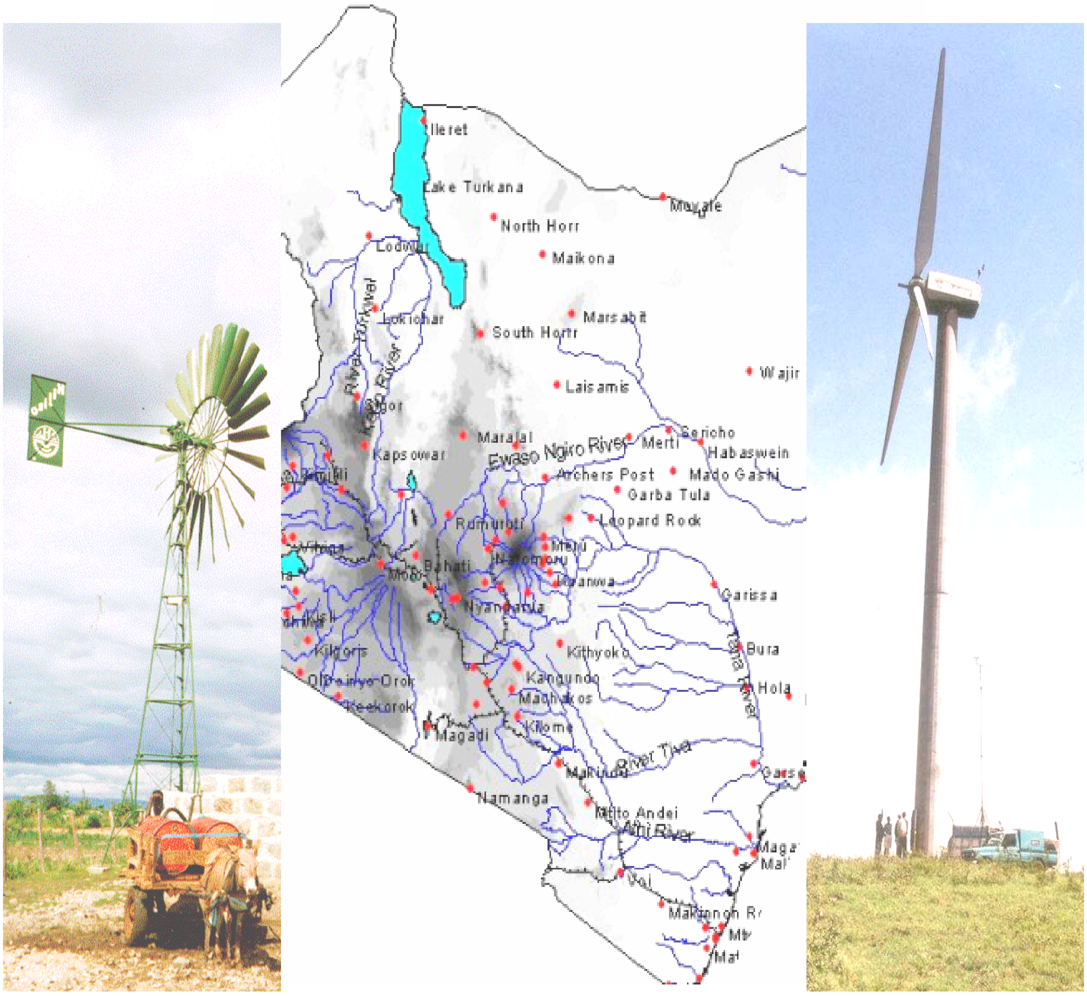
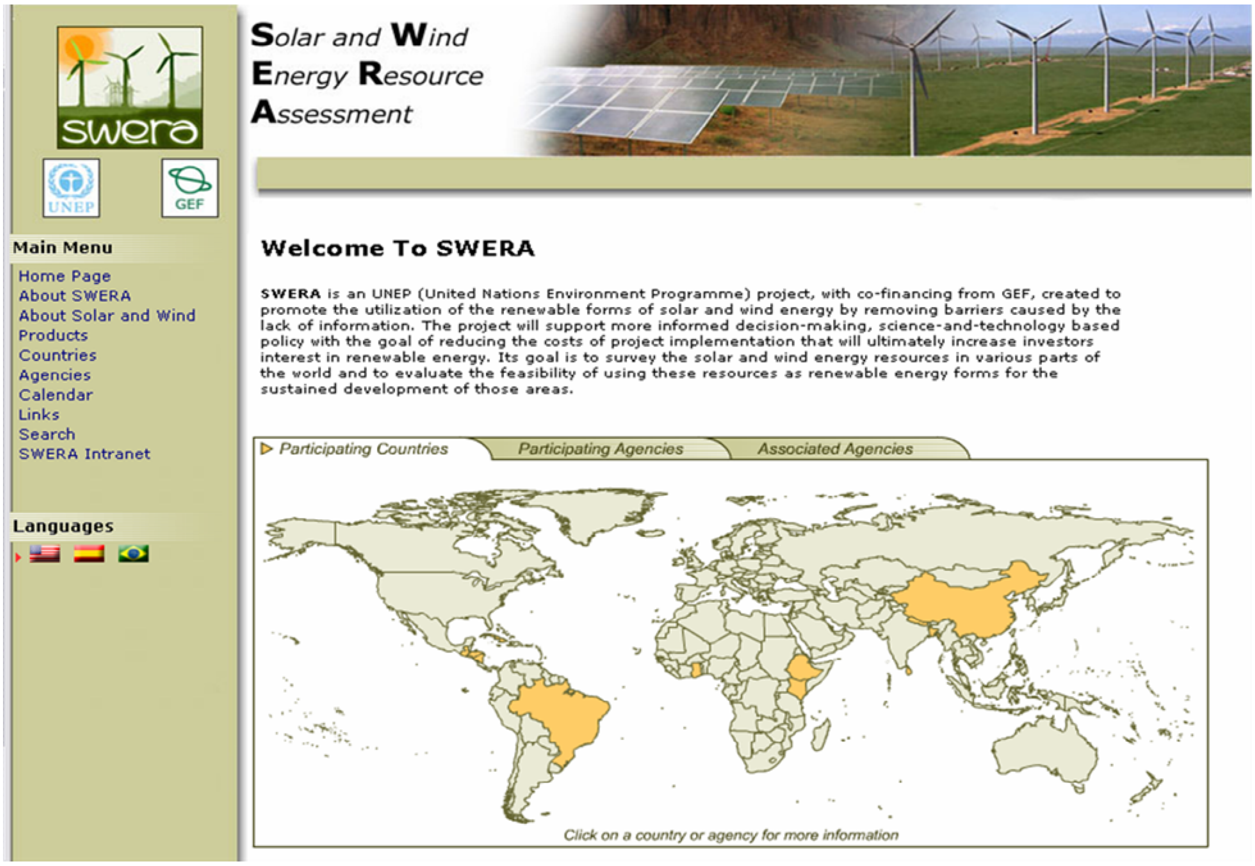
KENYA COUNTRY REPORT

SOLAR AND WIND ENERGY RESOURCE ASSESSMENT



Nairobi, 23 May 2008

UNEP RISØ DTU DLR PRACTICAL ACTION Ministry of Energy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SWERA is an UNEP (United Nations Environment Programme) project, with co-financing from GEF, created to promote the utilization of the renewable forms of solar and wind energy by removing barriers caused by the lack of information. The project will support more informed decision-making, science-and-technology based policy with the goal of reducing the costs of project implementation that will ultimately increase investors interest in renewable energy. Its goal is to survey the solar and wind energy resources in various parts of the world and to evaluate the feasibility of using these resources as renewable energy forms for the sustained development of those areas.
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Disclaimer

This report is a compilation of information relating to the Solar and Wind Energy Resource Assessment Project (SWERA) including data capturing and analysis, computation and mapping using GIS and other technologies to produce a national solar and wind atlases for Kenya.

The contents of this report do not necessarily reflect the views of the United Nations Environment Programme, Government of Kenya, Practical Action or any other party or organizations and countries involved in the SWERA project. Any omissions or alteration of the intended meaning and discrepancies are highly regretted.

Daniel Theuri
Lead Implementer
SWERA National Team

Nairobi, 23 May 2008

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The European team comprised of the Institute of Thermodynamics DLR of German Aerospace, RISOE, the European Wind Research Centre, NREL the National Renewable Energy Laboratory of USA, Tata Energy Research Institute (TERI) of India and a host of other partners specific to the countries and regions.

The Local partners comprised of Practical Action in Eastern Africa, the Department of Meteorology in the University of Nairobi and Regional Centre for Mapping of Resources for Development.

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1 Introduction

1.1 *Background and Context*

Kenya's energy supply and demand matrix is changing at a fast pace and the local resource exploitation is increasingly becoming more costly with dwindling opportunities especially in the cheaper large hydropower. On the other hand the perceived risks in utilizing other energy resources limit capacity of government and private sector investments. At the international scene, the climate change discussions are increasingly focusing on the green house gas emissions. Slowing and eventually reversing growth in global greenhouse gas emissions will require, amongst other initiatives, the large-scale use of renewable energy technologies for producing thermal energy, electricity, and hydrogen fuel.

The global trends are that solar and wind energy is becoming the fuels of choice to replace the unclean thermal fuels especially for heat and electricity.

It is estimated that the target of 70,000 MWe of wind electric capacity is aimed globally with most of them in Europe and the United States. The developing countries especially Africa holds tremendous potential in resource base and there is rate of energy service demand is rising fast. Similarly, the potential applications of photovoltaic technologies are expected to continue to grow robustly (>30%/year), with market breakthroughs as installed system prices fall below ca. US$ 4 – 6 per watt over the coming decade. Solar thermal power plants especially concentrated solar Power (CSP) may also achieve large-scale commercial "breakthrough"

In the developing countries like Kenya and Ethiopia, investments in solar and wind are hampered by lack of hard data and information to support policy, planning and investment decision making. Wile most of data capturing gin the country is primarily for agro meteorology and civil aviation use, other critical factors include costing of solar and wind energy development is the proximity of possible generation locations to load centers and electricity grid stations. The surface topology has a major influence on micro-climate resulting in highly variable wind resources and significantly variable solar resources over small areas. Without reliable resource information, potential investors tend to avoid the risk of wind or solar project development activities. Main stream investors, venture capital firms and independent power producers are not aware of viable renewable energy options and in investment opportunities waiting to be exploited.

The primary objective is to influence investment decisions by promoting and supporting renewable energy by overcoming informational barriers in solar ands wind energy financing. Information on the potential for solar and wind energy will influence policy and national planning by providing national institutions with readily available options and alternatives to delivering energy services using multiple sources, critical in securing energy supplies in the country .

The energy sector is one of the sectors expected to be highly impacted negatively by climate changes. The impacts range from disruption of supply chains to imbalances in biomass production. The recurrent droughts in Kenya increasingly being attributed to climate variability affects considerable energy supply systems and in extreme cases disrupting the economic activities in the country. The reliability of the solar and wind energy resources relative to other fluctuating resources can therefore be important. Without accessible, high quality information solar and wind energy development opportunities for enhancing supply diversity and security will be missed.

In the case of solar, very few weather stations make actual pyranometer solar measurements, so solar information has to be derived from human-based cloud cover observations, or simple instruments that record only the number of direct sunshine hours in a day. Available global solar resolution data1 is lower resolution and can be improved for microclimates. In the case of wind, the measurements can often be blocked by nearby obstacles (encroaching construction and trees), resulting in unrepresentatively low readings. Furthermore, in many countries, areas with the best wind resource have no measurements at all, this leaving with the impression that the total wind resource availability is much lower than is actually the case.

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1. The U.S. National Aeronautics and Space Administration (NASA), Langley Research Center (LaRC) has developed a world-wide surface solar energy data set as part of its activities with the World Climate Research Program. The data set provides daily and monthly global horizontal solar resource data on 280x280 km cells for a four-year period. The data are completely derived from weather satellite data, although validation studies using ground-based measurements have been conducted. This data set is readily accessible through the Internet, and on CD-ROM available from NASA/LaRC.

The current global low resolution wind map is considered inadequate for energy assessment in most regions of the world. In addition, for both solar and wind measurements, many countries do not have the financial resources to maintain and properly calibrate the measuring equipment, further contributing to the uncertainty of resource assessments using these data. Due to mechanical component deterioration in anemometers, errors in wind speed are systematically biased to under representation of wind speed. Data can be difficult to access and is often not in digitized format.

UNEP with its mandated Global Resource Information Database (GRID), a facility for gathering, archiving and making information accessible and the Division for Technology Industry and Economics with the ministry of energy and relevant stakeholders have been undertaking Solar and wind energy assessment

1.2 *Energy Policy and Planning implications*

The energy policy in Kenya vide sessional paper number 4 of 2004 was a great shift form the earlier energy policies of yester years. There is a more pronounced emphasis on renewable energy resources including wind and solar energy especially for thermal applications.

It is also apparent that the policy change at a time when the national demand was on an upward swing thus creating pressure on costs and the need to develop local resources. The wind and solar mapping is therefore an expected link in resource identification for energy supply in the country. It was also well established that the reason why solar and wind were not factored in the nation energy planning matrix was the scarcity of information and data that is critical in aiding decision making and planning.

Availability of reliable and easily useable resource data is therefore essential for government and industry to identify in-country power generation potential and upraising of the security of supply for the country. The lack of data and information is a primary obstacle to both public-sector and private-sector investments and the barrier removal opportunity for this project was identified through the experiences of some developing countries in considering the requirements for incorporating large-scale use of solar and wind energy systems in national energy development planning.

1.3 *Methodology*

The SWERA project was a highly collaborative researching and analytical project involving international and national players. The activities focused on reviewing available information and assessment capacity of each participating country and validating available data sets and as reference data. All data sets and the associated methods used were subjected to a technical review with emphasis on adding value to existing solar and wind resource information to be made available to support informed selection and use of existing data in the global archive.

A survey of available solar information including previous projects by government and non governmental organizations, meteorological service, and universities was carries. Data and other relevant information were gathered and sites for validation selected. Practical Action in collaboration with department of Meteorology in Nairobi University gathered relevant in-country data sets to support the solar assessment process and included solar validation data and meteorological data used as input to the models (such as surface temperature and relative humidity, aerosol optical depth). The available data sets were digitized into a spreadsheet format .the available data was reprocessed to create a typical meteorological year data set as validation data.

A GIS toolkit was developed and is capable of accessing and processing GIS based data as part of assisting users to access and process their data according to local needs. Cross-model comparisons among the results of the various methodologies identified above established the level of uncertainty limits for the model results. For solar purposes for example a factor for the correction of satellite map values to remove the variation of the 3 years of satellite data from the long-term average was derived.

A Review of Existing Wind Surveys and Assessment Methodologies undertaken before the SWERA project was undertaken to identify the wind resource, assessment capacity and related information already available to the country or region. The studies undertaken and the information generated by the project served as validation data sets and as the reference data for interannual, diurnal and seasonal variability and areas of interest in the country identified. These included Ng'ong hills near the large demand centre of Nairobi, Coast where demand for electricity and solar thermal applications is high/

Data and information on wind energy was identified and collected from synoptic stations (ground-based measurements), upper-air stations (weather-balloon measurements), and marine data where available (i.e., ships, buoys). Data sets form the country underwent critical analysis for quality assessment using a local wind expert with guidance from the SWERA team to facilitate the use and integration of the available data with the wind models that were developed.
To undertake the wind analysis the lead collaborator and the partners were trained by Risoe on the use and application of a highly localized method (WAsP) for adjusting ground measurement data and developing time-based information.
Using both the WAsP and the KAMM models high resolution maps were generated and a wind atlas document (non-map, meta-data stored information including interpretation of the wind maps and summaries of the salient wind characteristics maintained.

Some selected dataset for both solar and wind underwent conversion and Integration into GIS format especially for archiving while a GIS Toolkit was developed to support the analytical functions that can be performed within a GIS. These include terrain, population information, administrative boundaries, and when available in the public domain land use, load centers, transportation and transmission corridors. The data and associated information from ground based measurements and the qualifying information on data sources and limitations was integrated with the GIS data. Among the data identified for Kenya includes administrative boundaries, Population i.e. Households, major roads , rivers , towns , land use , contours, DEM , protected areas , power stations and grid net work and the synoptic stations.

A global archive of solar and wind information with reference data sets and technical reviews supporting informed use will be established. These will include:

- Standard GIS data sets representing wind resources with supporting documentation
- Standard GIS data sets representing solar resources with supporting documentation
- Accompanying meta-data and data sets for wind and solar including TMY's, time series, etc
- Standard set of GIS data sets for topography, land use and population density
- Reports detailing technical review activities and findings
- Links to web sites that are pertinent to this project, such as the international, regional and country sites, GEF focal points or their designated agencies, the GIS Toolkit, and other UNEP/GRID sites

Finally three case studies in the utilization of SWERA tools in energy planning is attached to demonstrate the potential for support to planning and development. The advantages of the information and tools leading to better targeted and more effective pre-investment resources, more accurate techno-economical analysis leading to realistic cost-benefit projections, framing specific policies and financial incentives to attract private sector investment, and energy development policies.

1.4 *Structure of this document*

The reports begins with an introduction and context giving an overview of the energy policy and planning implications , the methodology context, geography and demography. Chapter two provided the structure of the economy and its relationship with energy. This is followed by the energy situation and supply matrix, energy demand and supply including energy security policy options.

Chapter five gives the institutional arrangements in the energy sector followed by chapter six on barriers and constraints facing renewable forms of energy and the pertinent issues.

Chapter eight introduces the solar and wind resource assessment followed by solar thermal power applications and wind resource in Kenya.

This report has attempted for the first time to undertake pre-investments analysis of three hot spots for wind energy at Ras Ngomeni, north of Malindi , Ng'ong hills near Nairobi and Marsabit hills in the north of the country.
Lastly, the application of RETscreen renewable energy modelling software has been demonstrated and used to show the energy availability form a wind farm and compared with a small hydro power plant.

