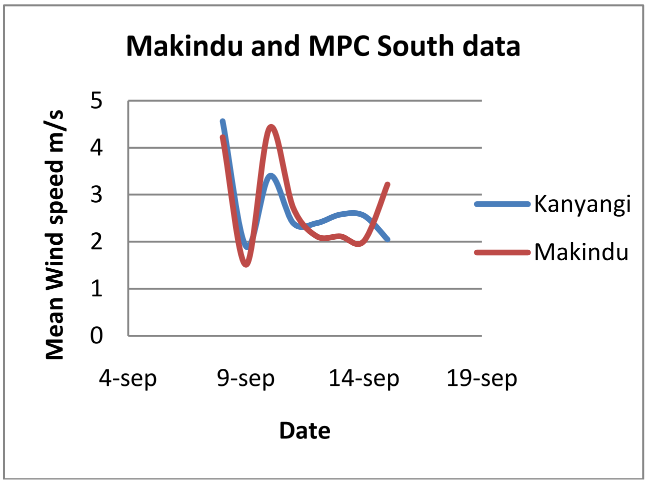


Figure 37: Data Makindu and MPC south

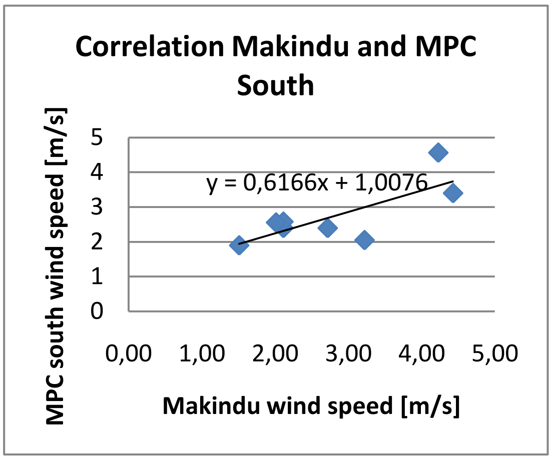


Figure 38: Correlation Makindu and MPC south

This gives Equation 7.10 as a solution to Equation 7.4.

$$U_{MPC\ South} = 1.0076 + 0.6166U_{Makindu}$$ Equation 7.10

With this known the yearly wind data for MPC south can be predicted, giving the bar graph in Figure 39. Fitting a Weibull function to this, gives the blue graph in this same figure.

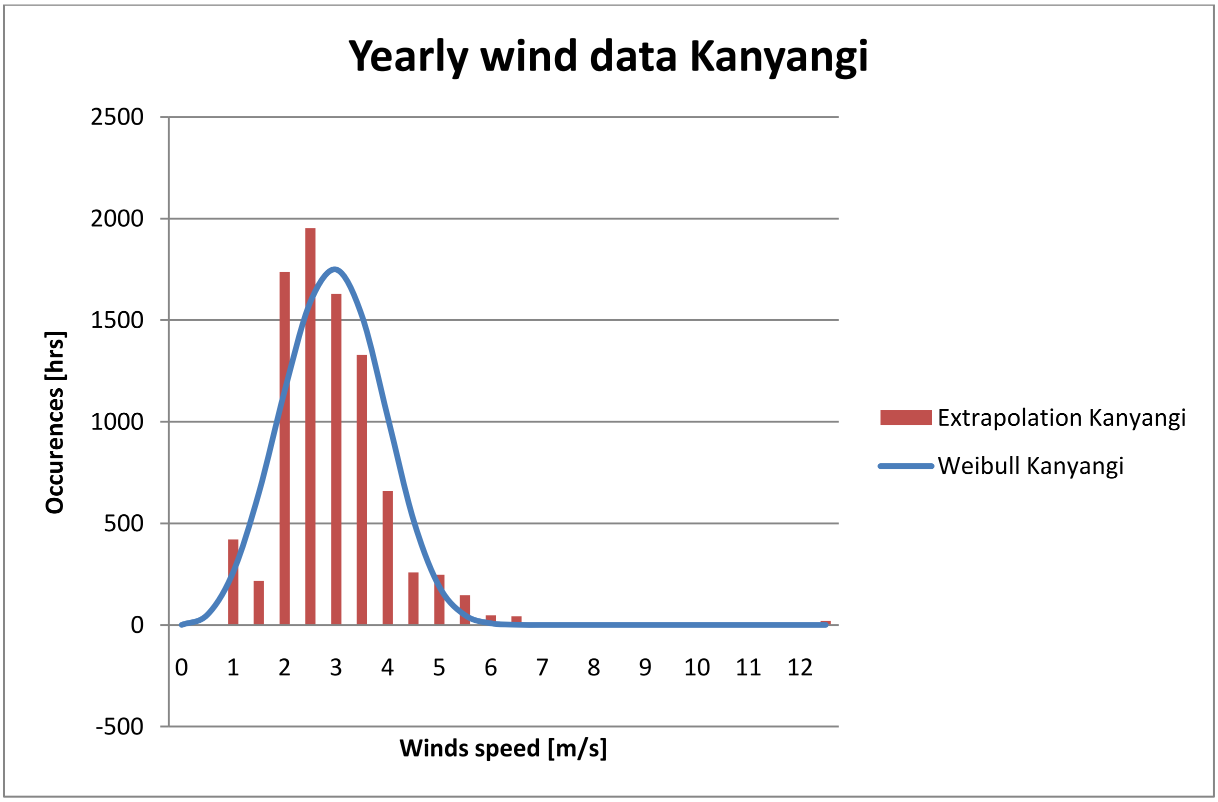


Figure 39: Yearly wind data MPC South

For MPC South this gives a Weibull function with shape factor, *k*, of 3.39 and a scale factor, *A*, of 3.27. The predicted yearly mean wind speed at MPC South will be 2.94 m/s.

7.3.4 Judging the data

The variables of all three locations are known. With that some other variable can be calculated that can assist in judging whether the locations are suitable for using wind energy (17). The variables are:

- Turbulence intensity $I = \frac{\sigma_v}{\bar{U}}$
- Average power density $\frac{\bar{P}}{A} = \frac{1}{2}\rho\bar{U}^3$
- Energy pattern factor $k_e = \frac{\frac{1}{2}\rho\overline{U^3}}{\frac{1}{2}\rho\bar{U}^3}$

For each of the three locations, these variables are calculated and put in Table 3.