1.5 *Country Context*

The government is a parliamentary democracy modeled along a Westminster system of government with the president being the head of state. A Prime Minister nominated from the party with a majority number of seats in parliament over see the running of ministries.

The country's economic growth which had stagnated to negative growth as a result of poor governance in the 80s and 90s is slowly reversing the trends since 2002 general election and rebuilding of the infrastructure. However, violence rocked the country after disputes on results of the 2007 elections but a truce brokered by ex- UN secretary general is keeping a tight power balance.

Major exports include coffee and tea and considerable income is obtained from tourism earnings with regional trade in manufactured goods like cement and petroleum products contributing to major earnings for the country. Currently, the building industry and services are one of the prime movers of the economy.

The official language in Kenya is English while Swahili, a language spoken widely in eastern Africa is the commercial language. The Kenyan capital, Nairobi is an important commercial and communication hub for the region and is the regional head quarter of several bodies including the United Nations.

1.6 *Geography and climate of Kenya*

Kenya, situated on the eastern seaboard of Africa is bisected by the equator latitude into two halves. It extends 5•N and 4.76•S and between 34• E and 41.6•E and covering an area of approximately 592,275 square kilometers with a 200 km economic zone along the Indian Ocean. The country boarders Ethiopia to the north, Sudan to the north west, Uganda to the west, Tanzania to the south and Somalia to the east and Indian ocean to the south west with a coarsely length of 470 kilometers.

The land mass rises from sea level along the Indian Ocean to 5199 meters above sea level on the snow capped Mount Kenya. The topography is characterized by four physical features which make the Kenya be dubbed as a country of contrasts. The coastal low land called the Nyika stretches for most of the coastal lowland, and covering most pf the eastern and north eastern provinces of the country. This gives rise into the highlands which are characteristically wet and heavily populated although covering only 25 per cent of the land mass.

The highlands rise above 1,400 meters but human settlements occur in some places up to 2800 meters above sea level. The highlands and the country in general is then bisected by the great east African rift valley which extends a distance of 750 kilometers and stretches between, 40 and 70 kilometers wide. The highest drop in the valley is over 1300 meters and influences the climate of the country greatly. The rift valley is also associated with tremendous geothermal resources which are already being tapped to feed into the national electricity power needs.

The area west of the rift valley constitutes western highlands with high rainfall associated with the Atlantic Ocean and Congo forest influences. The country shares a small portion of the Lake Victoria, the largest flesh water lake in the world with other two east African countries of Uganda and Tanzania. Most of the country estimated at 75 % is however arid and semi arid supporting less than a quarter of the population.

Kenya, being a tropical country has a bimodal rainfall heavily influenced by the inter tropical convergence zone pressure belts whose largely pronounced movement up and down from southern Africa triggers the onset of rains. The April May June marks the long rains and the October November short rains. The local relief and Lake Victoria influences the rainfall and climate to a great degree.

In the last few years climate change impacts have started manifesting themselves through more frequent droughts, flooding and seasonal variation. The impacts of these variations on energy systems are well pronounced due to heavy reliance on hydro power.

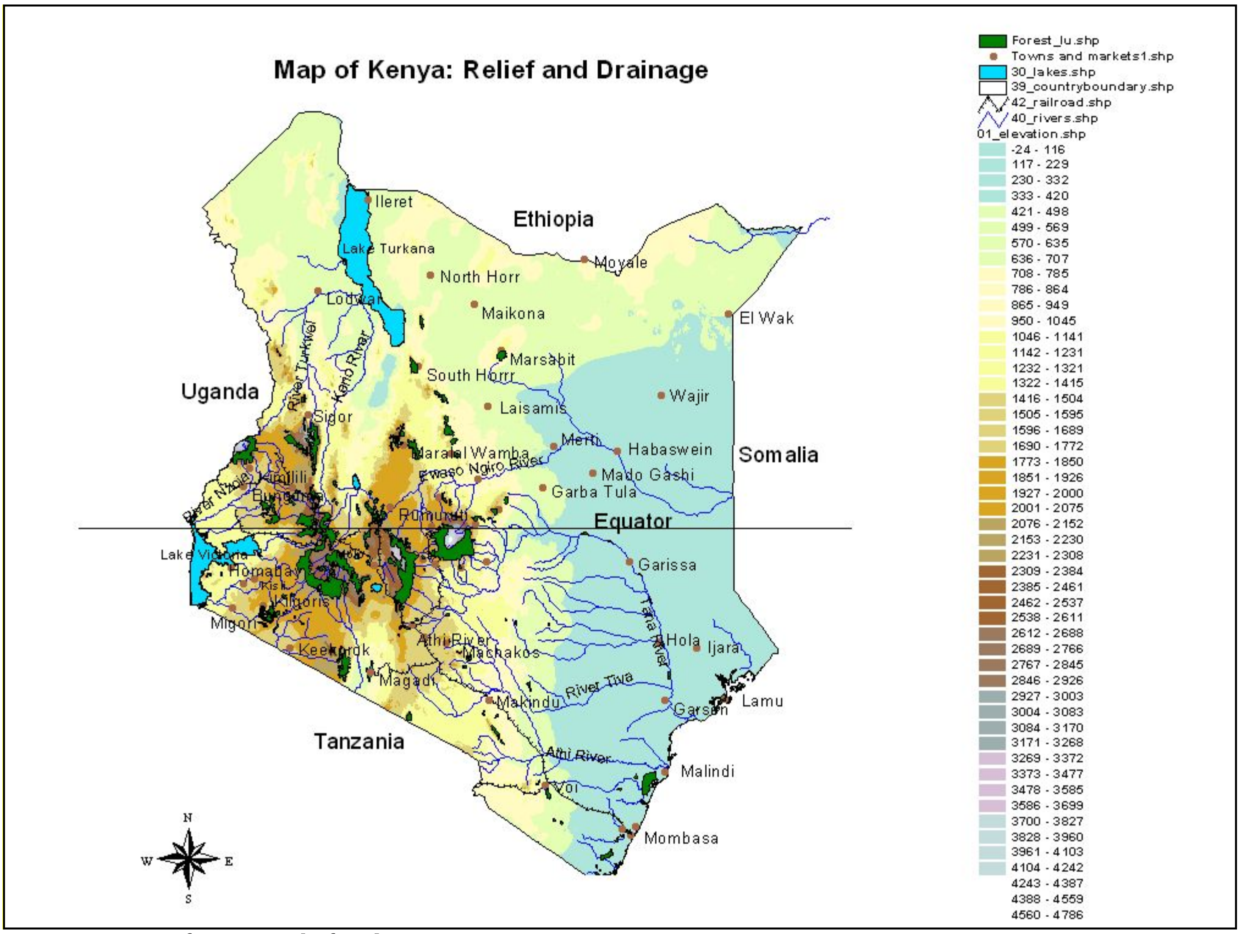


Figure 1: Map of Kenya Relief and Drainage

1.7 *Demography*

The last national census was carried out in 1999 where the population was found to be 28 million. By 2007 the population was estimated at 36.5 million people out of whom 51 % are women. By the same year 48% of the population was estimated to live below poverty line with most of the people dependant on agriculture for livelihood. Kenya has a mean household size of 5.1 but with a very high age dependency ratio where population less than 14 years of age contributes 41.9 % of the national population. The productive age of 15 – 64 was 54.2 % and those above 65 are around 3.5%.

The distribution of the population follows the land productivity with the highest densities being found in the provinces of central Kenya. Western, Nyanza and parts of the eastern providence. According the Kenya integrated household budget survey (2007), the highest densities were in urban settlements while a few pockets of rural Kenya was as dense and may qualify as true peri-urban settlements occasioned by such high population densities. The map below show GIS generated household densities by sub-location.

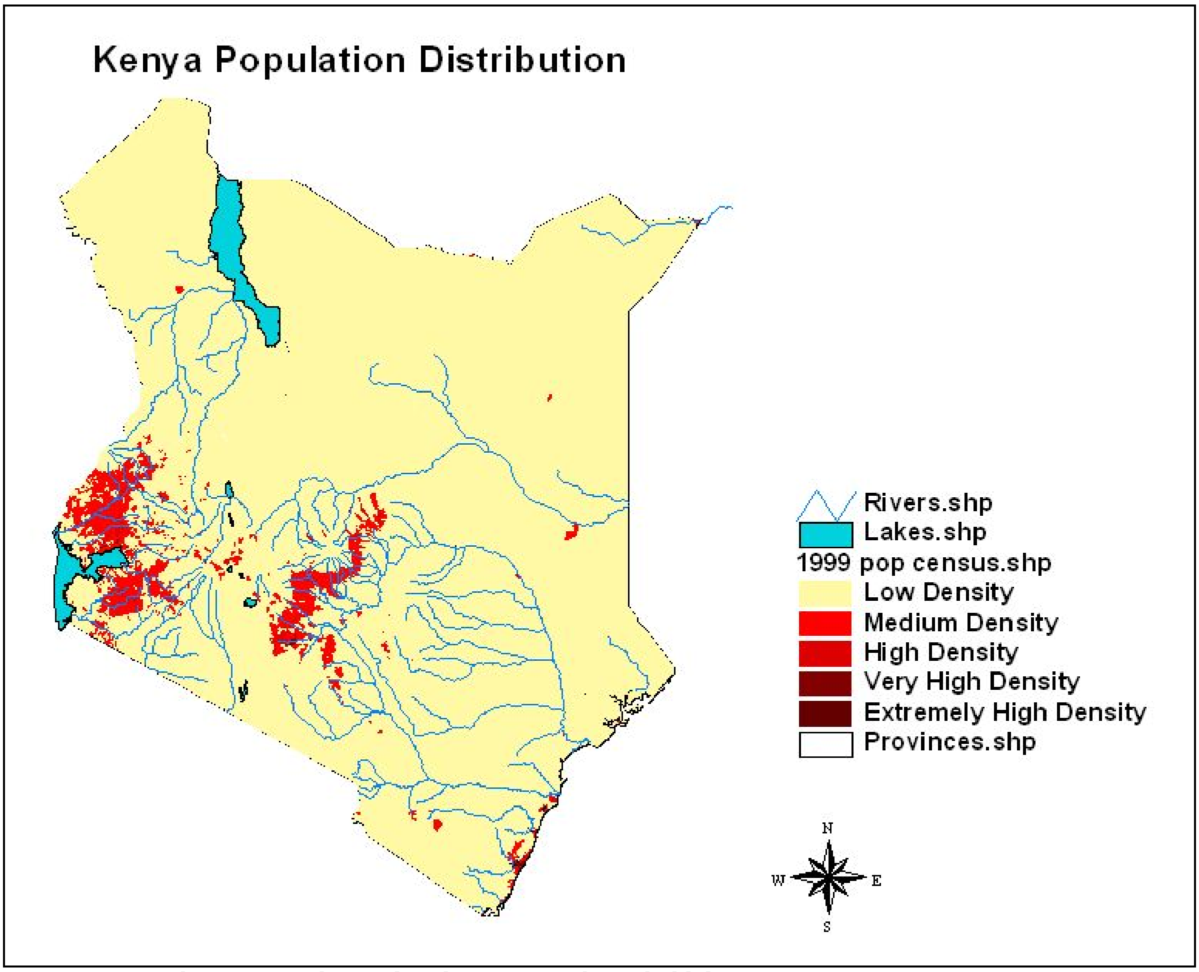


Figure 2: Map showing population distribution using household densities

The challenge is to develop energy resources to meet the demand for energy services in the large population densities. While several villages may appear as low density there are several pockets of very high density requiring service lines to be dropped or isolated distributed systems put in place.

2 Structure of the Economy

Kenya's economic development has experienced mixed results in its short history. The early years after independence from Britain were characterized by impressive growth. This growth was however checkered by the oil price shocks of the 73 and 79 which together with poor commodity prices especially for tea and coffee eroded the gains made in early years. By the late 80s and most of 90s almost all economic sectors of the country had stagnated with poverty rising from 48 percent in 1990 to about 56 percent in 2003.

To turn economic performance around and reduce poverty, the Government that came into office in December 2002 has formulated an Economic Recovery Strategy for Wealth and Employment Creation (ERSWEC, March 2004) which emphasizes accelerated economic growth and employment creation, increased productivity across all sectors, provision o f basic needs and equitable distribution o f national income. The performance of the economy which is heavily dependent on agriculture suffered with a decline in agricultural productivity.

The GDP growth in 2003 was 1.8% compared to 1.1% in 2002 and in this fiscal year the Government reduced the budget deficit to below 3.5% of GDP. This was achieved through improvements in revenue collection and restructuring of domestic debt, which resulted in substantial savings on debt service payments. The positive effect of these interventions was a substantial drop in interest rate on Treasury bills, which declined from 8.4% at the end of 2002 to 0.8% in September 2003 before rising to 1.5% at the end of 2003.

Other main market rates followed the decline in the Treasury bill rate. On average, bank overdraft rates declined during the year from about 19% to 14%. Trends in annual underlying inflation, which is a stable indicator for policy purpose, remained at about 2.7% for most of the year. The overall annual inflation, however, increased from 2% at the end of 2002 to 9.8% at the end of 2003 due to rise in food and fuel prices in the middle of the year.

The GDP growth trends have continued to show that the economy is recovering and last year the economy registered 5.8% growth in 2005 with equally impressive growth in 2003 where it registered 2.8% and 4.3 % in 2004. In the same periods the GDP per capita grew from 448 USD at 2001 prices to 456 USD in 2003 to 448USD in 2004.

Agriculture sector despite registering poor growth rate due to successive droughts in 2001 and 2004/05 continued to drive the economy. But by 2004 the tourism, external trade and construction have picked up momentum to become the major drivers. Coffee and tea and horticulture exports have been the major players. Tea registered growth despite the drought to increase form 236.3 thousand tones in 2000 increasing to 293.7thousand tones in 2003 to 324.6 thousands tones in 2004. Coffee on the contrary registered decreased growth due to its sensitivity to drought from 61.2 million kg in 2003 to 49 million kg in 2004.

The volume of trade has increased form 382.3 billion KES in 2000 to 465 Billion KES in 2003 and 579 Billion KES in 2004 generating total exports (fob) grow form KES 134.5 billion in 2000 183.2 KES in 2003 and registering 214.8 KES billion in 2004. The country at the same period imported (cif) 247.8 Billion, 281.8 and 364.s KES in the same years respectively.

In the money supply and banking the net foreign reserves increased form USD 1.2 billion in 2000 to USD 1.74Billion to in 2003 rising to USD 1.987 billion in 2004. In the same period private domestic credit increased from USD 4.2 billion in 2003 to USD 5.1billion in 2004.

The direct taxation, customs and exercise and Value added taxes and other indirect taxes constituted the largest single source of public revenue. In the meantime public borrowing both internally and externally was drastically reduced from USD 651million and 227 million respectively in 2003 to USD 78 Million and USD 122 million.
In 2006 Real GDP grew by 5.8% against the revised growth of 4.9 % in 2004. The impacts of the drought that impacted on the country in the last part of the 2005 and the dramatic rise on fuel pieces has somehow reduced the growth in the economy. Significantly the areas that experienced drought are the livestock areas and on the whole agriculture , forestry , trade and transport and communication underpinned the economic growth registering 6.7m 6.5 and 8.3 5 respectively. Despite the high oil prices in 2005 inflation decreased form 11.6 % in 2004 to 10.3 % in 2005. The national currency the Shilling strengthened against all major currencies with the government revenue collection growing by 11.1% form KES 307.1 Billion in 2004 to 342.3 billion in 2005. However in 2006 the exports reduced from 17% to 13 % mostly attributed to drought.

2.1 *Energy-Economy Indicators*

In the energy sector, domestic supply of electricity has been growing at an average rate of 7.6 % per annum in last five years and 7.9% 2003/04 and year 2004/05. Total generation in the fiscal year 2004/05 reached 5,246 million Kilowatt Hours (kWh), up from 4,864 million kWh in fiscal year 2003/04. Hydropower remains the largest single source, accounting for 55 – 60% of total electricity supply. Geothermal and fossil fuelled thermal plants contributed to 19.3% and 25.9% respectively in fiscal year 2004/05. The contribution of Hydro is to large extent dependent on recharging of the main reservoir at Masinga dam. In 2003/04 year hydroelectric power accounted for 67% of total supply while geothermal and thermal sources accounted for only 16.2% and 16.8% respectively. While generation has been growing on average by 7.9 % in the last five years consumption has been growing by 7.6% and sustained growth will require an additional 423 mega watts by 2008. This is envisaged to be contributed through projects which include the Sondu Miriu hydro-power plant and Olkaria Geothermal extension projects. These projects when fully commissioned will provide an additional 95 MW.

The petroleum sub sector, the main driver of the commercial sector has been experiencing sharp increases in prices that reached a peak of 70 US dollars in 2006 form $ 35.95 per barrel in June 2004 to US $ 55.5 per barrel in June 2005. As this report go to press it was reported at US $135 a barrel.

The bulk of the population continued to obtain their primary energy from biomass energy often obtained unsustainably tending to deplete the resource base. It is estimated that over 89 % of the population depend on biomass whose overall contribution to the national energy matrix is 68% in real terms.
The environmental degradation due to energy harvesting have been estimated to be major especially in terms of loss of biodiversity, soil loss, soil fertility reduction and siltation of the hydro power intake structures and cavitation. Biomass use is also associated with in door air pollution while external air pollution is mainly from fossil fuel combustion is mainly felt in cities and towns and power generation plants.

The energy sector players are basically drawn from the major activity they engage in. Generation is dominated by the Kenya Electricity Generating Company (KenGen), a state-owned company with 88% o f the country's generating capacity of 1,197 MW by 2006. The balance of capacity is provided by Independent Power Producers (IPPs). In 2006 the government released 30% pf the KenGen through an initial public offer which was over subscribed. Today the public owns 30% of the giant generating company. The transmission network of 2035 km of 220 and 132kV lines is owned and operated by the Kenya Power and Lighting Company (KPLC), a publicly quoted company in which the public sector holds a 51% equity interest (GoK 41%; National Social Security Fund 10%). KPLC is also the country's sole licensed bulk power purchaser and distributor. It also executes the rural electrification program on behalf of the Government. KPLC, the bulk supply tariff was reduced from about US$0.03 per kWh to about US$O.O23 per kWh in June 2003 but a tariff review would be inevitable if KPLC is to be sustained The Minister for Energy in a bid to encourage wider use of renewable introduced new guidelines on renewable energy production which advices special tariffs on wind , biomass cogeneration, small hydro.

3 Energy Situation Analysis and Matrix (2007)

In 2007, the country's population stood at 35.5 million people distributed in 6.860 million households with an average size of 5.1 persons per Household. About 75 % of the households are found in rural areas average household size of 5.5 persons while some 25% households are in urban areas but with a smaller household size at 4.0. For most of this population firewood remains the predominant fuel for cooking with 68.3% households using. 80% of the rural households use firewood compared with 10% urban residents. Charcoal, derived from primary biomass is the second most popular cooking fuel used by 13.3% of the households. Kerosene paraffin is ranked third predominant cooking fuel and the most common in urban areas with 44.6% reporting using it (Nairobi and Mombasa reporting 63.5% and 53.6% respectively).

Kerosene is on the other hand the most popular lighting fuel with over 75% reporting using it. This translates to 86.4% of the rural areas using kerosene for lighting. Electricity is the second most popular energy for lighting at 15.6% where 51% of the urban households connected and 4% of the rural households. It is noteworthy that 1.6% of the households are using solar photo voltaic for lighting.
Significantly, 4.5% of the population use biomass fires for lighting. The most affected is the North-eastern province at 19.1% and Rift Valley at 10.6%.

Other fuels used in Kenya include Liquefied Petroleum Gas (LPG) used by 3.5% mainly urban dwellers (11.9%) report using gas for cooking. Other fuels including biogas contribute little to the energy matrix.

Appliances used for cooking heating and lighting are also important in energy equation. In 2007, 60.8% of the population was still using the three stone traditional stoves largely in rural areas (78%). This has serious health implications due to in door air pollution and environmental degradation. Modern cooking appliances like LPG cooker, kerosene cookers and improved cook stoves are only appreciably used in urban areas and apart from kerosene stoves not many people use them.

A number of non energy services critical in meeting the millennium goals include provision of clean water, which, together with collection of firewood constitutes the major burden for rural women and the children especially the girl child and a major boost to health services since most of the rural water supplies are unclean. Provision of energy for health facilities will increase access to health services while lighting and powering schools will boast the education in terms of extra curricular studies and retention of good quality teachers due to better services.

The national efforts are focused on increasing access to services in a holistic and pragmatic manner. The UNDP supported regional strategy for scaling access to modern energy services is geared towards realising maximum impacts on Millennium Development Goals and address national poverty reduction strategies. The strategy is based on High Impact, Low Cost, Scalable (HILCS) interventions that are target based as follows:-

- Address the cooking and heating practices by 50% of those who at present use traditional biomass for cooking, including reducing indoor air pollution to safe levels, and increasing the sustainability of biomass-derived fuels production.
- Increase access to reliable electricity for all urban and peri-urban poor.
- Increase access to modern energy services such as lighting, refrigeration, information and communication technology, and water treatment and supply, all schools, clinics, hospitals and community centers.
- Increase access to mechanical power within the community for all communities for heating and productive uses.

It is recognized that many players are currently engaged in delivering services or interventions that are intended to deliver the services necessary for poverty reduction. It is also noted that the post election violence in Kenya reverse the well being of many leading to increased poverty and loss of the gains made in yesteryears.

The national energy matrix generally tends to follow the same path as economic level of activities. Annual growth grew form 1.4% in 2002 to 6.7% in 2007. However, political turmoil occasioned by dissatisfaction with the 2007 election results is expected to reduce growth significantly in the 2008.

3.1 *Energy Demand*

The energy demand is largely driven by the low level requirements of modern energy services. However it is important to note that these services are not in essence in low demand but under suppressed demand due to unavailability or high costs associated with the primary carrier the national grid power. Other services like heating depend on low valorization fuels like biomass and biogas hence accounting for very little apparent consumption. the commercial energy services petroleum and electricity contributed dominating the economic activities with the highest demand registered in road transport for liquid fuels, Aviation and power generation and industrial commercial uses. It is significant to note that in commercial energy 387,000 tonnes of oil equivalent are used for power generation. Increased use of wind and solar have plenty of room to play a significant role in national energy matrix.

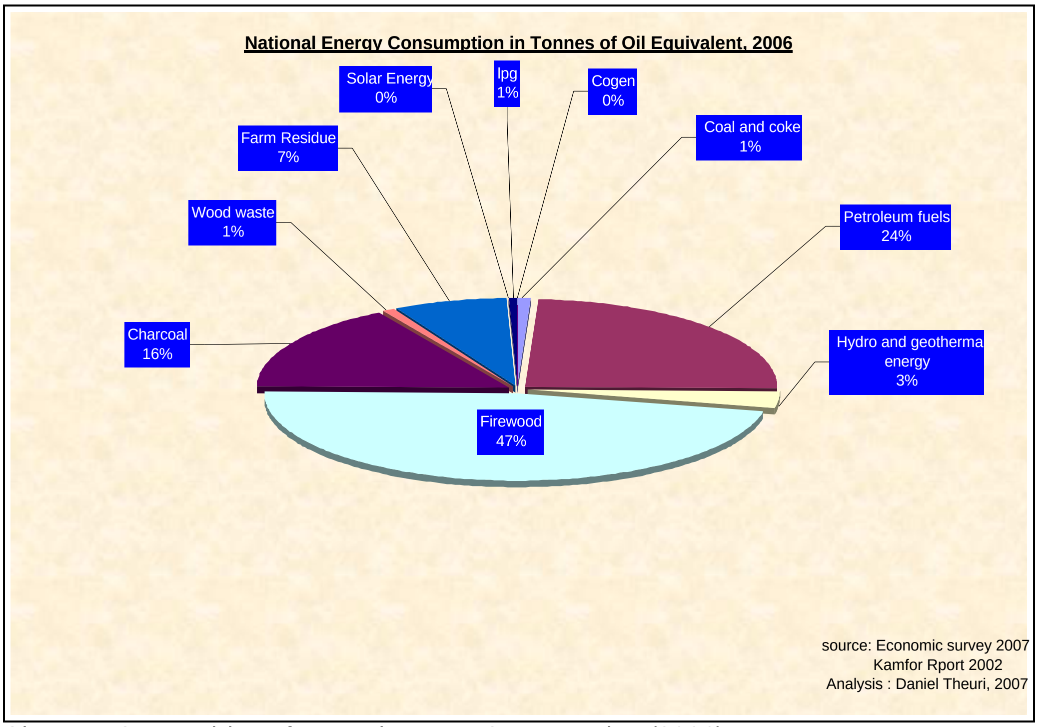


Chart 1: Composition of Annual Energy Consumption (2006)

Notes on above pie chart
* Biomass projected at 3% growth from Yr. 2000 consumption figures (Source Kamfor Report)
Assuming 3MW installed receiving 4.5 kWh / d for 365 days and operating at 16% efficiency
Coke and coal are mainly used in cement and steel production.
Source: Economic survey 2007and Projections of Kamfor 2000 Figures growing at 3% pa

3.2 *Electricity*

In the energy sector, domestic supply of electricity has been growing at an average rate of 6.5 % per annum in last few years and reached over 8.3 % 2006/07. The total installed capacity by end of June 2007 was 1197 MW with an effective installed capacity of 1153 MW. The peak demand in the same period reached 1053MW confirming the increased growth rate of 8.3% Total generation in the fiscal year 2006/07 reached 5894 million Kilowatt Hours (kWh), up from 5,246 million kWh in fiscal year 2005/06. Hydropower remains the largest single source, accounting for 55 – 60% of total electricity supply. Geothermal and fossil fuelled thermal plants contributed to 19.3% and 25.9% respectively in fiscal year 2006/07 respectively. Wind energy continued to play an insignificant role with only one turbine sending power to the grid accounting for 0.2 GW in 2006/07. While generation has been growing on average by 7.9 % in the last five years consumption has been growing by 7.6% and sustained growth will require an additional 423 megawatts by 2008. The figure below (chart 2) show the installed capacity in 2007 , the effective capacity and the sales contribution by each category.

	Installed capacity	Effective installed capacity	Energy sales by type and category	
Kinden	677.3	659.4	Hydro	3277
	153.7	135.1	Thermal	421
	115	115	Geothermal	900
	0.4	0.4	Wind	0.2
REP	5.6	4.4	Thermal	12
PIP	145	143	Thermal	868
	13	12	Geothermal	112
	2	0	Co-gen	4
Emergency Power	100	96	Thermal generation	131.1

Chart 2: Total Installed Capacity

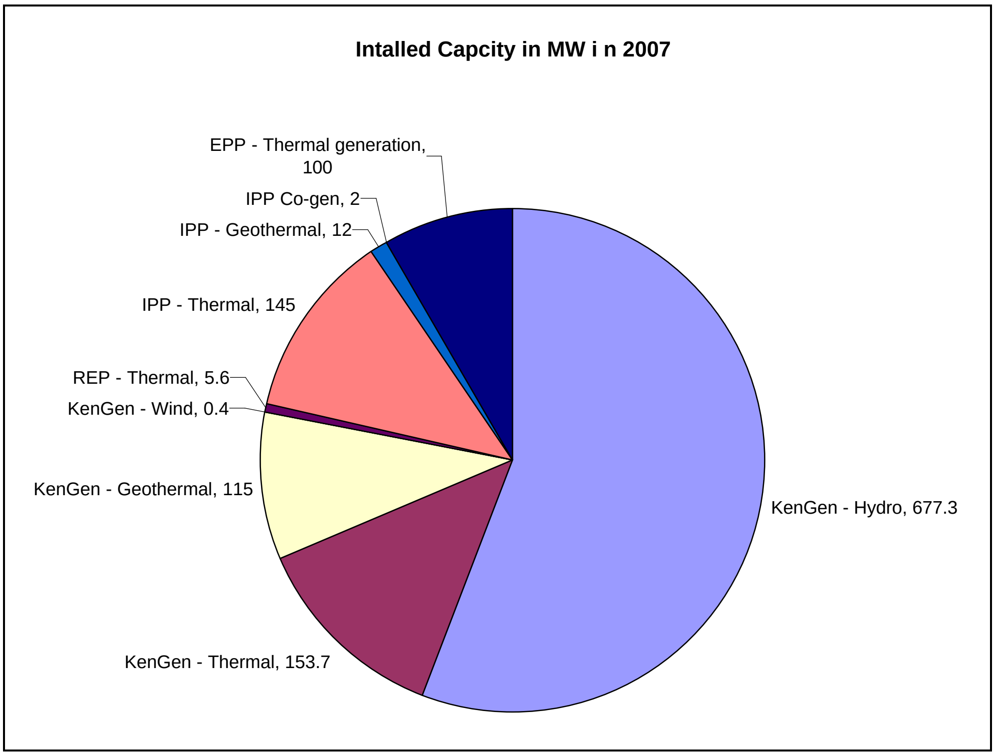


Figure 3: Installed electricity in MW in 2007

3.3 *Rural Electrification*

The rural electrification in Kenya is an important programme in increasing access to electricity derived energy services. There has been a marked growth of customers connected to this programme which averaged 8.8 % in 2006 growth period. The numbers increased to 110,724 as of July 2006 form 101793 in July 2005. The rural consumers who are mainly households and small service establishments on average consume 154 units per month (using 2006 figures)

4 Energy Supply

4.1 *Hydropower*

The hydro power dominates commercial energy production in Kenya but use of biomass is the most dominant fuel accounting for 68% of the national energy consumption followed by petroleum at 22% electricity at 9% while the rest account for only 1 %

Kenya is mountainous country with highlands rising over 4000 masl. The Mount Kenya, a conical formation extinct volcanic mountain has permanent snow on top. The highlands with its high rainfall is source of five drainage systems in the country which are estimated to dissipate some 6000 MW out of which 2265 are of 30 MW and above while the Small, Mini and Pico hydros are estimated at 3000 MW. Out of this potential over 700 MW has been developed and connected to the national grid. Another capacity of about 1 MW of mini and micro hydro has been developed for own use mainly by institutions and commercial agricultural enterprises. This hydropower capacity is located in five geographical regions, which represent Kenya's major drainage basins, i.e. Lake Victoria basin (1,840GWh), Rift Valley region (1,120GWh), Athi River basin (460GWh), Tana River basin (2,560GWh) and Ewaso Ng'iro North River basin (620GWh). In 2006 the total installed capacity for electricity was 1177.8 MW sourced mainly form hydro and geothermal sources which are clean sources of electricity.

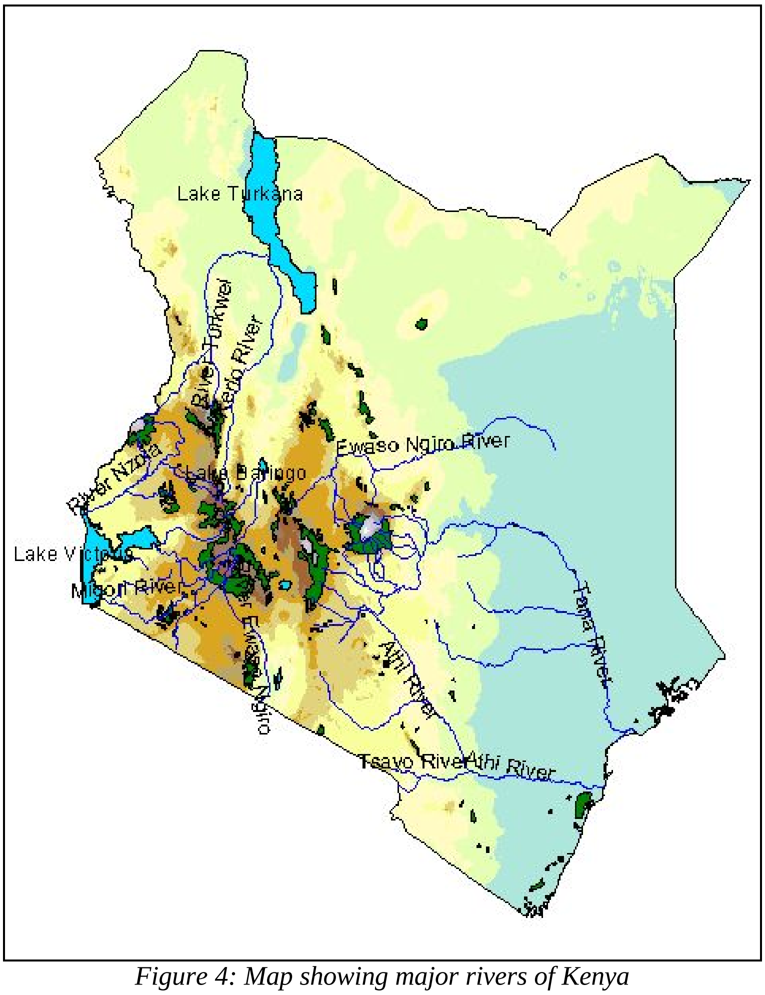


Figure 4: Map showing major rivers of Kenya

4.2 *Geothermal Energy*

Geothermal resources in Kenya are located within the Rift Valley and are associated with numerous very young volcanic centers. Initial investigations carried out in the past and which are as yet to be updated indicate that Kenya's Rift Valley has a potential of more than 2,000 MW that can be exploited for generation of electricity using conventional methods for at least 20 years. Actual potential for power generation may exceed this estimate if binary generation systems are used concurrently with the conventional system. These resource estimates are based on preliminary surface reconnaissance data as only Olkaria and Eburru have been explored by drilling.

Currently, only 128 MW of an estimated 2000 MW of geothermal potential has been developed, accounting for about 5% of the total installed generating capacity. KenGen owns 115 MW of this capacity and an IPP 13 MW. These two plants are located in the Olkaria geothermal field. In addition to this, KenGen is currently developing a 64 MW plant in Olkaria North East (Olkaria II), while the IPP is developing in parallel a 48 MW plant in Olkaria North West (Olkaria III). The two plants are expected to be commissioned in the first and third quarters of 2003 respectively. Through exploration drilling, a potential site for Olkaria IV plant of around 64 MW has been identified and plans for full appraisal of the steam field for development are under consideration.

4.3 *Fossil Fuel*

Kenya has no known reserves of petroleum and all the national demand is imported. Petroleum oil is imported in form of crude oil for domestic refining through a local Mombassa port based refinery. With liberalization of the petroleum sector, private sector mainly the international multinationals have dominated the trade in oil products and white products are also directly imported.

Petroleum accounts for 20% of the total primary energy consumed in the country registering a domestic consumption of petroleum products has progressively increased form 2.466 million tones in year 2001 to 2.192 in 2003 then rising to 2.716 million tones in 2005, imported at a cost of Kshs.53.7 billion. Petroleum imports in the same year accounted for 25.7% of the country's total import bill, equivalent to 40% of total foreign exchange earnings from visible trade. Over the last five years petroleum and coal imports have averaged 2.5 million tonnes and 130,000 tonnes per annum respectively. Kenya's average per capita consumption of fossil fuels at 89.3 Kilogrammes of oil equivalent (koe) for the period 1996-2000 is far below the average of 384 koe for low-income economies and a world average of 1434 koe in 1994.