Location	Mean wind speed [m/s]	Turbulence intensity	Weibull		Power density [W/m²]	Energy pattern factor [-]
			k	A		
Kanyangi	3.1	3.45	5.51	3.4	18.31	1.386
Kanziko	3.9	3.7	5.85	4.2	36.6	1.32
MPC South	2.94	2.17	3.39	3.3	15.03	2.18

Table 3: Variables for the three locations

From the table it becomes clear that the secondary school in Kanziko has the best location for using wind energy. But still at this location, the power density is quite low. But when looking at the energy pattern factor and the turbulence intensity, the location seems to do have some potential. Both of these variables show that the wind distribution over the year has big deviations around the mean wind speed, meaning that there can be quite high peaks in the produced wind power during the days. When looking at Figure 40 it becomes clear that there are strong peaks during the collection of data. This is a strong diurnal variation, with peaks at the end of the afternoon. These peaks can be used for charging batteries at the end of the day. The power can be used in the evening hours for lighting in the school. The biggest drop in power production will be in the night hours when there is hardly any wind.

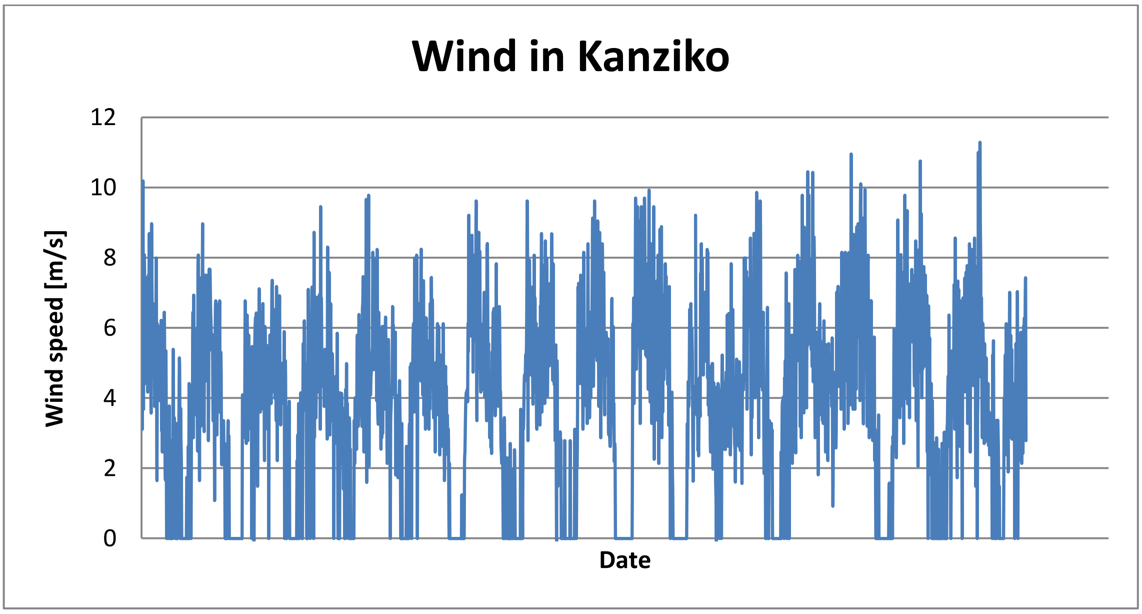


Figure 40: Wind Kanziko

7.4 System requirements

At all three locations the system will be made in the same way:

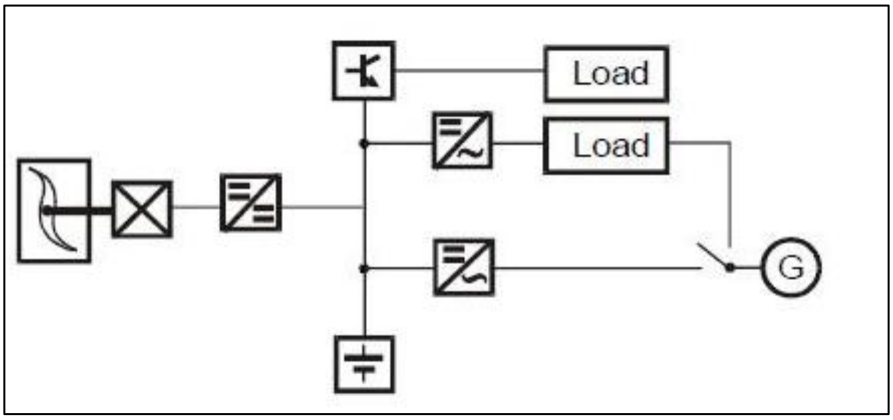


Figure 41: Schematic system wind system (26)

Figure 41 shows the schematic system that will be used. A wind turbine is connected with a DC-DC switch with the main power line. This is connected to a charge controller and a battery. The DC-loads (lamps) are directly connected to this main power line, and the AC loads are in a different loop with a possible back up of a diesel generator. The importance of battery storage is shown in the previous paragraph; the big variations in available wind power.

This paragraph will deal with some extra requirements if SASOL chooses to work with wind energy at the three locations. For this, data from Craftskills is used; assuming that SASOL will install a similar turbine as Craftskills is producing (13). These turbines are built with all local available material, only the magnets for the permanent magnet generator are imported. The blades are made from fiber glass, the turbine is controlled by tail furling, and braked with an electronic hydraulic braking system

Figure 42: Craftskills turbine

These turbines are available in the following sizes:

Power	Rated	Maximum	Diameter		Cut in	Cut out	Price[9]	
W	W	W	ft	m	m/s	m/s	KSh	Euro
700	700	800	9	2,7432	2	25	S200.000	€ 1.852
1200	1000	1400	12	3,6576	2	25	S250.000	€ 2.315
1800	1800	2000	14	4,2672	2	25	S400.000	€ 3.704
2500	2500	2700	16	4,8768	2	25	S580.000	€ 5.370
3500	3500	5000	18	5,4864	2	25	S700.000	€ 6.481

Table 4: Details Craftskills turbines (13)

When checking these data a power coefficient of approximately 0.11 is found, which seems reasonable. This can be done by assuming a rated wind speed of 12m/s:

$$Cp = \frac{P}{\frac{1}{2}\rho U^3 A}$$

Equation 7.11

This means as well that power predictions can be made with these turbines and the Weibull data from the three locations. That will be done in the following paragraphs. Equation 7.12 shows how the Weibull data and the calculated Cp can be used to predict the power output of the turbines. *E* is the total produced energy in *kWh*, U_i is the wind speed of a certain bin with the corresponding amount of hours $p(U_i)$ from the Weibull distribution function.

$$E = \sum_{i=0}^{N} \left[Cp \frac{1}{2} \rho {U_i}^3 A \, p(U_i) \right]$$

Equation 7.12

For all three locations the installed equipment will be listed based on interviews with the schools and people from SASOL and the work done by Berges (4). Besides that it is assumed that the schools are open 300 days a year.