Kenya do not have proven resources for coal but exploration by the ministry of energy has been going on for the last three years with indications for a major find. The presence of the karoo geology which is associated with coal bearing rocks all the way to South Africa gives hope that the is deposits of coal yet to be found. Mui basin found in the eastern part of the country has shown possibilities of coal deposits being found. Such a find would have significant impact on the national energy matrix especially in power generation. On average the country spends consumes 90,000 metric tones of coal and coke all imported into the country.

4.4 *Power Generation*

The national generation network comprises of hydro power based generation which contributes around 58% of the total energy delivered. The few working wind electric turbines registered 0.003%. The thermal generation with its associated emission could benefit from wind and solar resource utilization. In 2007 a total of 5725 GWh were delivered to KPLC for distribution from local energy sources. The potential for increasing the heat enthalpy of the geothermal using the solar thermal application is high especially considering the areas in the south of lake Turkana which is estimated to hold considerable geothermal resources yet to be explored.

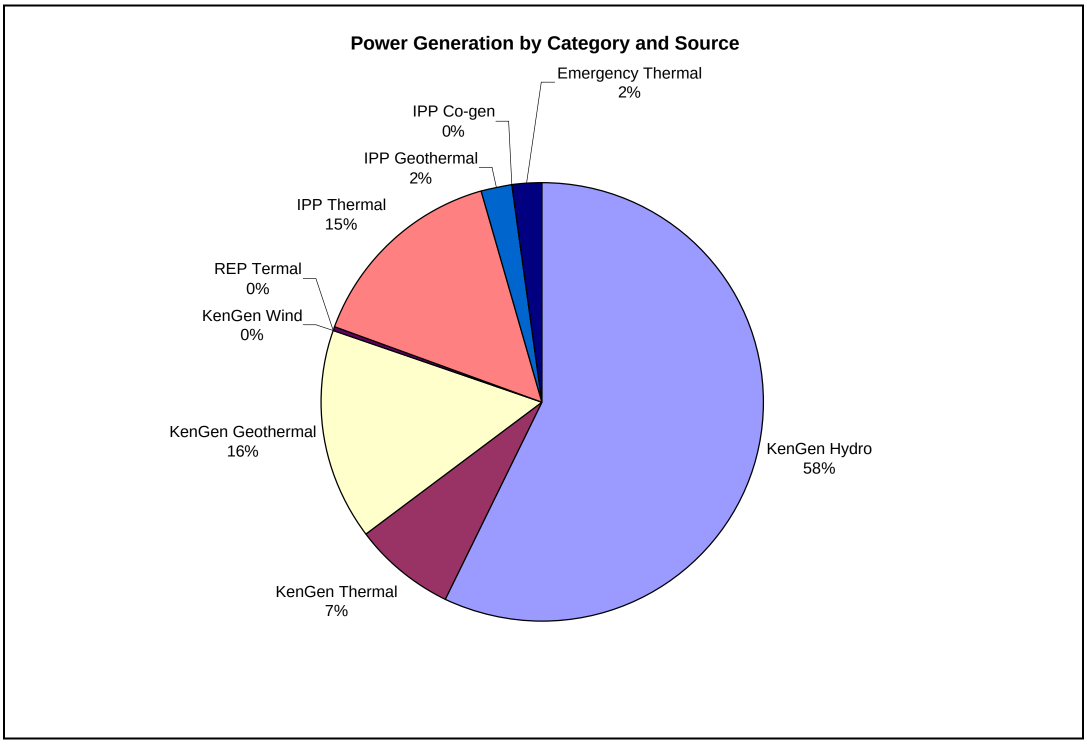


Figure 5: Power category and source

4.5 *Grid Network*

The national grid network in Kenya comprises over 30400 km of both transmission and distribution lines. As the end of July 2006 some 1323 km of 220 kV lines, 2035 km of 132 kV and 630 km of 66 kV lines were transmitting electric energy to consumers through a distribution network comprising of 7826 km of 33 KV lines and 18532 km of 11 kV lines that ultimately feed into the low voltage drop lines. The map below show the transmission network.

Figure 6: Distribution network in Kenya

4.6 *Biomass Energy including Co-generation*

Biomass energy meets the largest user demand category mainly for household cooking, small rural enterprises and some specialized industries in the country like the tea curing by some tea factories. It is sourced mainly from farmlands although a significant amount is obtained form trust lands and government forests.

The only biomass material currently used for co generation is the sugar bagasse. Sugarcane is one of the most prolific biomass producers and production in Kenya largely in western part of Kenya with three distinct zones while the Tana delta in the coast is emerging as major ground for fast growing canes. The central Nyanza sugar belt the oldest producing zone suffers heavy clay soils that make operations very expensive, and relatively low rainfall that reduce yields. Central parts of western province currently served by Mumias sugar Factory and Nzoia sugar Company have some of the highest productivity but the area is constrained with the dwindling land sizes. The South Nyanza belt is served by one factory that has a current crushing capacity (3,000 tons cane a day (TCD)) that is below the region's requirement. It has the best potential for expansion in the sugar industry. Plans are underway to increase the factory capacity to 6,500 TCD.

The total land under cane production in 2005 stood at 144,465 Ha out of which 56,500 was harvested to deliver some 4.8 million tones with a cane yield of approximately 71.46 Tonnes cane per ha. The potential for entropy heat for co generated power is higher in the Tana river in the cast province where higher solar irradiance is recorded compared with the low activity areas of western Kenya and Nyanza.

4.7 *Solar Energy*

Kenya being astride the equator and extending four degrees either side receives a considerable amount of solar radiation. Early assessments indicated that the country received on average 4.5 kWh per square meter per day. Since solar assessment was the subject of the this study a detailed analysis of the solar energy available in the country is given later.

4.8 *Energy Security Policy Options*

The energy security options are currently few and narrow in impacts and there is need to identify other sources to guarantee supply and limit the damage occasioned by small range of equally small systems. The overdependence on imported fuels strain the economy and reduce degree of market actors in predicting long term energy pricing. It is the government policy to enhance security of supply by measures among them widening the energy resource base, increasing the role of renewable primary wind energy and solar energy and improving the operating environment for the players.

The recent feed in tariff offered by the government for renewable energy supply of electricity is policy instrument directed towards releasing security of supply and increasing the role of local energy resources.

5 Institutional Arrangement in the Energy Sector

The main actors in energy sector are the government, quasi governmental specialized organization, private sector and regulator. The government through the ministry of energy is responsible for policy formulation and articulation and in providing of enabling environment for all stakeholders. Over the years the government through the ministry have overseen the least cost power development planning process and directs the rural electrification programme and planning.

Tow utilities operate in the power sector with KPLC distributing and retailing the power while KenGen 70% owned by government while public owns the rest dominate the power generation.

The private sector is more pronounced on the petroleum sub-sector which was fully liberalized in 1994. The government owned Kenya pipeline company delivers the bulk of the white fuels to major consumer centers of Nairobi, Nakuru and Eldoret and Kisumu.
In the power sub sector a number of IPPs are active in the power generation mainly using thermal power systems and one IPP in geothermal power generation in the rift valley.

The Energy Regulatory Commission was created recently with the enactment of the Energy Act in 2006 and will be responsible for regulatory and tarrification processes and it is mandated by environmental management authority to be the leading institution on energy and environment matters.

6 Barriers and Constraints in Utilization of Major Energy Resources

In 2005 the SWERA project commissioned a study on policy analysis and market penetration for wind energy and applicable to solar identified a number of existing barriers and constraints Among these were

a) The traditional duplicity of the distortion of the energy prices due to hidden subsidies especially in the power sector;
b) Absence of suitable legal and regulatory framework and lack of institutional support to promote widespread use of wind energy; some of which the new Energy Regulatory Commission is expected to address;
c) High initial capital costs of the systems despite gradual reduction of the indirect taxes by the Government over the years with no significant price reductions;
d) Lack of awareness of potential opportunities, market niche for electricity production and the economic benefits offered by wind energy technology and,
e) Lack of appropriate credit and financing mechanisms to facilitate acquisition of wind technology by the rural population.
f) Associated capital flight in acquiring REs especially solar and wind energy, where up to 90% of the costs go to suppliers abroad.
g) Lack of necessary infrastructure to support the technology.
h) The traditional planning mechanism exclusively based on conventional power production systems in LCPD

In conclusion therefore, the report recommends that in order to improve on increase the penetration of wind technology in the country on a scale large enough to have a significant impact on Kenya's total energy needs, several steps ought to be taken. Some of these are;

1. The Government's wind data collection programmes should be strengthened and expanded to include more sites outside the synoptic stations. There is need to complete the Wind Resource Atlas to include detailed economic analyses of potential sites to reduce project costs and accelerate wind park development.

2. The Rural Electrification Masterplan should be updated to include mature renewable energy systems for decentralized systems and intensify rural electrification reform by incorporating options like block concessioning through open bidding.

3. Explore alternative financing mechanisms for acquisition of wind energy systems like end-user financing, interest rate subsidy; credit enhancements; partial credit guarantees and; provision of seed funding for RESCOs to overcome initial market barriers.

4. In developing the Least Cost Power Development Plan, the method of financial analysis for investment in both renewable energy and conventional systems should factor the real market risk of using fossil fuels. The conventional approach tend ignore the risk differentials and either overestimate the cost of renewable based-electricity or underestimate the cost of fossil fuels.

5. There is need to improve the wind power infrastructure by extending or reinforcing the national power grid to areas with high wind potential like Northern areas of Kenya that have high wind potential yet not connected to the national grid.

6. To establish a favorable institutional framework there is need to establish institutions for regulation, financing, business development and research and development with clear roles and responsibilities.

7. There is need to improve the capacity of RESCOs and MFIs to participate in the wind energy market through training, adaptive research and facilitating establishment of SME production units in rural areas.

7 Pertinent Issues

7.1 *Policy and Legislative Situation*

The policy framework are set out by the sessional paper number 4 of 2004 on energy policy and outlines the broad objectives that the wind and solar energy resources are to be addressed. The policy recognizes the importance of the two renewables and goes ahead to provide for incentives for the large scale utilization of the two energy resources largely untapped to date. The policy recognized the urgent need to allow vertically integrated renewable energy mini grids systems for rural electrification even in areas the public supplier is operating. It also provides for appropriate incentives for large scale use of these RE Technologies and their specific applications like water lifting and pumping.

7.2 *Data and Information to support decision making and investment planning*

The greatest challenge that has been facing renewables in Kenya is lack of data to support planning and investment decisions. This problem affect the entire spectrum of the stakeholders form planners to practitioners including enthusiasts. SWERA project recognized this major weakness and is attempting to provide such a facility for making readily available data to support decision making.

7.3 *Environmental Issues*

The national Environment Management and Coordination Act sets the modalities and requirements for the environmental management. An environment impact assessment is mandatory for all energy projects. This is undertaken under close supervision of the lead agency the Energy Regulatory Commission mandate to deal with all environmental issues of the energy sector by the NEMA.

It is anticipated that most of the wind and solar electric and thermal applications will be beneficial in reducing carbon emissions associated with biomass and fossil fuels in heat generation for water heating and electricity generation especially in the remote places. An investor interested in utilizing any wind or solar will need to familiarize with the EMCA 1999 and any other reparatory requirements as set in place by the regulator.

7.4 *Energy Use and Carbon Emissions*

Whereas Kenya is not a net emitter, it is increasingly being realized that it will be important for the country to use a cleaner development roadmap that will displace most of the fossil based thermal generation and the biomass use for heating and cooking. The solar and wind energy together with hydro power are among the clean energy systems with nil emissions.

8 SOLAR AND WIND ENERGY RESOURCE ASSESSMENT

8.1 Overview of the Solar Resource

Kenya being situated astride the equator receives high irradiance and most of the northern and north eastern areas are known hotspots. Most of this solar energy is used for photosynthetic conversion while considerable amount is used for drying and heating mostly cereals, coffee and biomass. Recognizing that the maximum irradiance cannot exceed 1.356 kW/m^2 obtainable at the equator, the country is thus exposed to high radiation moderated by climatology and altitudinal differences. This is the first time detailed work on solar analysis of Kenya have been undertaken using a higher resolution than the earlier available works. Energy service provides, Project planners and policy makers have only relied on low resolution solar maps generated by NASA and which are in 100 km by 100 km grids.

8.2 High Resolution Solar Radiation Assessment for Kenya

The radiation assessment was carried for Daily National Irradiance (DNI based on the Deutsches Zentrum fuer Luft- und Raumfahrt e.V. (DLR) method and the method for deriving Global Horizontal irradiance (GHI) is based on a combined method of (DLR) and SUNY. The high resolution solar radiation assessment is based on data of the geostationary satellite Meteosat 7 located at an orbit at 0° latitude and 0° longitude and scans a specific area every 30 minutes with a spatial resolution of 5x5 km². The solar radiation is calculated for the complete country for the years 2000, 2001 and 2002 and the data is available in a digital GIS-format (ESRI Vector-Shapefile) where 3 annual and 36 monthly average daily total sums of GHI and DNI are given for each 10km x 10km geo-referenced pixel. The complete database (ESRI-Shapefile and MS-Access database) can be downloaded from the SWERA-homepage (http://swera.unep.net).

For following sites hourly time series of GHI and DNI for three years are calculated:

Stations/Sites	Lat (degree)	Long (degree)	Elevation (m)
Dagoretti	-1.30	36.75	1935
Eldoret	0.53	35.28	2120
Embu	-0.50	37.45	1607
Garissa	-0.48	39.63	138
JKIA	-1.32	36.92	1748
Kericho	-0.48	35.18	1968
Kabete	-1.25	36.73	2089
Kakamega	0.28	34.77	1706
Machakos	-1.58	37.23	1722
Kisii	-0.68	34.78	1837
Kisumu	-0.10	34.75	1236
Kitale	1.02	34.98	1840
Lamu	-2.27	40.90	30
Lodwar	3.12	35.62	544
Makindu	-2.28	37.83	1076
Malindi	-3.23	40.10	21
Mandera	3.93	41.87	356
Marsabit	2.32	37.98	1447
Meru	0.08	37.65	1640
Mombasa	-4.05	39.63	17
Moyale	3.53	39.05	1197
Msabaha	-3.27	40.05	98
Mtwapa	-3.93	39.73	23
Wilson	-1.32	36.82	1804
Nakuru	-0.28	36.07	1976
Nanyuki	0.05	37.03	2034
Narok	-1.10	35.87	1706
Thika	-1.02	37.10	1574
Nyahururu	-0.03	36.35	2558
Voi	-3.40	38.57	603
Wajir	1.75	40.07	262
Nyeri	-0.43	36.97	1935

The hourly time series can be downloaded from the SWERA web-site using Kenya_Sitename_Lat_Lon_Z_Year. For example for Dagoretti site the file name is: Kenya_Dagoretti_S1.30_E36.75_Z1935_2000

The detailed report and the methodology used for this project is annexed at the end of the report.

In order to obtain a clear overview of energy resources available in the country, deliberate efforts at increasing the solar intensity classes was taken. Overleaf find Direct national irradiance (DNI) and Horizontal irradiance maps. They have been arranged to show a typical meteorological year followed by years 2000, 2001 and 2002. A monthly variation for both DNI and GHI is also provided to provide the reader with an overview of the monthly variation.

Direct normal radiation (DNI) Three Year Average 2000,2001,2002, Monthly Variation