[9] Including inverter, cabling, battery

7.4.1 Kanyangi secondary

The school consists of eight classrooms, and two rooms for staff. In total there are two computers installed a t the school. For power demand this means (4):

Rooms	Amount	Equipment	Demand per room	Total Demand [W]	Hours	Energy [Wh]	Yearly [kWh]
Classroom	8	Lighting	2 energy saving bulbs (11W)	176	3	528	
Staffroom	2	Lighting	1 energy saving bulb (11W)	22	3	66	
Computer room	1	Lighting	1 energy saving bulb (11W)	11	2	22	
	2	Computers	2 X 300W	600	2	1200	
TOTAL				**809 W**		**1816**	**544,8**

Table 5: Demand Kanyangi

7.4.2 Kanziko Secondary

Kanziko secondary has a teacher room, a head teacher room, two buildings for classrooms, with in total six classrooms and a separate kitchen.

Rooms	Amount	Equipment	Demand per room	Total Demand [W]	Hours	Energy [Wh]	Yearly [kWh]
Classroom	6	Lighting	2 energy saving bulbs (11W)	132	3	396	
Staffroom	2	Lighting	1 energy saving bulb (11W)	22	3	66	
	1	Computers	1 X 300W	300	2	600	
Kitchen	1	Lighting	1 energy saving bulb (11W)	11	2	22	
TOTAL				**465 W**		**1084**	**325,2**

Table 6: Demand Kanziko

7.4.3 MPC South

At MPC south it is not totally clear yet what will be in the different buildings and how big they will be. To get some idea for their demand it is possible to assume that the field office will be equipped with similar equipment as the field office in Kitui. This means the following:

Rooms	Amount	Equipment	Demand per room	Total Demand [W]	Hours	Energy [Wh]	Yearly [kWh]
Offices	4	Lighting	2 energy saving bulbs (11W)	88	3	264	
		Computer	1X300W	1200	3	3600	
Toilet	1	Lighting	1 energy saving bulb (11W)	11	2	22	
Kitchen	1	Lighting	1 energy saving bulb (11W)	11	2	22	
TOTAL				**1332 W**		**3908**	**1172,4**

Table 7: Energy demand MPC South

7.4.4 Overview

Using Equation 7.12 to calculate the energy production for the Craftskills turbines for each of the three locations gives Table 8. The table shows when a certain turbine delivers sufficient energy to meet the demand. For Kanziko one 1800W turbine will deliver sufficient energy. It shows as well that using wind energy at the MPC South or at Kanyangi would require more than one turbine. From Table 8 it can be concluded that Kanziko offers the best possibilities for using wind energy in Kitui district.

Turbine	700 W	1200 W	1800 W	2500 W	3500 W	Demand
Kanyangi	98,42	140,60	253,07	351,49	492,09	544,8
Kanziko	194,67	278,10	500,58	695,25	973,34	325,2
MPC South	98,21	140,31	252,55	350,77	491,07	1172,4

Table 8: Energy production and demand in kWh

8 Economical Feasibility

To determine whether a project is economically attractive often a cost benefit analysis, CBA, is done to calculate if a project is profitable or not (27). When choosing between different projects a CBA can give insight in what project deserves the preference. In a CBA the cash in- and outflows are taken in account and are discounted to the start of the project, Equation 8.1. What will be done in this chapter is a cost comparison between different types of rural electrification, where maintenance cost will be discounted. Since the school in Kanziko already has a diesel generator, the avoided diesel cost and maintenance cost of the generator can be considered as cash inflows.

This cost comparison will be part of a multi criteria analysis, MCA. A MCA is a tool to determine what option is the best of a selection. In this case what is the best option for rural electrification? Or more specific, what is the best option for electrification at the secondary school in Kanziko? The following three options are taken into account:

- Wind generation
- Solar generation
- Diesel generation

8.1 Cost comparison

The best way to compare the costs of the three options will be to create statistical indicator, like cost per produced kWh in the operational time of the electricity generator.

8.1.1 Wind turbine

For the wind turbine this can be done quite easily, since all the information is available in the previous chapters. The only extra necessary information is that the battery of the turbine will last for four years, that the life time of the turbine is ten years (13) and that the discount rate is 3% (28). With that cost made in the future can be discounted to the present time. Besides that the avoided expenses of the use of a diesel generator, which is used at the moment can be used as cash inflows, see paragraph 8.1.3.

$$Discounted\ cashflow = \frac{Cashflow(year)}{(1+r)^{year}} \qquad \text{Equation 8.1}$$

Outflow		**Inflow**	
Initial investment	€ 3.7404,00	Discounted Rest value battery	€ 117,13
Battery 314,81		Discounted Avoided diesel cost	€ 1.279,08
Discounted cost (after 4 years)	€ 279,71		
Discounted cost (after 8 years)	€ 248,52		
Total Cash Outflow	**€ 4.232,23**	**Total Cash Inflow**	**€ 1.396,21**

Produced energy [kWh] 5005,77

cost/kWh **€ 0,57**

8.1.2 Solar energy

When using solar energy, extra information is required to be able to make the calculations. The cost for a complete PV system[10] is about €10/installed Watt (15). In Kenya, 1 square meter delivers approximately 7 kWh per day (29). Known is as well that 1m^2 of a solar panel is approximately a 100 Wp panel, for a multi-crystalline PV panel. These panels have an efficiency of about 15%. Other efficiencies that have to be taken into account are the influences of the temperature, 85%, the reflection, 96% and the electrical losses, 80% (26) (30). This means that a solar panel of 1m^2 can produce:

$$6.98x0.15x0.85x0.96x0.8x365 = 250kWh/year \quad \text{Equation 8.2}$$

This is not sufficient to power the school in Kanziko, so more area of panels is needed:

$$A_{required} = \frac{E_{Kanziko}}{E_{PV,year}} = \frac{325}{250} = 1.3m^2 \quad \text{Equation 8.3}$$

The result from Equation 8.3 means that the installed solar power will be 130Wp, that means that the system will cost about €1300,-. The life time of a solar system is 15 years, only the batteries will have to be replaced every 4 years as well, as in the case of the wind turbine. This results in the following overview:

Outflow		**Inflow**	
Initial investment	€ 1.300,00	Discounted Rest value battery	€ 117,13
Battery 314,8148		Discounted Avoided diesel cost	€ 1.279,08
Discounted cost (after 4 years)	€ 279,71	Discounted Rest value solar panel	€ 322,44
Discounted cost (after 8 years)	€ 248,52		
Total Cash Outflow	**€ 1.828,23**	**Total Cash Inflow**	**€ 1.717,86**
Produced energy [kWh] 3243,12			
cost/kWh	**€ 0,03**		

8.1.3 Diesel generator

Comparing a diesel generator with the other two options for electricity production means that there has to be assumed that the generator produces the required amount of energy for the school. For this required amount of power the fuel consumption can be calculated, since it is known that a specific 2.5 kW generator (which is already installed at Kanziko secondary) can deliver 2.5kW for 18hours with 12.5liters of diesel (31). With the known demand, the running hours can be calculated and the diesel consumption will be:

$$t(hours) = \frac{E_{Kanziko}}{P_{generator}} = \frac{325}{2.5} = 147.8\ hours \Rightarrow \frac{147.8}{18} x12.5 = 102l \quad \text{Equation 8.4}$$

[10] Including PV panel, inverter, charge controller and cabling

The diesel price has been changing in Kenya, but is taken as a constant, since it is not known how the price is going to change in the coming ten years. The actual diesel price is 80kSh/l, €0.75/l in Kenya (32). Amongst the fuel cost, other yearly costs are the maintenance cost of the generator, which are about €0,50/hour, when running on full capacity (33).

For the diesel generator the following cost overview can be made:

Fuel	€ 76,00		
Maintenance	€ 73,86		
DISCOUNTED COST Year:	1		**€ 145,49**
	2		**€ 141,25**
	3		**€ 137,14**
	4		**€ 133,14**
	5		**€ 129,27**
	6		**€ 125,50**
	7		**€ 121,85**
	8		**€ 118,30**
	9		**€ 114,85**
	10		**€ 111,51**
Total cost			**€ 1.278,29**
Produced kWh		3252	
Cost/kWh			**€ 0,39**

The conclusion on the financial comparison is that financially the solar PV system is most attractive. This option is the cheapest of the three. The next paragraph will show with the help of a MCA whether solar is the overall best option for electricity production in Kanziko. Changes in required energy could affect this result significantly, since the diesel generator is now only running for 147 hours a year, if that would be higher the life time would be shorter, and the costs for maintenance higher. A rise in increased energy could mean that an extra wind turbine is needed, with high extra initial cost, whereas a PV system can be easily scaled up, this aspect is taken into account in the multi criteria analysis done in paragraph 0.

A sensitivity analysis showed that discount rate variations have an effect on the cost of wind and solar energy in a comparable manner, and for diesel energy in the opposite way (rate increase, price decrease). The results are shown in Table 9.

Discount rate	Wind	PV	Diesel
0,01	€ 0,55	€ -0,02	€ 0,44
0,02	€ 0,56	€ 0,01	€ 0,41
0,03	€ 0,57	€ 0,03	€ 0,39
0,04	€ 0,58	€ 0,06	€ 0,37
0,05	€ 0,58	€ 0,08	€ 0,36
0,06	€ 0,59	€ 0,10	€ 0,34
0,1	€ 0,62	€ 0,16	€ 0,28

Table 9: Discount rate variations

Checking for the influences of a demand increase results in the second column in Table 10 It is assumed that the required power production is equal to the power production of the wind turbine (otherwise a second turbine has to be installed. This shows that then the solar system will be delivering funds. This is because the increase in diesel cost (so an increase in the inflow of avoided diesel cost) is bigger than the extra investments needed for the PV system.

System	Demand increase	PV cost increase	PV efficiency decrease
Wind	€ 0,43	€ 0,57	€ 0,57
PV	€ -0,01	€ 0,09	€ 0,09
Diesel	€ 0,39	€ 0,39	€ 0,39

Table 10: Variations in demand/cost/efficiency

When the calculations made in 8.1.2 are based on wrong assumptions with respect to the cost of the solar panel, the third column in Table 10 is obtained. Here a price increase of 20% of the solar system is taken into account. It shows that solar is still the cheapest option. An equal value for the cost of the solar system is obtained when assuming the solar system is 10% less efficient (fourth column in Table 10).

The sensitivity analysis of the CBA shows that the values of the cost can vary, but the PV system remains financially the most attractive option.

8.2 Multi Criteria Analysis

A MCA is a tool to be able to choose between different alternatives to reach a certain goal (34). The goal is to deliver sufficient electricity to the secondary school in Kanziko. As shown in the beginning of this chapter, three alternatives are being investigated. The differences between the alternatives are judged with various criteria. The criteria are based on the 3P triangle: Figure 43. The three P's stand for:

- People
- Planet
- Profit

Figure 43: 3P Triangle

The three P's can also be referred to as Social, Environmental and Economic. The following criteria are used in this MCA and will be described and explained in the following paragraph:

Economic:

- Initial investment
- Running costs per kWh
- Adaptable output power
- Upscaling
- Status of development

Environmental:

- Greenhouse gasses
- Fine particles

Social:

- Comfort
- Educational aspect

The technical criteria are embedded in the economic and environmental criteria.

8.2.1 Chosen criteria

This paragraph will describe the different criteria mentioned above. It will also be stated whether a criterion is negative (a high value has a negative influence on the rating of an option, or positive, and if the criterion is quantitative or qualitative.

<u>Economic criteria</u>

Costs per kW

The costs calculated in paragraph 8.1 are being used for this. The lower the price, the better an option will be rated. The two criteria "Initial investment" and "Running cost per kWh" are taken together as one criterion. However the initial investment can be very important, since for most of the people in a developing country, high initial investments are impossible. This will be taken into consideration when comparing the different options after the MCA.

This is a negative, quantitative criterion.

Adaptable output power

In what extend is the output power adaptable to the current needs. It is preferable to be able to change the production to save costs for example in times when less energy is used. Since cost reductions are very important when low funds are available, this criterion is taken into consideration. This is a positive, qualitative criterion.

Upscaling

It is a common phenomena that when power is available, the demand for power will rise. When a energy system can be easily scaled up it could be beneficial for a project.
This is a positive, qualitative criterion.

Status of development

This criterion is a qualitative measure for the current installation to be upgraded to new technologies that will come in the upcoming 10-20 years. The larger this value the better it will be for the option, easier to be upgraded. It shows as well that the technology is well engineered and thus is a reliable technology.
A positive qualitative criterion.