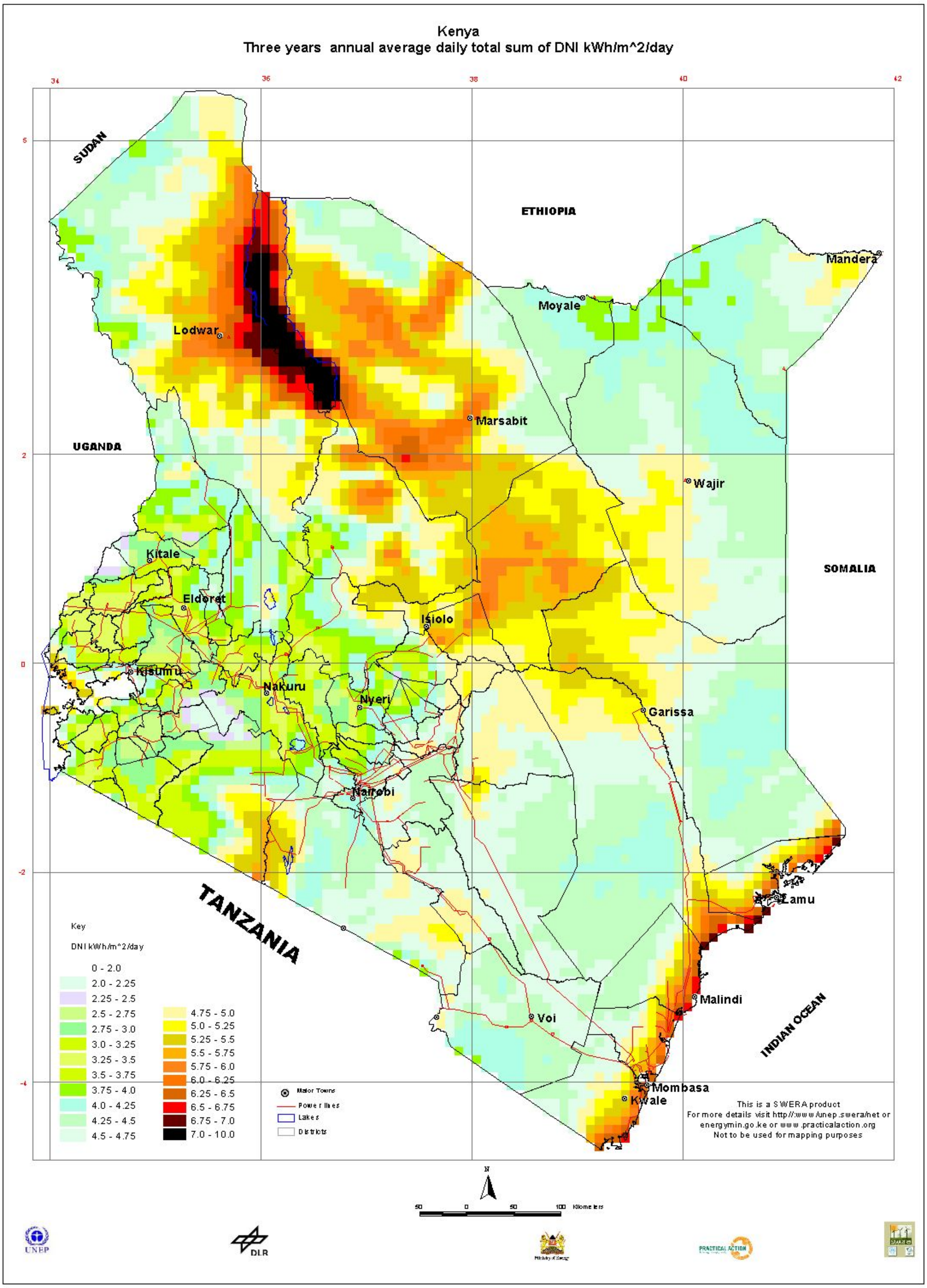


Figure 7: Map showing DNI 3 yr Average

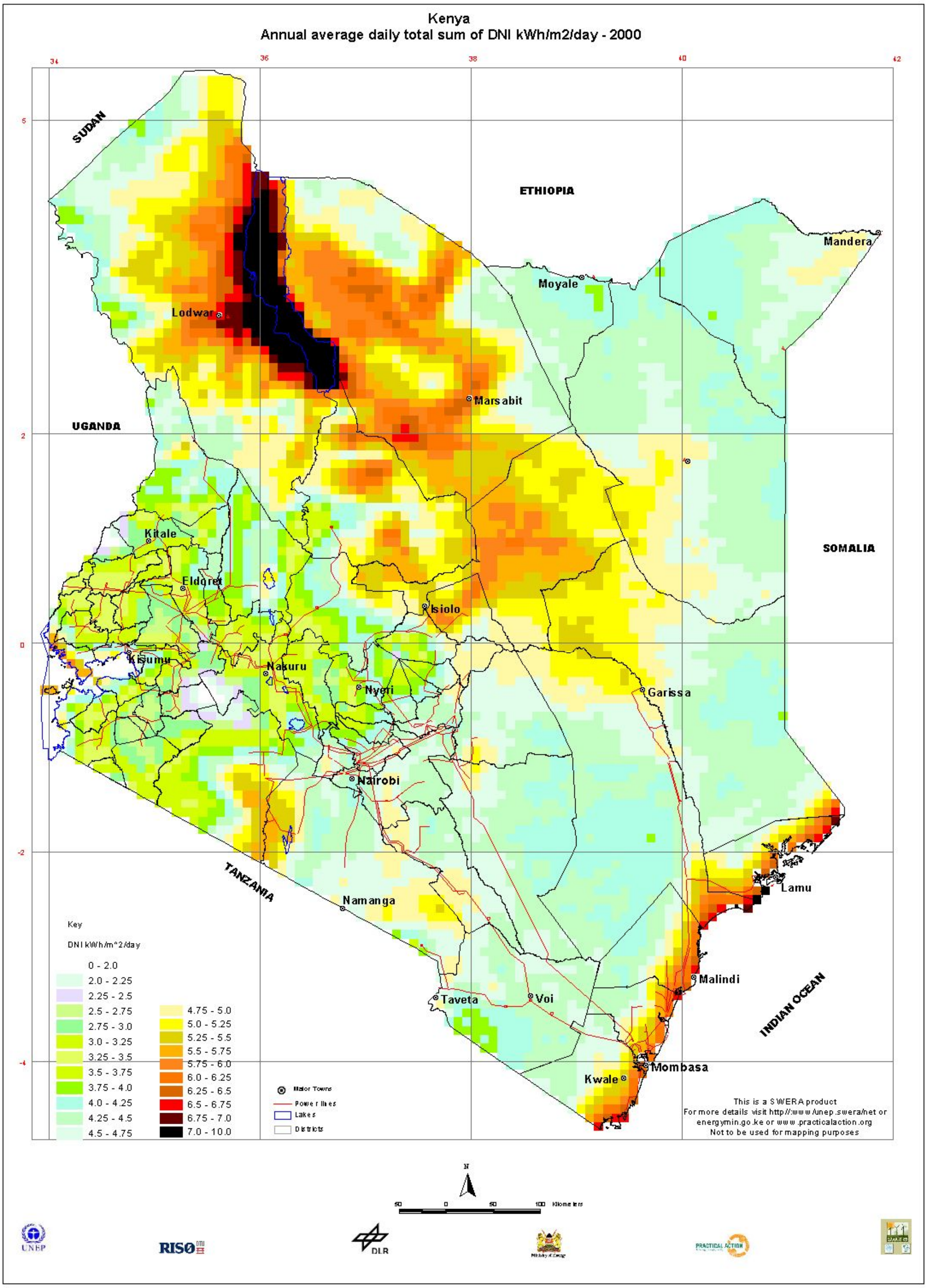


Figure 8: Map showing DNI in yr 2000

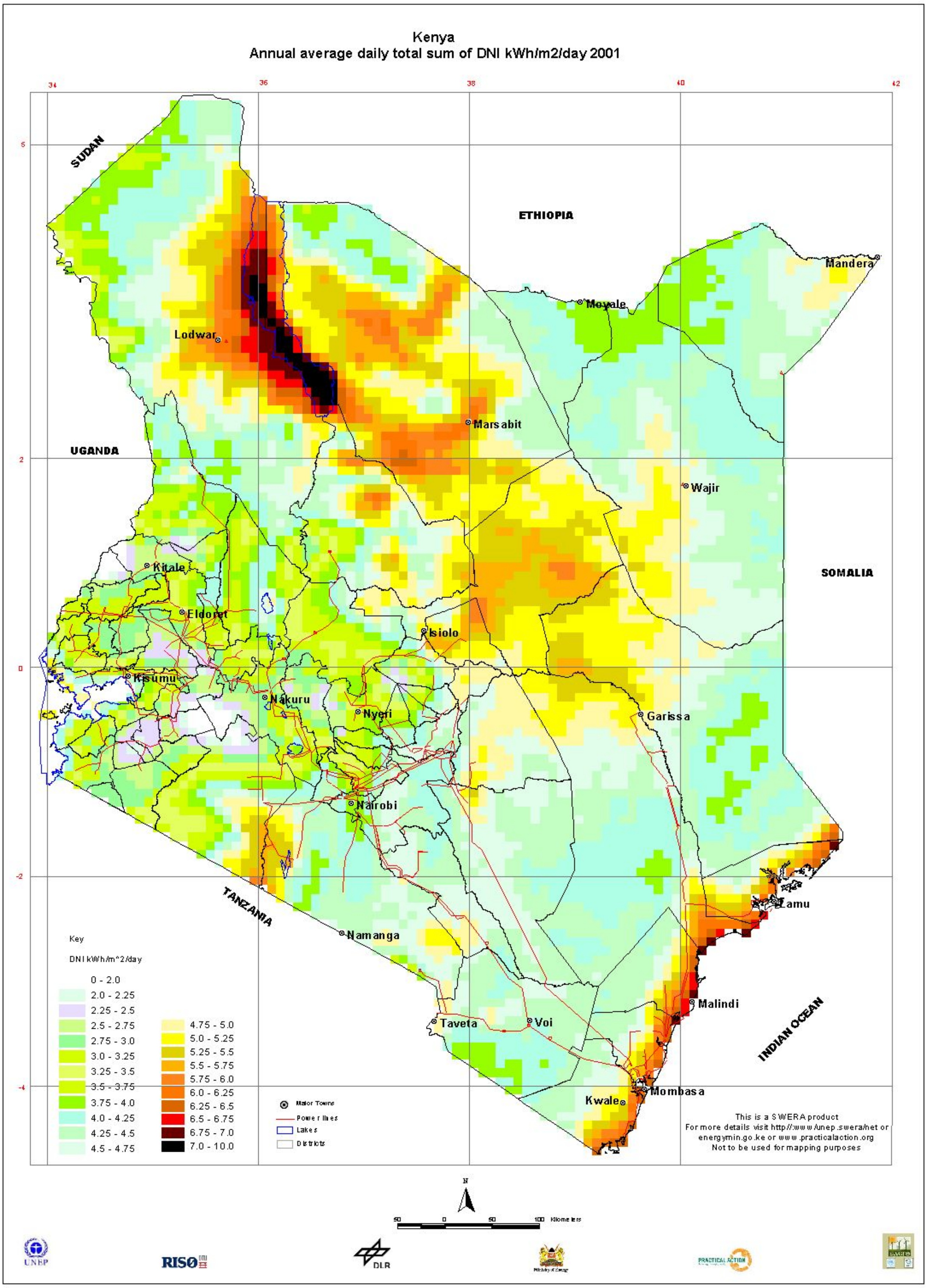


Figure 9: Map showing DNI in Yr 2001

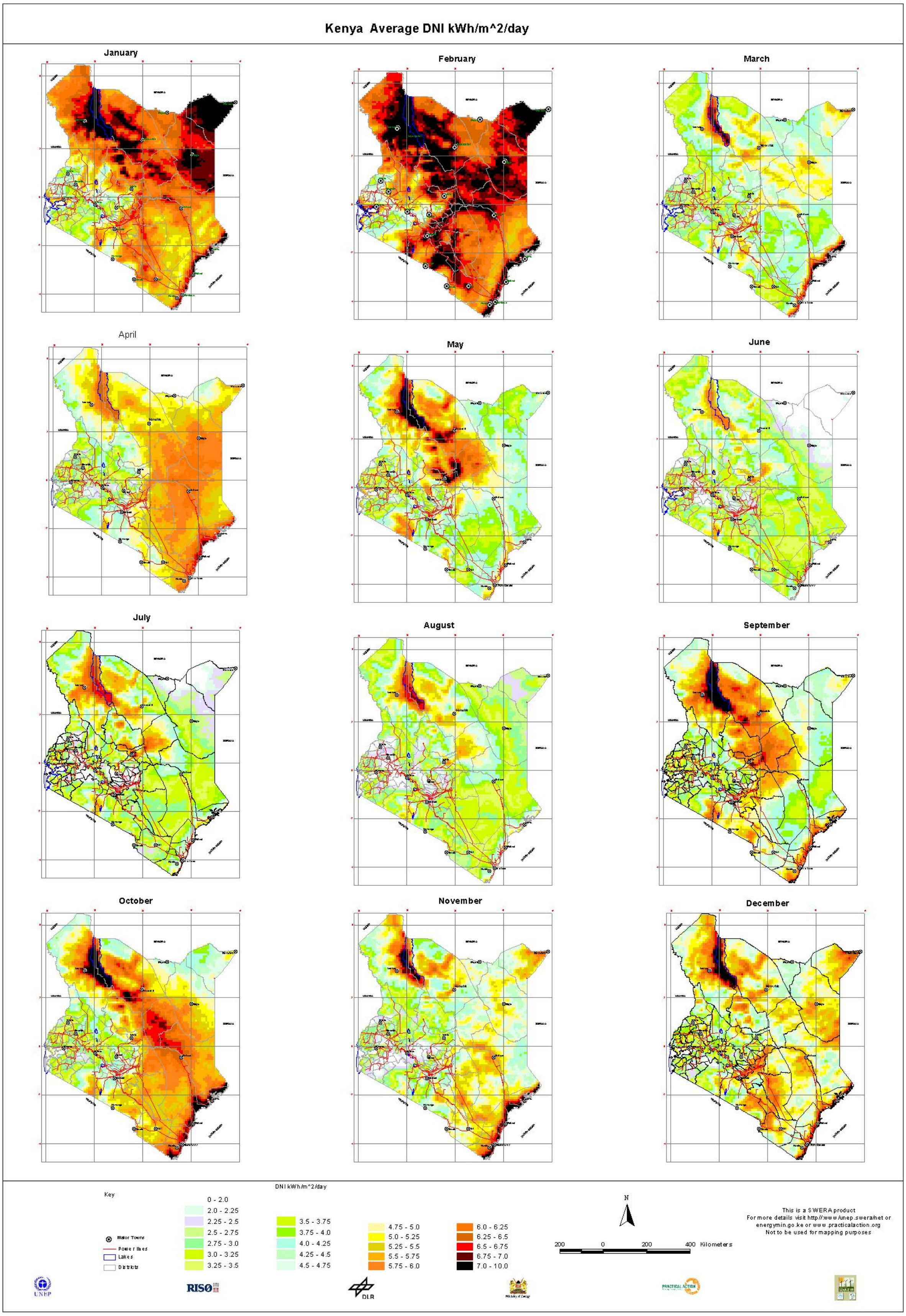


Figure 10: Average Monthly DNI for Kenya

Global Horizontal Radiation Three year average 2000, 2001, 2002, Monthly Variation