<u>**Environmental criteria**</u>

Greenhouse gasses

This value gives an indication of the kg CO2 production per year. Less pollution is preferable. Data are based on the work by Kemmoku et al (35). This is a negative, quantitative criterion.

Fine particles

This value gives an indication of the amount of fine particles production per year. Included in this criterion is as well the disposal of the waste. PV systems can be recycled easier than a wind system for instance. No quantitative data is available, so this criterion is a negative qualitative one.

<u>**Social**</u>

Comfort

A measurement for the level of comfort of the installation. Many things are taken into this criterion, for example: The noise, the smell, safety but also aesthetic. But also required maintenance is taken into consideration. This is a positive, qualitative criterion.

Education aspect

Since the power generator will be installed on a school, the educational effect should be taken into account, which is also a strong whish of SASOL.
This is positive, qualitative criterion.

8.2.2 Dividing weighing factors

Based on my own experience and conversations in Kenya, with SASOL and beneficiaries the following distribution of weighing factors is created:

Criteria	**Weighing factor**
Economic	
Costs per kWh	**35**
Adaptable output power	**10**
Upscaling	**10**
Status of development	**10**
Environmental	
Greenhouse gasses	**10**
Fine particles	**5**
Social	
Comfort	**15**
Education	**10**

8.2.3 Results

The evaluation matrix gives the scores for the criteria for each of the options. In the fifth column either a "+" or a "-" sign is shown. This indicates the direction of the effect. If a high amount is positive a "+" sign is shown, and if a high amount is negative, a "-" sign. Table 11 gives the evaluation matrix for this MCA.

Options	Diesel	Wind	PV	+ / -	Dimensions	Weighing factor
Economic						
Total running costs	0,39	0,57	0,034	-	€/kWh	**35**
Adaptable output power	+++	+	+	+	Qualitative	**10**
Upscaling	+++	+	++	+	Qualitative	**5**
Status of development	++++	++	++	+	Qualitative	**10**
Evironmtental						
Greenhouse gasses	330	7	27	-	ton CO2/yr	**10**
Fine particles	++++	++	+	-	Qualitative	**5**
Social						
Educational aspect	++	++++	+++	+	Qualitative	**15**
Comfort	+	++	++++	+	Qualitative	**10**

Table 11: MCA Evaluation matrix

8.2.4 Standardization

To be able to compare the quantitative data, they have to be standardized. This is done for Table 12 according to Equation 8.5:

$$e_i = \frac{(n_i - n_{lowest})}{(n_{highest} - n_{lowest})} \quad \text{Equation 8.5}$$

$e_i =$ the standardized score for option i

$n_i =$ the actual score for option i

$n_{lowest} =$ the lowest recorded score for the effect

$n_{highest} =$ the highest recorded score for the effect

Options	Diesel	Wind	PV	+ / -	Dimensions	Weighing factor
Economic				0		
Total running costs	0,335821	0	1	-	€/kWh	35
Evironmtental						
Greenhouse gasses	0	1	0,93808	-	ton CO2/yr	10

Table 12: Standardised scores

8.2.5 Dominance scores

With the standardized scores, the dominance scores for the quantitative criteria can be calculated:

$$a_{ii'} = \sum \left(w_j \left(e_{ji} - e_{ji'} \right) \right) \qquad \text{Equation 8.6}$$

With:

$a_{ii'} =$ Dominance score for option i compared to option I’

$w_j =$ Weighing factor for criterion j

$e_{ji} =$ Score for option i for criterion j

$e_{ji'} =$ Score for option i' for criterion j

This leads to Table 13.

	Diesel	Wind	PV
Diesel		1,75	-32,63
Wind	-1,75		-34,38
PV	32,63	34,38	

Table 13: Dominance scores quantitative

This shows that based on only the quantitative criteria PV is the best option.

The dominance scores for the qualitative criteria are calculated in a similar way:

$$\alpha_{ii'} = \sum \left(w_j * \mathrm{sgn} \left(n_{ji} - n_{ji'} \right) \right) \qquad \text{Equation 8.7}$$

With:

$\alpha_{ii'} =$ Dominance score for option i compared to option i’

$w_j =$ Weighing factor for criterion j

$n_{ji} =$ Score for option i for criterion j

$n_{ji'} =$ Score for option i' for criterion j

The dominance qualitative scores are shown in the next table:

	Diesel	Wind	PV
Diesel		5	5
Wind	-5		5
PV	-5	-5	

Table 14: Dominance qualitative scores

Based on the qualitative criteria the diesel generator will be the best option in Kanziko

To get a complete overview the overall dominance scores is calculated according to Equation 8.8:

$$m_{ii'} = w_{qt}d_{ii'} + w_{qw}\delta_{ii'}$$ Equation 8.8

With:

$m_{ii'} =$ Overall dominance score

$w_{qt} =$ Summation of the quantitative weighing scores

$$d_{ii'} = \frac{a_{ii'}}{\sum_i \sum_{i'} |a_{ii'}|}$$

$$\delta_{ii'} = \frac{\alpha_{ii'}}{\sum_i \sum_{i'} |\alpha_{ii'}|}$$

With the help of Table 15 the best option for electricity production in Kanziko can be chosen:

	Diesel	Wind	PV
Diesel		9,74	-1,51
Wind	-9,74		-2,08
PV	1,51	2,08	

Table 15: Overall dominance scores

The table shows that the scores of solar versus the wind and diesel are higher. That means that the solar PV system could be the best option for the secondary school in Kanziko. The second place is for the diesel system, since they already own it. The scores for the wind generator compared to the other two options are negative, so less favorable. It must be noted that the differences between the three options are marginal (the maximum score can be about 25 units, Equation 8.8.). In order to know whether this MCA is reliable, reliability and sensitivity analyses are done in paragraph 8.2.6.

8.2.6 Reliability and sensitivity analysis

The reliability analysis takes variations of the different data into account. The influence of deviations in for instance the running cost can be investigated. When varying the costs with 10%, the influence on the final result can be investigated. These costs can vary for different machines and brands, but also different sources give different prices. Manually a change of 10% has been applied to the different data. When increasing the cost of the solar system (with values calculated in paragraph 8.1.3 and simultaneously decreasing the cost of the other systems no effects are witnessed, see

Table 16, so in all cases with price changes, the PV systems remains the best option. In the other cases with prices changes, the wind system remains the best solutions.

	Diesel	Wind	PV
Diesel		9,187	-2,07
Wind	-9,18		-2,08
PV	2,07	2,08	

Table 16: Reliability, cost variation

But when for instances changing the quantitative criterion "status of development", adding another '+' to wind energy, will change everything:

	Diesel	Wind	PV
Diesel		6,07	-5,17
Wind	-6,07		5,25
PV	5,17	-5,25	

Table 17: Reliability analysis2

All of a sudden the MCA does not give a definite solution. This fact has to be taken into account when decisions are being made.

The sensitivity analysis is a combination of a reliability check and to check for instance whether a minor change in weighing factors has an influence on the dominance score. When for instance decreasing the weighing factor of the costs with 5, and adding this to the 5 of the upscale criterion will totally change the output of the MCA into:

	Diesel	Wind	PV
Diesel		15,03	5,03
Wind	-15,03		-10
PV	-5,03	10	

table 18: Sensitivity analysis

This shows that the three options are quite close to each other and when taking a decision there has to be paid attention to check the numbers used for the MCA, besides that expected variations need to be taken into account.

8.3 Discussion

From this multi criteria analysis can be concluded that a solar energy system can be the best option for electricity generation for the secondary school in Kanziko, based on the presented data.

The reliability and sensitivity analyses show that the costs of the solar system does the job for 'winning' the MCA. It shows as well that the analysis is quite sensitive for variations of weighing factors, but stable for cost variations. With a certain degree of cautiousness it can be concluded that solar energy is the best solution for energy production in Kanziko, based on the fact that the school already owns a diesel generator, and that the high initial investment costs will be paid by a donor organization.

It has to be mentioned that the weighing factors are assigned to the project in a subjective way, from an engineering perspective, with a focus on cost. It is likely that the MCA will give different results when other criteria are taken into account. Besides that, the diesel generator is a technology that has been used for a long time, so the data of the different criteria for the diesel generator will not change in the near future, whereas this could happen for the other options, which might enforce the position of the wind generator or the solar PV system. In the future the MCA could give a totally different outcome, since a time dependent factor has not been taken into account, e.g. the costs are assumed to stay constant over time.

A last remark is that the costs of the wind generator system are based on three weeks of wind measurements, which are extrapolated over a year. When doing longer term measurements more reliable data are available. This counts as well for the solar energy system, since this MCA uses a mean energy production for solar energy in Kenya. When doing this in a proper way, the production of a solar system should be calculated in a more thorough way, but that is not in the scope of this research.

9 Conclusions and Recommendations

This report started to highlight the contribution of energy to development with the help of the Millennium Development Goals. It showed that energy can contribute to development by offering people alternatives for wood-fires and the use of kerosene lamps. In the rural areas of Kenya these are the main energy sources. The use of kerosene will be reduced when electricity is available. Lighting and electricity contribute to development by enabling schools to teach after sunset, to use modern educational media, but also by enabling pupils to study at night time.

There are three options of bringing power in the rural areas of Kitui district, Kenya; a diesel generator, solar PV system or a small scale wind turbine. This research has been focused on the use of a wind turbine. This because it was a new field for the client, the Kenyan NGO SASOL. Besides that the country has showed some renewed interest in small scale wind energy, since a study done by the Kenyan government (19), in cooperation with some partners, showed that Kenyan has some potential sites for wind energy. However the locations in Kitui district were not amongst those locations. For small scale wind energy, local geographical variations can influence the wind speeds significantly. In order to get the wind speeds in the rural areas of Kitui district, local measurements were done on three locations; Kanyangi, Kanziko, Ikutha. Short term measurements were done. The obtained data were correlated with data from a meteorological station in Makindu. With the found relation, yearly wind data were predicted with longer term data from Makindu. An overview of the results is given in the following table.

Location	Mean wind speed [m/s]	Turbulence intensity	Weibull		Power density [W/m^2]	Energy pattern factor [-]
			k	A		
Kanyangi	3.1	3.45	5.51	3.4	18.31	1.386
Kanziko	3.9	3.7	5.85	4.2	36.6	1.32
MPC South	2.94	2.17	3.39	3.3	15.03	2.18

The table shows that Kanziko has the highest average wind speed and the highest power density. So Kanziko is the best location for a wind energy project from these three locations, when focusing on power production. The turbulence intensities of all three locations are quite high. This is because there are some strong diurnal variations on all three locations. The diurnal variations are caused by temperature difference between day and night. For all three locations the winds are almost always coming from the South-East direction.

The Multi Purpose Center which is going to be build in Ikutha, could be a potential location as well for the wind turbine, but only when focusing on educational aspects. With the low wind speeds at Ikutha, marginal energy production is estimated.

As stated above, the three options for electricity generation in Kanziko are a diesel generator, a solar PV system or a wind turbine. In order to be able to find the best option a cost comparison and a multi criteria analysis (MCA) were done. The cost comparison was based on the energy demand from a school in Kanziko. A solar PV system turned out to be the cheapest option for Kanziko. The MCA showed that the solar PV system was as well the best option for Kanziko. Some remarks have to be made on these results:

- The wind energy data are based on three weeks of measurements. Longer term data are required.
- The costs of the diesel generator are based on an average constant diesel price, and a low amount of running hours per year. When the energy demand increases, the variable maintenance cost of the diesel generator will increase, the life time decrease and the CO_2 emissions increase. Whereas for the solar PV system and the wind turbine only the initial investment will increase. Changes in the diesel costs will influence the costs of solar and wind energy significantly, since avoided diesel costs are taken as a cash inflow.
- The high initial cost of the wind turbine has to be considered
- The educational aspects of the wind turbine, contribute significantly to the results of the MCA.
- The MCA is quite sensitive to changes in the weighing factors that are used.
- The differences between the PV-system and the wind generator are marginal.
- The costs of the solar system are quite low, based on the assumption that after 10 years of operation the solar system can be sold for its rest value. Most likely the PV system cannot be sold for this value, since developments are expected. New systems will be more efficient and cheaper. So the actual costs of the solar system will be higher.

A clear outcome of this research, based on the done measurements, is that wind energy is not a very attractive option for electricity generation for the three locations included in this research. Besides that the supply of the wind power will not be very stable, caused by the very strong diurnal variations and the high turbulence. This makes a solar PV system more attractive. Solar irradiance is quite constant throughout the year; the locations are close to the equator, so 12 hours of sun and a normal inclination are guaranteed.

More wind measurements are required to make more reliable statements. When new measurements are done, they should be done at different heights as well, 4, 6 and 10 meters for instance. To be able to notice present wind shear.