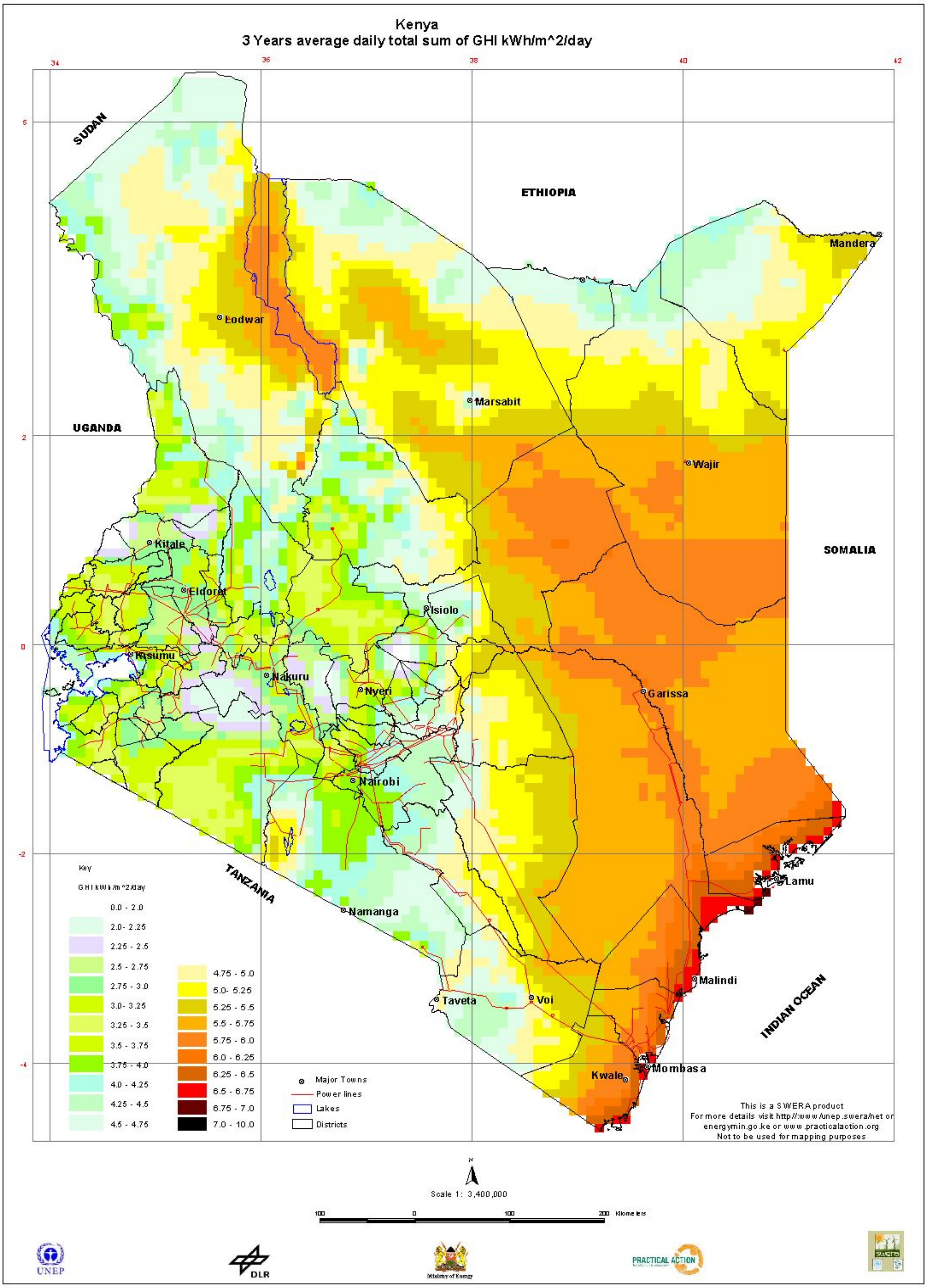


Figure 11: Map showing 3 Yr average GHI for Kenya

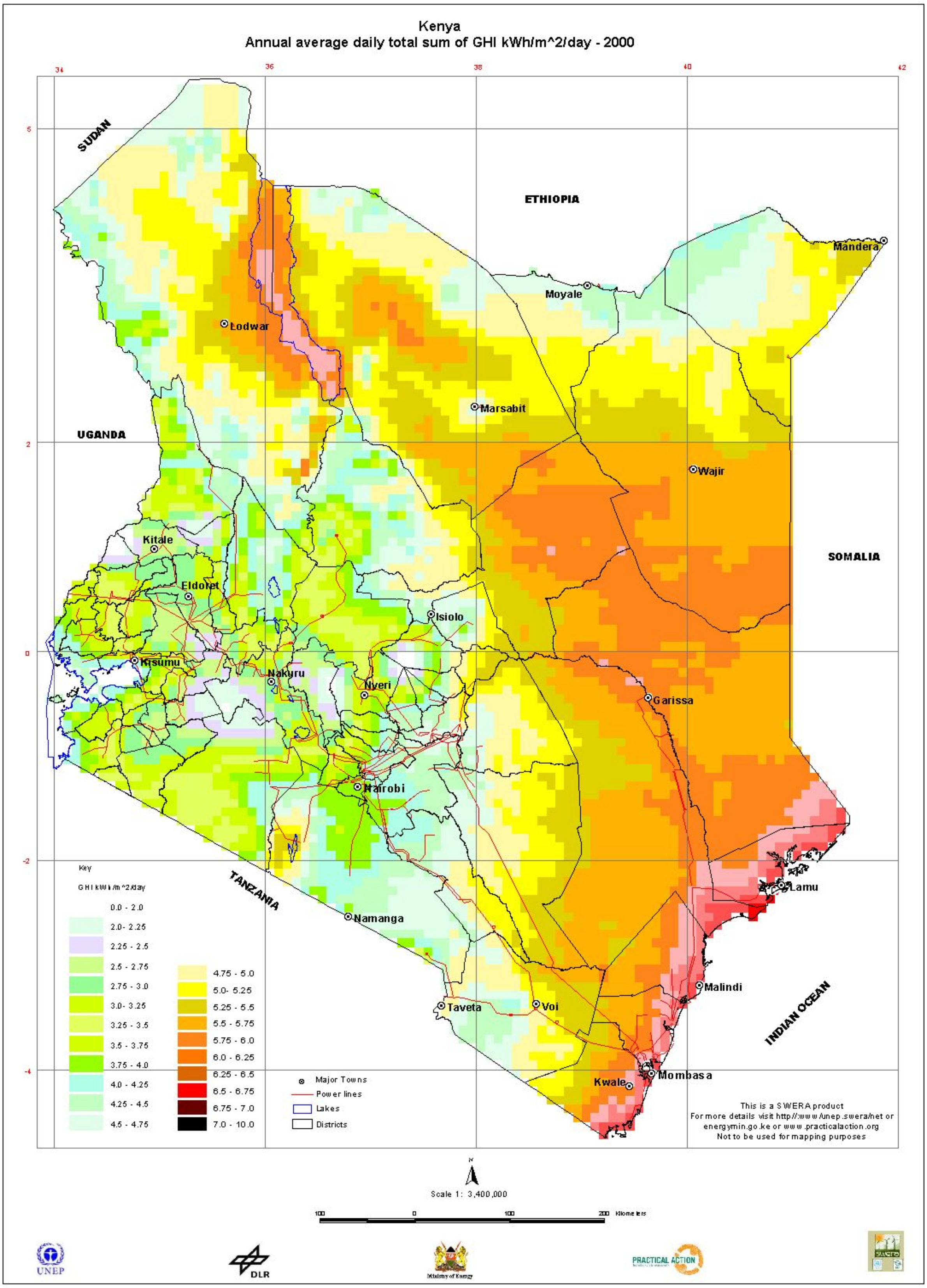


Figure 12: Annual average daily total sum of GHI in Yr 2000

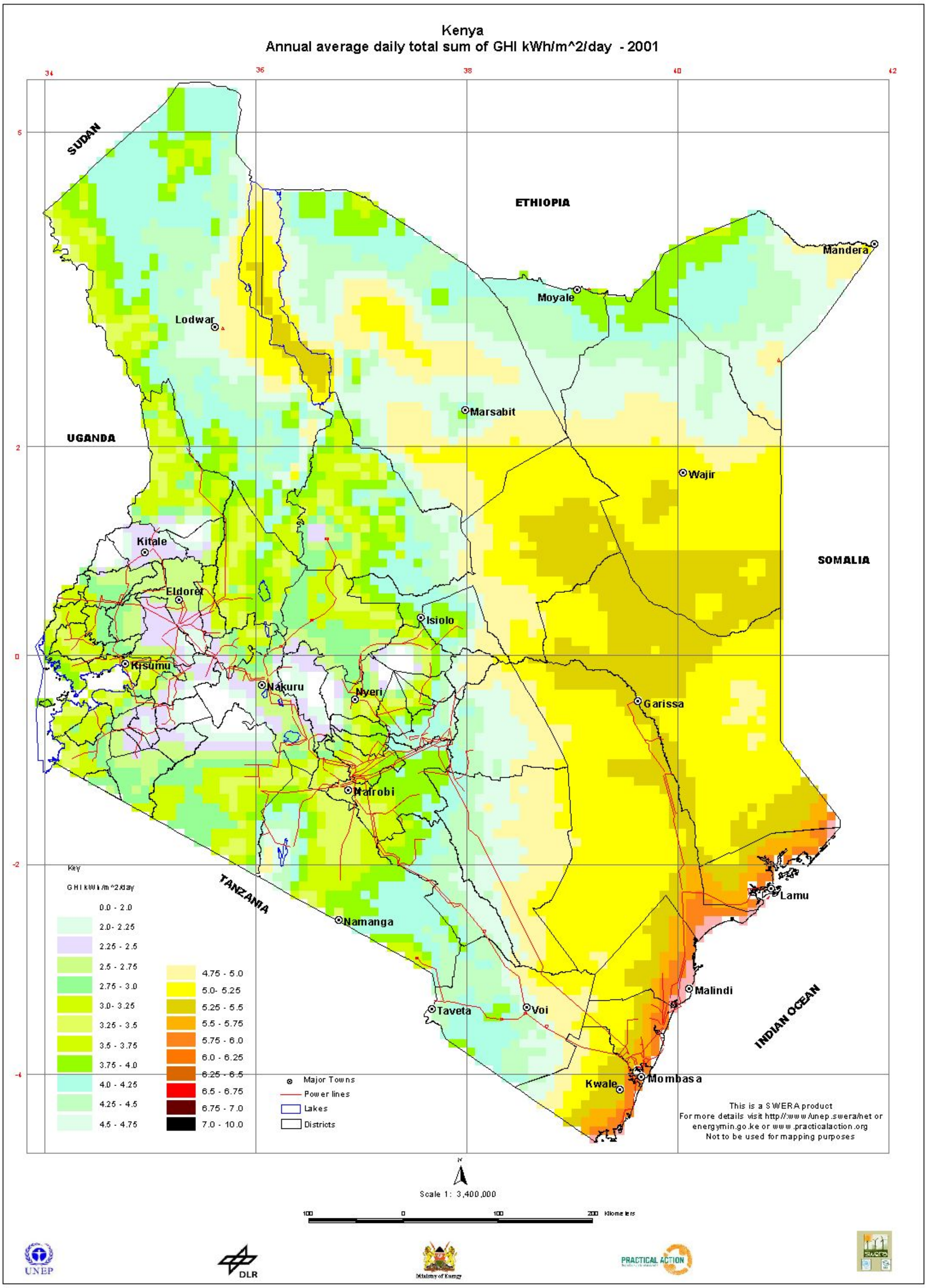


Figure 13: Annual average daily total sum GHI in 2001

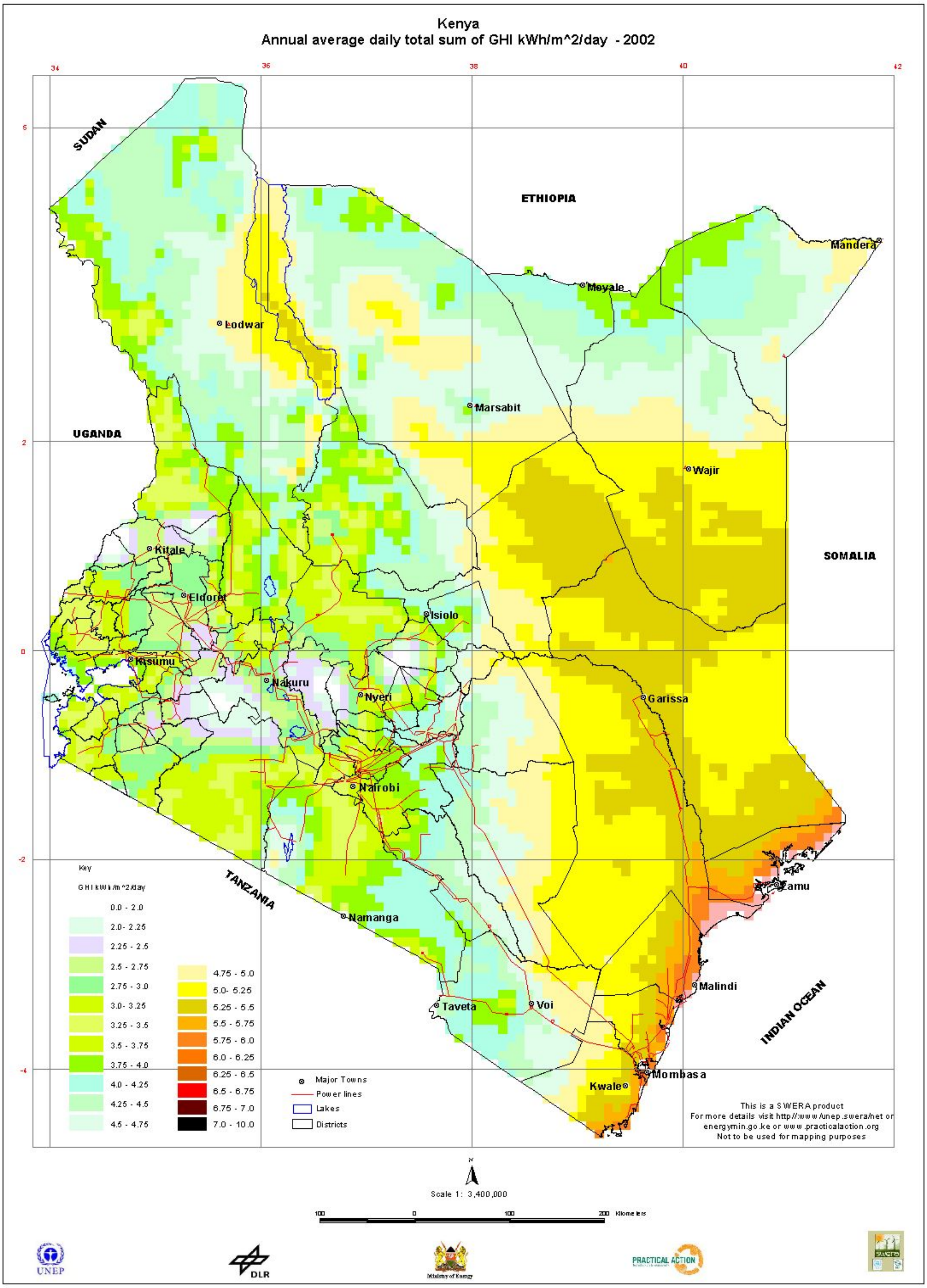


Figure 14: Annual average daily total sum of GHI 2002

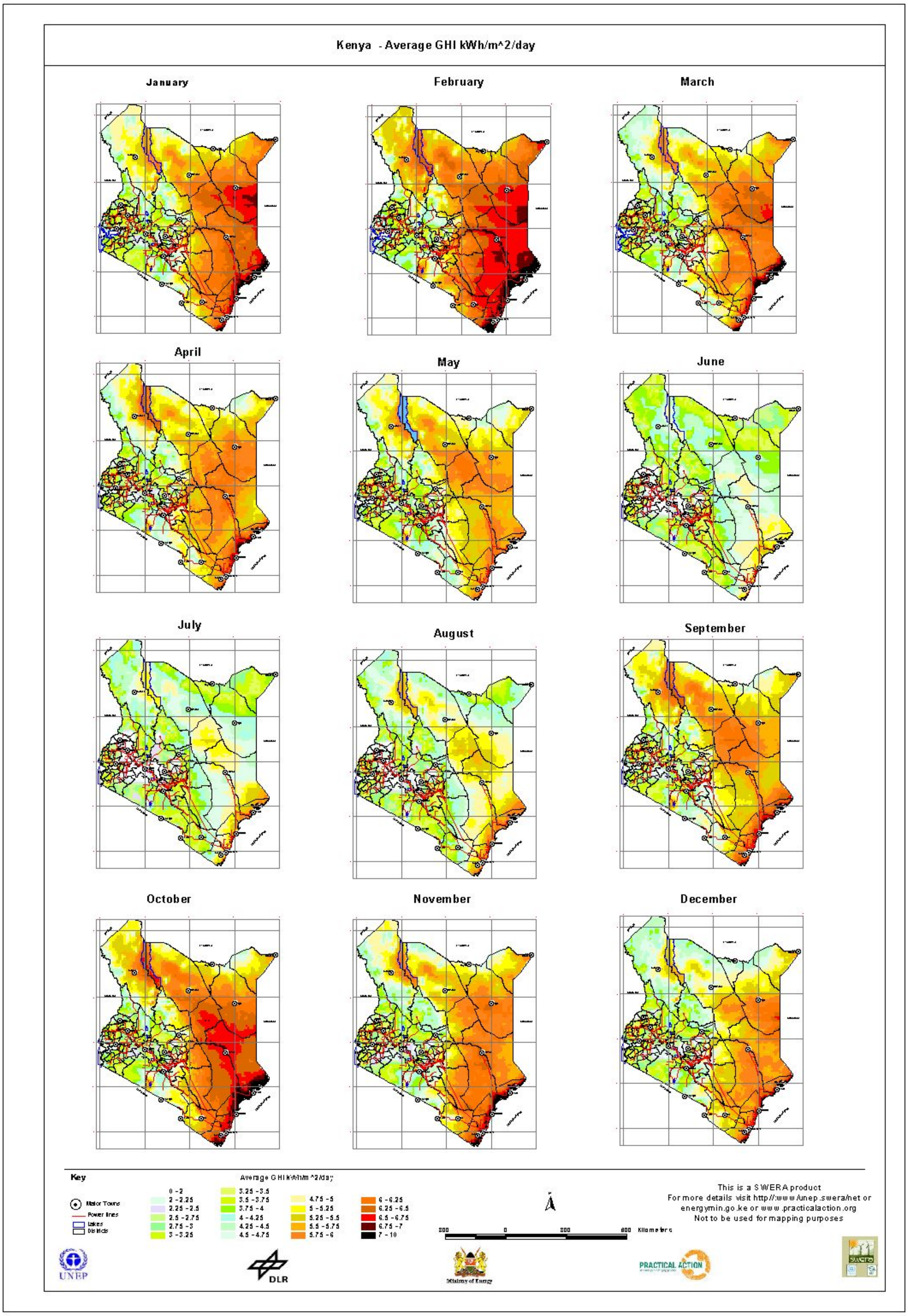


Figure 15: Average GHI annual variation

8.3 *Sources of Solar Data*

It is important to point out that this project is the first one to generate solar radiation for the whole country and generated time series for 34 ground sites which are currently the meteorological synoptic stations for the country. Some attempt to measure solar radiation and had been attempted earlier by GTZ but data available was for very short duration and truncated.

8.4 *Validation and Improved Resolution*

The only available data is from the GTZ supported measurements during the especial energy programme project in early 1990s. This data although sketchy provided a good validation measurements for the few stations made available.

8.5 *Analysis of solar energy availability*

The tables below show an analysis of the solar energy available

Direct Normal irradiance classes (kW/m2)	Area in m2	Area in km2
3.5 - 3.75	41,720,510,832	41,721
3.75 - 4	61,515,459,217	61,515
4 - 4.25	140,326,019,914	140,326
4.25 - 4.5	177,347,142,669	177,347
4.5 - 4.75	137,571,606,058	137,572
4.75 - 5	96,199,395,971	96,199
5 - 5.25	62,363,710,886	62,364
5.25 - 5.5	48,826,286,200	48,826
5.5 - 5.75	33,847,776,301	33,848
5.75 - 6	20,211,093,540	20,211
6 - 6.25	24,675,125,872	24,675
6.25 - 6.5	33,689,633,269	33,690
6.5 - 6.75	22,468,446,880	22,468
6.75 - 7	16,240,000,000	16,240
7 - 7.25	6,736,000,000	6,736
7.25 - 7.5	2,656,000,000	2,656

8.6 *Power Analysis*

Considering that direct normal irradiance of 6.0 kW/m2 will provide heat for institutions , households and industry. The total area capable of delivering 6.0 kW/m2 per day is about 106,000 square kilometers whose potential is 638,790 TWh.

The table below show the total available area for given diffuse light in kW per square kilometer.

Global Horizontal irradiance in kW/m^2	**Area in Meters**	**Area km^2**
3.25 - 3.5	53,244,189,628	53,244
3.5 - 3.75	79,417,367,195	79,417
3.75 - 4	72,484,828,594	72,485
4 - 4.25	65,089,287,998	65,089
4.25 - 4.5	93,006,696,264	93,007
4.5 - 4.75	87,634,065,762	87,634
4.75 - 5	75,624,402,327	75,624
5 - 5.25	81,086,060,136	81,086
5.25 - 5.5	65,284,559,921	65,285
5.5 - 5.75	121,378,257,487	121,378
5.75 - 6	75,615,113,910	75,615
6 - 6.25	8,403,914,456	8,404
6.25 - 6.5	8,272,000,000	8,272
6.5 - 6.75	48,504,590,756	48,505
6.75 - 7	26,378,087,768	26,378

9 Solar Thermal Power

9.1 *Solar Thermal applications*

Solar thermal energy is a technology for harnessing solar energy for heat using Solar thermal collectors often characterized low, medium, or high temperature collectors. Low temperature collectors are flat plates generally used to heat swimming pools. Medium-temperature collectors are also usually flat plates but are used for creating hot water for residential and commercial use while high temperature collectors concentrate sunlight using mirrors or lenses and are generally used for electric power production.

9.2 *Low- and Medium Temperature Collectors*

Assuming a cut off line for low temperature collectors of 5.0 kWh /m2 then the country have an area of 825,000 square kilometers of resource available. It is important to note that the cut off line is arbitrary and some technologies will deliver heating even in lower thermal resource space heating. Collectors can use air or water as the medium to transfer the heat to its destination. The medium temperature collectors could be used to produce approximately 50% of the hot water needed for residential and commercial and a typical system costs $5000-$6000. Medium-temperature installations can use any of several designs: common designs are pressurized glycol, drain back, and batch systems.