Another recommendation is to design an own wind turbine. Now a marketed turbine was used for the cost comparison between the three options. An own design, made with local available material could make a turbine cheaper, and thus more favorable. It could be possible as well to work together with Craftskills by offering them labor and sharing of knowledge and revenues. The tower contributes to the costs of a wind turbine, when making an own tower, a significant cost reduction can be achieved.

In the comparison between the three options a solar PV system was included, but no thorough research was done on this. This thorough research is required for locations in Kitui district to be able to judge whether solar energy is feasible in Kitui district. This research will be done in February 2010 until April 2010.

10 Literature

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11 Attachments

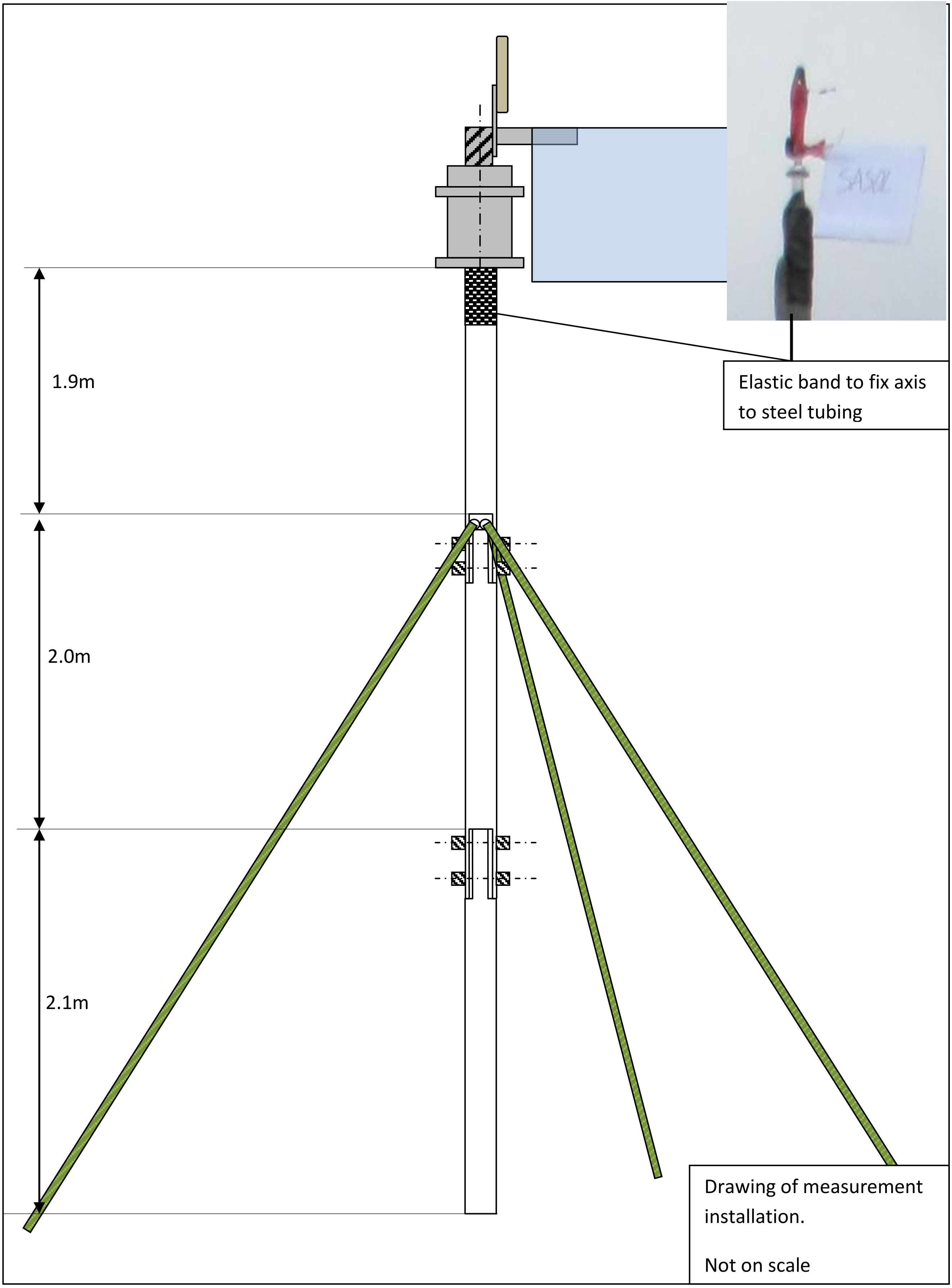
Attachment I: Measurement installation

Attachment II: SASOL Capabilities

Attachment III: Personal reflection

Attachment IV: Roughness Lengths

11.1 Attachment I: Measurement installation



Drawing of measurement installation.

Not on scale

11.2 Attachment II: SASOL capabilities

SASOL (SAhelian SOLutions) started in 1990 as a local Kenyan NGO dealing with drought mitigation and capacity building. Initially SASOL was helping schools with building water storage tanks for roof catchment of water in Kitui district. It became evident that more water was required and thus SASOL focused on building so-called sand storage dams. Up till now SASOL has made over 750 of these dams. In 2003 SASOL started to cooperate with a Dutch NGO: the Ex-change foundation. From that moment on SASOL shifted interests from just building the dams to different projects, driven by dissemination of best practices. Nowadays the focus is environmental friendly technologies for construction, energy provision and agricultural practices and tree growing. The achievements of SASOL are that they have built over 750 sand storage dams, installed over 100 pumps, created bio-digesters, and did research on water quality, water catchment, water management and rural electrification. All technologies that promote to mitigate effects of climate change. SASOL has been awarded in 2004 with the Dubai International Award for Best Practices To Improve The Living Environment (UN-UNHabitat and the Dubai Municipal) and in 2009 SASOL was awarded with the Best Practice Exhibition Award by the Kenyan Ministry of Housing.

SASOL is the client of this research. I think that if they are interested to start a wind energy project they first have to do some longer term measurements. At least data of one year are needed. The predictions made in this report are based on roughly three weeks or even only one week of data. So SASOL should be doing extra measurements. I explained one of the employees of SASOL how to do the measurements and what he has to pay attention to. Unfortunately I could not leave my wind meter in Kenya, because I had to calibrate it, but I will give it to students going to Kenya in January 2010, so they can hand it over to SASOL and they can continue to do measurements in Kitui district. The SASOL employee will make sure the measurements are done and he will send the data to me, so I can process it. With these long term data I can make a design for SASOL.