9.3 *High Temperature collectors*

Where temperatures below about 95°C are sufficient, as for space heating, flat-plate collectors of the non concentrating type are generally used. The fluid-filled pipes can reach temperatures of 150 to 220 degrees Celsius when the fluid is not circulating. This temperature is too low for efficient conversion to electricity, since the efficiency of any heat engine increases as the temperature of its heat source increases. In concentrated solar power plants, the solar radiation is concentrated by mirrors or lenses to obtain the higher temperature.
Since the CSP plant generates first heat, it is possible to store the heat before conversion to electricity. With current technology, storage of heat is much cheaper and efficient than storage of electricity. In this way, the CSP plant can produce electricity day and night. If the CSP site has predictable solar radiation, then the CSP plant becomes a reliable power plant. Reliability can further be improved by installing a back-up system that uses fossil energy. The back-up system can reuse most of the CSP plant, which decreases the cost of the back-up system.
It is estimated that an area of 100,000.sq km is available for high heat collectors out of which about 20,000 are capable of powering a commercial CSP power plants. Zoning this with the availability of geothermal the area available for Geothermal CSP based system is estimated at over 6000.square kilometres

10 WIND RESOURCE

10.1 *Introduction*

Wind energy has been used in Kenya for many years primarily for lifting water in remote ranches and mission outposts. It was one of the earliest forms of energy to be introduced into the country at the turn of the 20th century. In early 1990s a grant by the Belgium government introduced three 200 kW wind electric turbines into the country to run a grid fed two turbine system rated at 350kW while the third 200 kW turbine was hybridized with a diesel power plant to feed the remote town of Marsabit in the north of the country. In typical years the two turbine system on Ng'ong hills near Nairobi feed some 1.6 GWh into the grid annually reflecting a very high availability. Due to operational issues only one of the turbines is still in use. However the operational data and information available form the turbines give a lot of hope to future investments in wind. Some of the benefits of detailed wind mapping includes zonation of promising areas for wind energy development, facilitate investments in a larger scale of wind energy projects and support informed decision making for public and private sectors in deployment o wind resources.

10.2 *Wind Resource Measurements*

The national meteorological services undertake wind measurements in its 34 or so stations spread out in the country. These measurements are carried out at 10 meters mainly for agro metrology and civil aviation. The data available for wind climate modeling was taken over long periods but due to suspect quality due to missing gaps only five years data and for around ten stations were used. However this was considered sufficient for the purposes of wind energy modeling.

The project involved data cleaning and analysis, modeling for sheltering obstacles, surface roughness and topography producing generalized wind climatology. The wind climate of a given location is then modeled for energy production as derived power density by computing for topography, surface roughness and obstacles preferably at the height of 50 meters, considered as the average height of most commercial wind turbine hubs.

The maps provided below show the wind speed and wind power density reflecting the available energy resources by location. The wind speed map has been modified to increase the number of classes to clearly identify the areas of different range of potential. In some of the areas it is expected due to directional impacts evident in the mountains of the north and north facing parts of mount Kenya and aberdares could have significant seasonal variation.

For estimation of the power density, the number of six classes have been maintained in accordance to SWERA project largely for purposes of comparison between the various countries participating in the assessment project as follows.

Table 1 Wind classification in Kenya:

Kenya Wind Classes				
Class Nr.	**Classification**	**Speed in m/s**	**Wind Power Density in W/m^2**	**Colour code**
1	Poor	0 - 4.5	0 - 90	
2	Marginal	4.5 - 5.5	90 - 165	
3	Moderate	5.5 - 6.5	165 - 275	
4	Good	6.5 - 7.5	275 - 425	
5	Very Good	7.5 - 8.5	425 - 615	
6	Excellent	> 8.5	>615	

10.3 *Wind resources in Kenya*

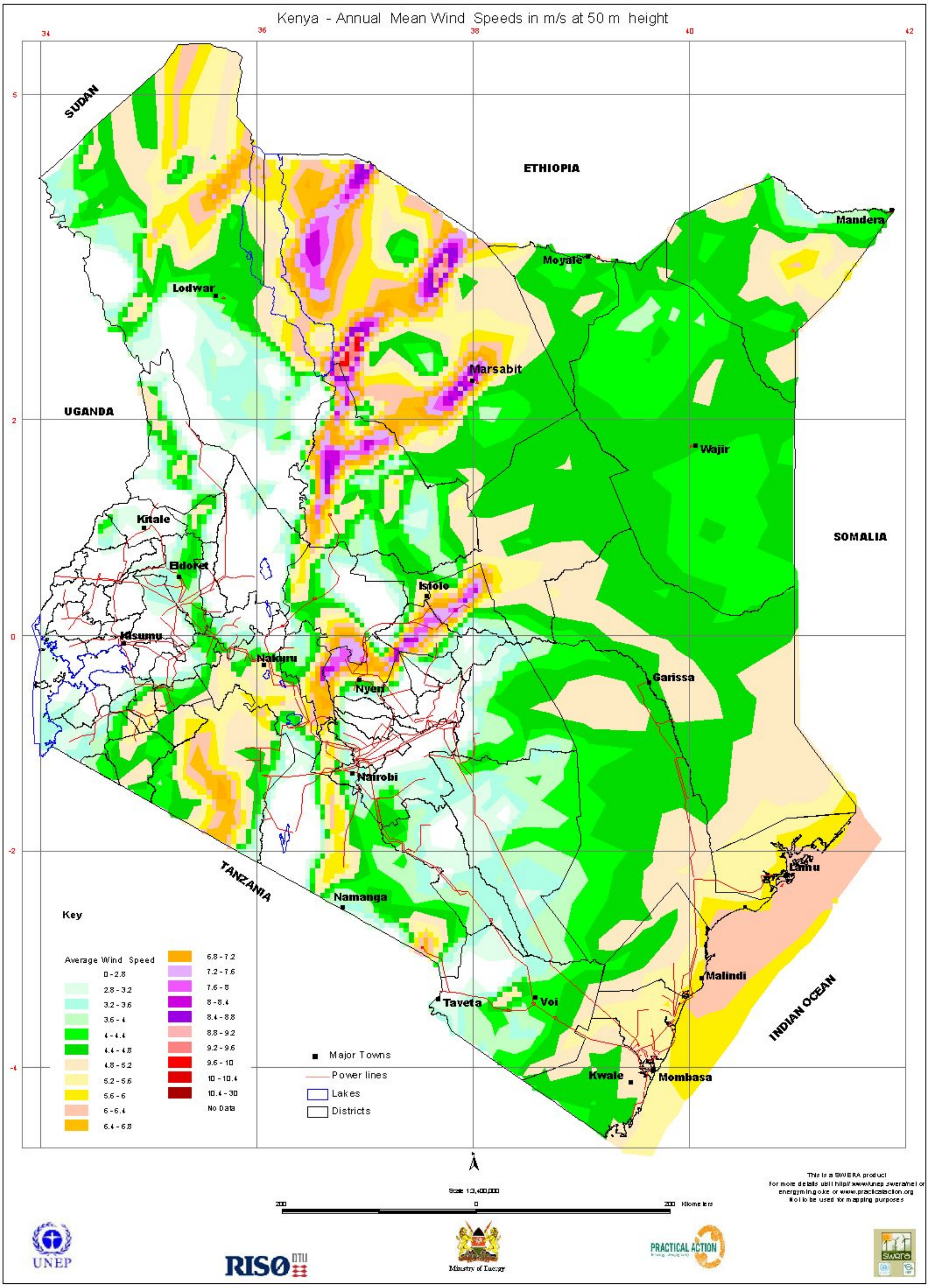


Figure 16: Map showing annual mean wind speeds at 50 m height above ground

10.4 *Wind power density*

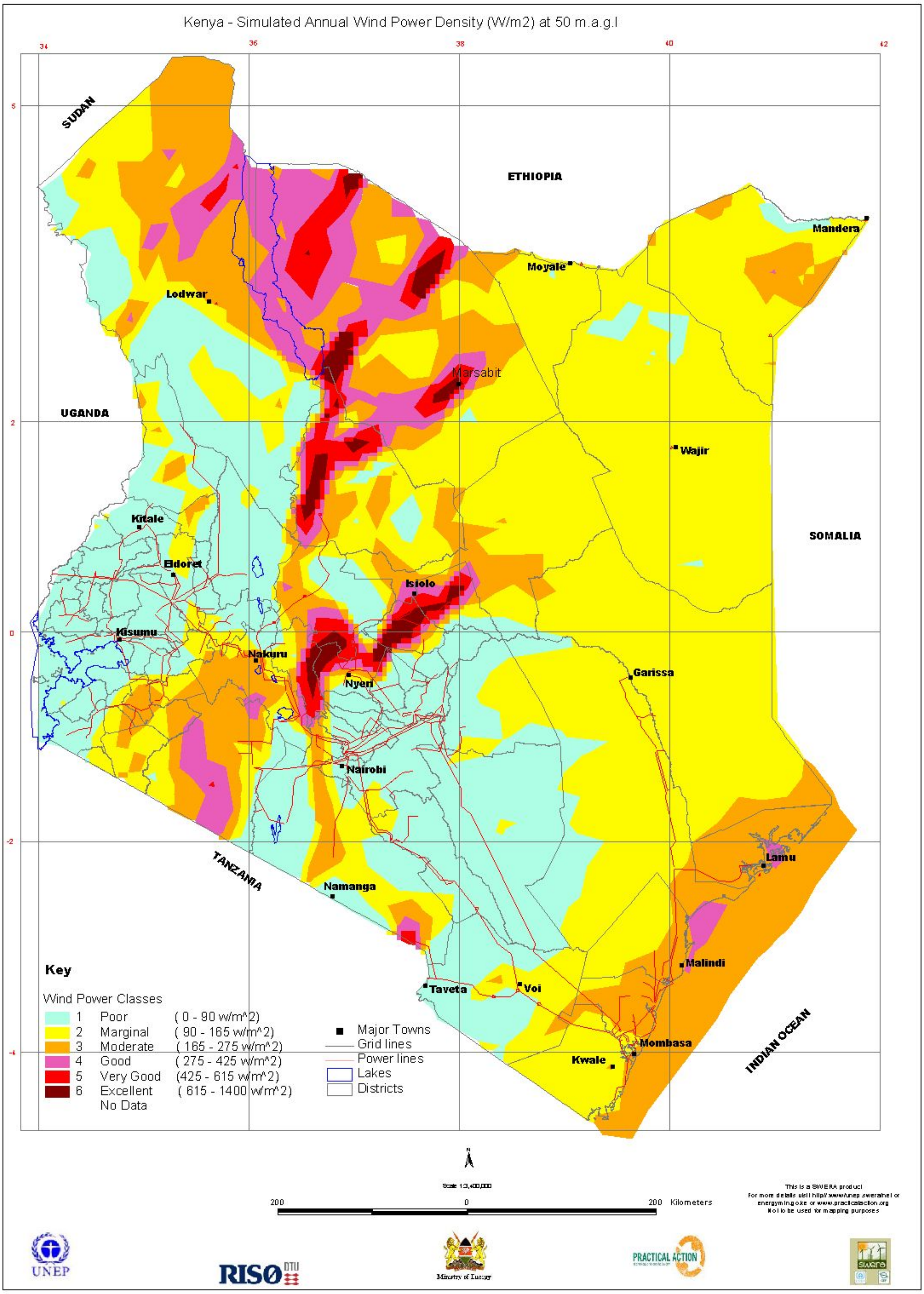


Figure 17: Map showing simulated annual wind power density at 50 m above ground

10.5 *Analysis of the wind data*

The wind speeds are used to generate the wind power densities. However it is important to note that a wind investments is much more than the two parameters used. The availability of other infrastructure is necessary to determine the size of the system. Proximity to a grid capable of conveying the power produced and supply of reactive power is necessary for megascale wind farm. It is evident that the northern parts of the country rising over 1000 meters hold the largest promise of delivering large scale power schemes once the conveyance systems are put in place.

Using the GIS , the wind power densities was overlapped with other thematic layers that can be interactively be analyzed for decision making. Among the layers are the power transmission lines, protected areas, towns, water bodies and district administrative boundaries. The tables below show some of the results from the analysis in terms of availability.

Wind Power Densities in Watt/m^2	Corresponding Area in Square Kilometers	Area in Hectares
100	194,631	19,463,047
200	278,591	27,859,079
300	79,834	7,983,401
400	23,664	2,366,404
500	10,199	1,019,861
600	6,439	643,899
700	4,326	432,618
800	1,631	163,130
900	1,065	106,490
1000	460	46,022
1100	128	12,790
1200	25	2,556
1400	51	5,114

Wind Speed Classes	Area in km^2	Area in Ha
2.8	65,034	6,503,437
3.2	29,412	2,941,218
3.6	33,567	3,356,689
4.0	37,870	3,787,013
4.4	76,079	7,607,948
4.8	141,159	14,115,874
5.2	83,269	8,326,872
5.6	44,813	4,481,298
6.0	29,990	2,998,977
6.4	27,137	2,713,740
6.8	11,113	1,111,305
7.2	6,955	695,541
7.6	6,050	604,985
8.0	4,026	402,580
8.4	2,417	241,675
8.8	1,149	114,930
9.2	460	45,972
9.6	409	40,883
10.0	153	15,337
10.4	26	2,556

The analysis indicates that on average the country has ample wind resources with wind speeds above 2.8 meters per second considered as the lowest for some water lifting applications.
For large size turbines the starting speed for most f the turbines is 3.5 m/s and from the analysis ands areas slightly in excess of half a million square kilometers are available. Considering firm energy availability then a speed of above 6 m/s is considered and this gives an area of close to 90,000 square kilometers of very excellent wind speeds.

10.6 *Best Wind Areas excluding Protected Areas*

The Best wind areas in Kenya irrespective of economic viability is Marsabit district, Samburu, parts of Laikipia, Meru north, Nyeri and Nyandarwa and Ng'ong hills. Other areas of interest are Lamu, off shore Malindi, Loitokitok at the foot of Kilimanjaro and Narok plateau are some of the hot spots.

Using households as proxies for potential beneficiaries, it is estimated that3.75 million households are in areas with less than 4 meters per second considered as low energy areas. Some 2.3 million households are in areas with between 4 and 6.98 meters per second considered good wind potential. Only 132,000 households are in areas considered very good to excellent of wind investment. This last class should also be seen as an opportunity for development of large wind farms as there would be minimal human interference.

11 Pre investment analysis of three hotspots for Wind

11.1 *Ras Ngomeni near Malindi*

Ras Ngomeni is a peninsula north of Malindi which is a raised coral reef hence very good for wind turbine foundation establishment. The area has a very clear sea frontage devoid of trees. It so noteworthy that the sand dunes forming the peninsula despite being formed by wind for many years is outside the strong wind spot which is somewhere in the sea and to the north east of the area.

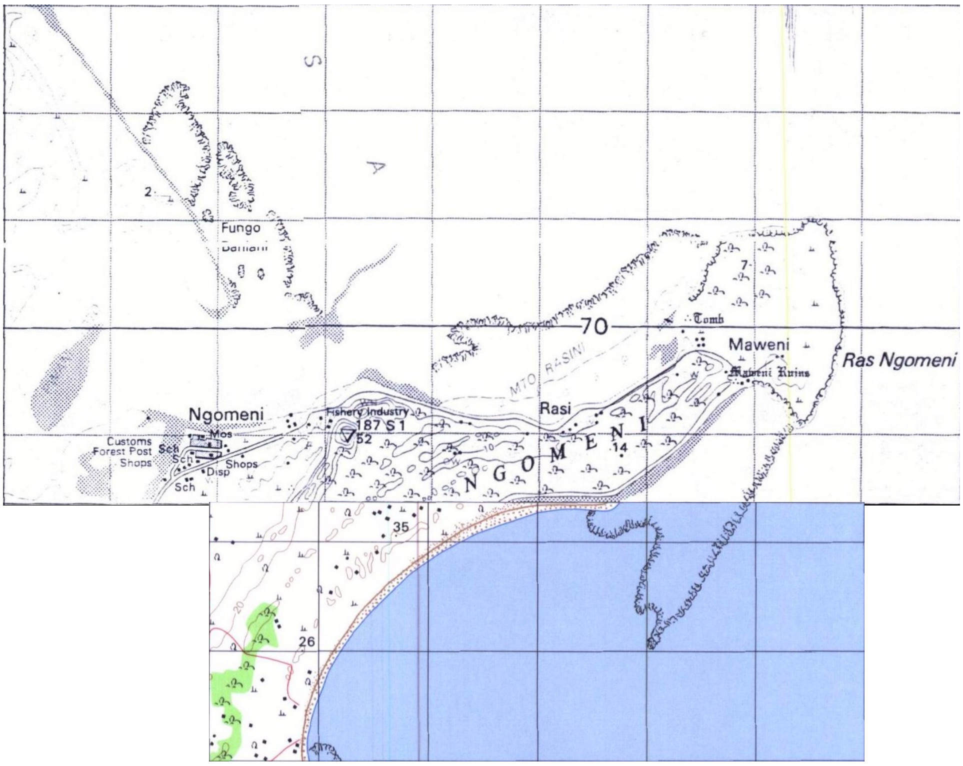


Figure 18: Map of Ras Ngomeni

11.2 *Topography of Ras Ngomeni*

The Area is characterized by sand dunes that rise upto 20 meters mainly deposited on coral reef. The peninsula is however a low land like most of the northern coast with few high grounds like the Ngomeni hill site of the survey of Kenya trigonometric point and a few hills to the west of the road from Malindi to Lamu on the west of road junction to Ras Ngomeni.