When a wind turbine will be built and installed SASOL has to be checking whether the turbine is functions well, and when installed, remains functioning. Best would be if SASOL would make a student project out of it, so that Dutch students can work on it, and include Kenyan students in the project. If the turbine is installed at the school, teachers have to be trained on how it works, but they also should include it in their teaching program. Like that you will get the maximum out of the turbine; it is not just producing power, but also becoming a school project.

Overall, I think SASOL is a great partner to do these kinds of projects with. They have a lot of experience with these kinds of projects and sufficient knowledge on renewable energy technologies is present.

11.3 Attachment III: Personal reflection

This chapter is written to describe how I experienced doing research in a developing country and how I experienced my stay in Kenya.

As this report shows it is very much possible to do research in Kenya. It is up to the researcher to be undertaking and persevering through the time of the field work. Since it can be hard to get the right information sometimes, or because it takes a long time to get things done. If you do not let yourself affected by this, a good start of the research is there.

I experienced that there is a lot of valuable knowledge available at the University of Nairobi. People are very willing to cooperate, and the level of the university seemed to be comparable to the level of the Dutch universities. The benefit of partnering with a local university is that they have the local knowledge at their disposal, and if not they know where to find it. I did notice as well that there is a big difference between the several universities. This is important to know since they also have different interests. Where one university is very willing to cooperate and gain knowledge as well, the other is willing to cooperate for money; pretend your work is theirs.

I met a fellow researcher in the town where I was living, a Dutch PhD student in anthropology. He was doing some research on development projects done in the past. He was getting a lot of information through interviewing the elder people, assisted by a younger Kenyan student who was his translator. Besides the interviews he had access to the Kenyan National Archives, giving him a lot of valuable information. This shows that also research on historical events can be done in the country.

For my research I could have got all the equipment I needed in Nairobi. Since I was not sure of this I bought it in The Netherlands and took it with me. Several big companies have an office in Nairobi, to cover the East-African market. That offers possibilities for researchers in Kenya, since they can get their equipment in Nairobi.

As I already wrote it is important to be persevering when doing your research in Kenya, and if you do that, it offers major opportunities. I did it, and I got me in the Ministry of Energy, talking to the director of renewable energy. I know of more people being like that in other developing countries and making big progress in their research.

This stay in Kenya of three months was an unforgettable experience. It was my second time to do a project in Kenya; in 2005 I did an intern there. The 2005 project left a great memory in my mind, and changed me. This made me wonder whether the most recent trip could correspond to this. Now when writing this report I can tell it did not just correspond to the 2005 project, but even left a greater feeling. This is probably because I was doing my research by myself, being the only white man in Kitui for at least a month. Like that I had a lot of interaction with the people and made many friends. The interactions taught me a lot, or emphasized things I already knew. As an example those two hours of work for me can be the difference between living or dying for a Kenyan. Again I experienced the openness, the hospitality and the gratitude of the Kenyans in Kitui. If you ask me if my project directly helped people to have a better life, I will have to answer no. But I hope I did contribute in a long term project and that I initiated future study on energy, or showed young people in Kitui the challenge in energy science.

When landing in Kenya and driving for the first time in four years to Kitui again, I noticed that the government is working hard on the roads in Kenya. All new asphalt roads were being created between Nairobi and rural towns. So I expected big changes in Kitui as well. There were some, but not what I expected. These roads did not change the basic needs of the people in Kitui, they still did not have a job, did not have sufficient (drinking) water, no electricity, no food, etc. It does show the importance of NGO's in this town/district. Without them it seems that these people are left out in the cold, since the government has other interests.

My stay in Kitui started with doing some work as student coach for the Dutch mechanical engineering and energy technology students. They had been working for three months in Kitui, so it was my job to see whether they did a good job and do an evaluation with them. Part of the work as a student coach was also looking for new projects and new cooperation with other NGO's. I did this in the first two weeks of my stay in Kenya.

Then I started to work on my own project, by writing a project plan, creating and testing the measurement equipment and finally installing the equipment at Kanyangi secondary school. Till the beginning of September I was the only Dutch student in Kitui. In September the first new students of the Ex-change program arrived. It was my job to introduce them in Kitui and to get them started. It was very nice to do this. It was though and very busy, since I had my own project running, had to be involved in a three day conference in Nairobi and make sure the Dutch students (25) were doing fine.

The conference on Small Scale Wind Energy for Developing Countries, was a nice break in this. Three days of presentations on this topic were given at Jomo Kenyatta University of Agriculture and Technology. Professionals from all over the world were involved. I had the opportunity to give a presentation as well. It was nice to be part of something like that.

When coming back in Kitui the last measurements had to be done in Kanziko. When coming there to pick up the equipment at Kanziko secondary all the pupils were asking me all kind of questions, they just finished classes. We sat down to talk till it became dark, since I still had to walk with the equipment back to town, a 30 minutes' walk. The pupils decided to accompany me to town, so I wouldn't get lost. It was a very nice experience!

The best comment I got during this stay in Kenya was the following: "Frits, you are not a mzungu, but you're Kenyan." I got this comment during my project work, because I was

- installing the measurement equipment by public transport, or motor bike
- talking a lot with Kenyans
- doing the 'dirty' jobs myself
- understanding the Kenyans
- eating local food
- listening to Kenyan music

To finish this personal reflection I would like to thank all the friends I made during my stay in Kenya for making my trip so great!

11.4 Attachment IV: Roughness Lengths

Roughness Classes and Roughness Length Table			
Roughness Class	Roughness Length m	Energy Index (per cent)	Landscape Type
0	0.0002	100	Water surface
0.5	0.0024	73	Completely open terrain with a smooth surface, e.g.concrete runways in airports, mowed grass, etc.
1	0.03	52	Open agricultural area without fences and hedgerows and very scattered buildings. Only softly rounded hills
1.5	0.055	45	Agricultural land with some houses and 8 metre tall sheltering hedgerows with a distance of approx. 1250 metres
2	0.1	39	Agricultural land with some houses and 8 metre tall sheltering hedgerows with a distance of approx. 500 metres
2.5	0.2	31	Agricultural land with many houses, shrubs and plants, or 8 metre tall sheltering hedgerows with a distance of approx. 250 metres
3	0.4	24	Villages, small towns, agricultural land with many or tall sheltering hedgerows, forests and very rough and uneven terrain
3.5	0.8	18	Larger cities with tall buildings
4	1.6	13	Very large cities with tall buildings and skycrapers