11.3 *WAsP anaysis for Malindi Met. Station*

The Malindi Met. station is located at co-ordinates (622217,9642918) UTM in a map that was called 'Ngomeni1' as given in Figure 1a below. The associated observed wind climate data were collected at -3.23°N 40.10°E. The site elevation is 20.0 m a.s.l.

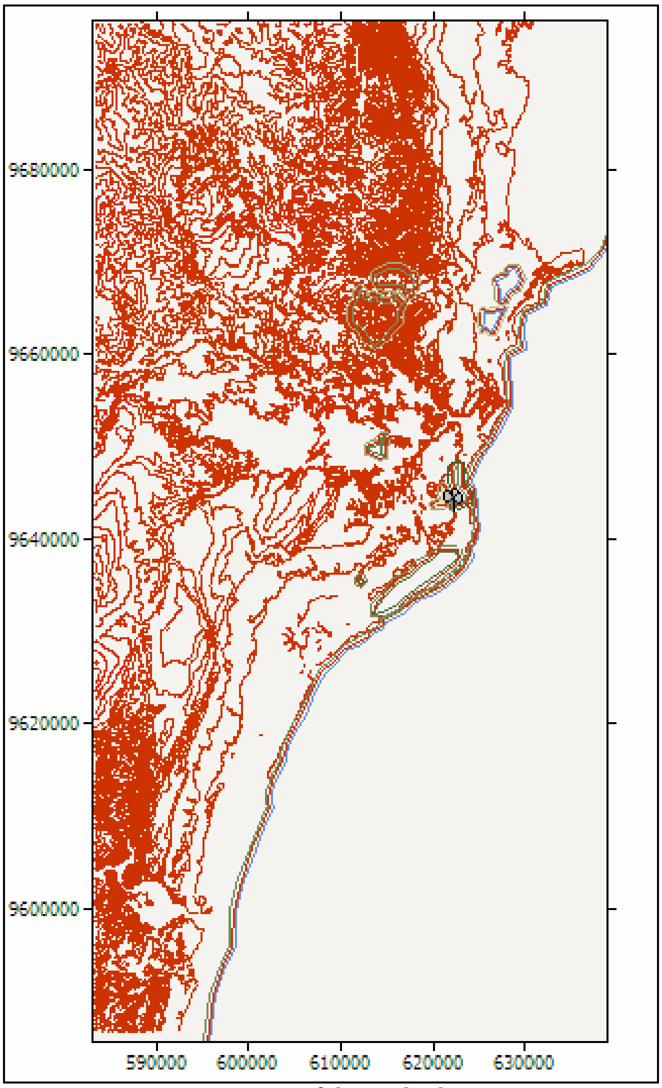


Figure 19: Position of the Malindi Met Station

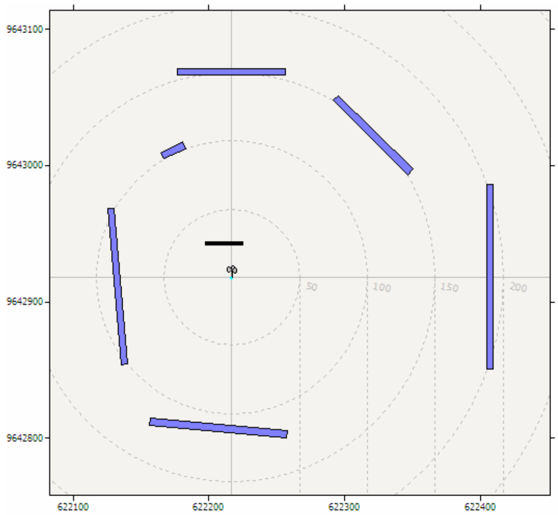


Figure 20: Map showing obstacle Map for Malindi Met Station

Obstacle	A1 [°]	R1 [m]	A2 [°]	R2 [m]	Depth [m]	Height [m]	Porosity
1	330	100	340	100	10	5	0.5
2	320	30	20	25	5	3	0
3	30	150	60	150	10	5	0.5
4	70	200	110	200	10	5	0.5
5	345	153	15	153	10	5	0.5
6	160	120	210	120	10	5	0.5
7	230	100	300	100	15	5	0.5

The observed wind climate for the Malindi site generated using WAsP analyses are shown in the tables and figures below. Figure 2 presents the observed wind rose frequency diagram and the Weibull fit.

Computed Parameter	Weibull fit	Combined	Discrepancy
Mean wind speed	4.81 m/s	4.67 m/s	-2.73%
Mean power density	102 W/m²	102 W/m²	-0.01%

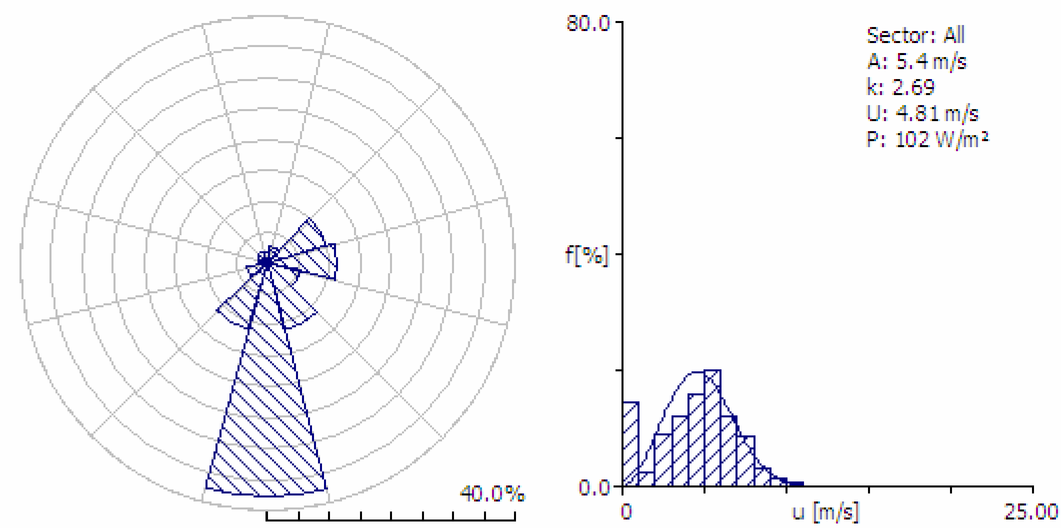


Figure 21: observed wind rose frequency diagram and the Weibull fit for Malindi_Met' Station- Position: -3.23°N 40.10°E; Anemometer height: 10.00 m a.g.l. The WAsP prediction for the met. Station is given in the table below.

-	Observed	Predicted	Discrepancy
Mean wind speed	4.81 m/s	4.68 m/s	-2.64%
Mean power density	102 W/m²	102 W/m²	0.40%

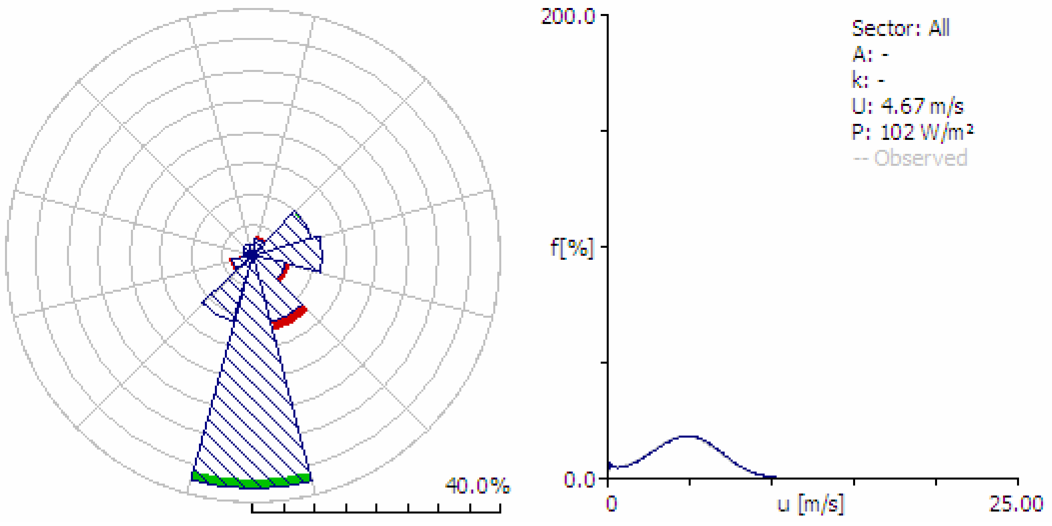


Figure 22: The WAsP predicted wind rose frequency diagram and the Weibull fit for Malindi_Met' Station- Position: -3.23°N 40.10°E; Anemometer height: 10.00 m a.g.l.

The wind atlas was computed using 4 reference roughness lengths, i.e. 0.000 m, 0.030 m, 0.100 m, 0.400 m and 5 reference heights (10 m, 25 m, 50 m, 100 m, 200 m) above ground level. The roses of Weibull parameters had 12 sectors each. These parameters represent the regional wind climate and were as summarized in table 1 below.

Table : Regional wind climate summary

Height	Parameter	0.00 m	0.03 m	0.10 m	0.40 m
10.0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	9.65 2.43 8.55 618	6.63 2.17 5.87 219	5.72 2.17 5.07 141	4.44 2.14 3.93 66
25.0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	10.53 2.47 9.34 796	7.86 2.28 6.96 350	7.01 2.26 6.21 250	5.81 2.22 5.14 144
50.0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	11.27 2.52 10.00 960	8.98 2.44 7.96 497	8.14 2.41 7.22 373	6.95 2.34 6.16 238
100.0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	12.14 2.49 10.77 1208	10.44 2.60 9.27 749	9.53 2.60 8.47 571	8.28 2.54 7.35 379
200.0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	13.26 2.44 11.76 1599	12.60 2.58 11.19 1326	11.48 2.58 10.20 1003	9.95 2.54 8.83 657

11.4 *Wind Resource Grid for Malindi*

The structure and the computational Grid Setup is shown in the table

Structure:	8 columns and 12 rows at 6630 resolution gives 96 calculation sites.
Boundary:	(585849, 9618131) to (638889, 9697691)
Nodes:	(589164, 9621446) to (635574, 9694376)

The WAsP modeled mean wind speeds at 50m above the ground is shown in figure 4 while figure 5 gives the resulting wind power density for the same region.

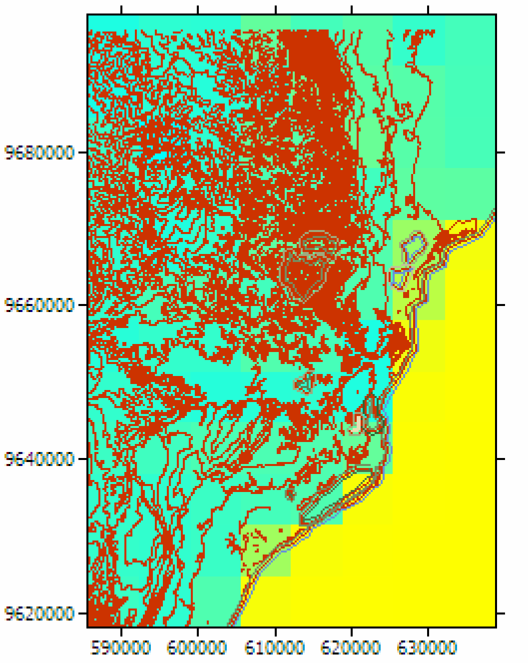


Figure 23: Modeled wind speeds at 50m a.g.l.

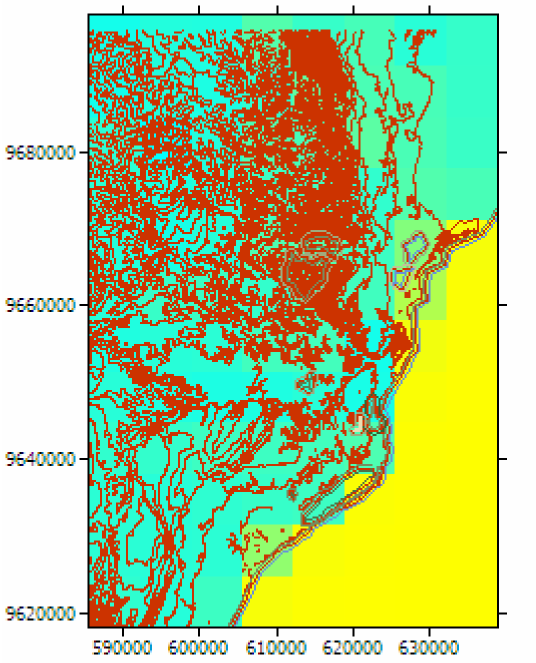


Figure 24: Modeled wind power density [W/m²] at 50m a.g.l.

Maximum Value:	9.80 m/s at (638889, 9624761)
Minimum Value:	6.46 m/s at (638889, 9624761)
Mean Value:	7.83 m/s at (638889, 9624761)

Mean Speed [m/s]

Maximum Value:	907 W/m² at (632259, 9624761)
Minimum Value:	261 W/m² at (632259, 9624761)
Mean Value:	501 W/m² at (632259, 9624761)

Mean Power Density [W/m²]

11.5 *Wind farm Analysis for Ras Ngomeni in Malindi*

The wind farm map is shown in figure 25 below. The figure shows the position of the twelve turbines both at Ras Ngomeni in the coastal peninsula and at the higher inland grounds.

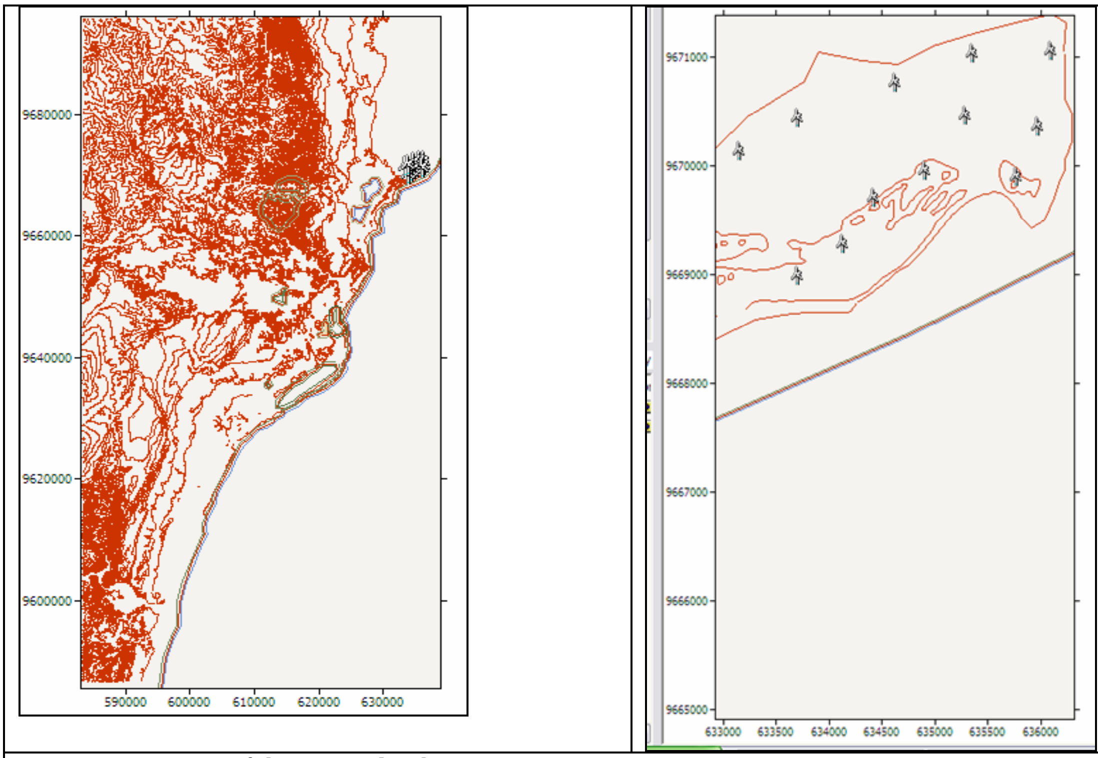


Figure 25: Position of the 12 wind turbine generators

The tables below gives Summary results of the wind farm analysis for Ras Ngomeni as well as the position of the various turbines. The net Annual Energy production from the 12 turbines is 13.830 GWh.

Parameter	Total	Average	Minimum	Maximum
Net AEP [GWh]	46.017	3.835	3.489	4.386
Gross AEP [GWh]	46.606	3.884	3.533	4.394
Wake loss [%]	1.26	-	-	-

The specific locations of each turbine, their elevation, net annual energy output and wake losses are shown in table below.

Turbine location, elevation, net annual energy output and wake losses.

Site	Location [m]	Turbine	Elevation [m a.s.l.]	Height [m a.g.l.]	Net AEP [GWh]	Wake loss [%]
Turbine site 1	(635338.8,9670967.0)	Vestas V52 (850 kW)	1	55	3.546	3.12
Turbine site 2	(636076.6,9670994.0)	Vestas V52 (850 kW)	0	55	3.770	1.3
Turbine site 3	(635955.1,9670292.0)	Vestas V52 (850 kW)	3	55	3.981	0.73
Turbine site 4	(634891.0,9669889.0)	Vestas V52 (850 kW)	14	55	3.995	0.82
Turbine site 5	(635266.8,9670400.0)	Vestas V52 (850 kW)	4	55	3.791	1.61
Turbine site 6	(635759.4,9669833.0)	Vestas V52 (850 kW)	20	55	4.386	0.18
Turbine site 7	(634605.4,9670697.0)	Vestas V52 (850 kW)	2	55	3.538	2.05
Turbine site 8	(634410.1,9669640.0)	Vestas V52 (850 kW)	20	55	4.031	1.56
Turbine site 9	(634111.6,9669209.0)	Vestas V52 (850 kW)	11	55	3.991	0.62
Turbine site 10	(633688.6,9668919.0)	Vestas V52 (850 kW)	10	55	3.992	0.82
Turbine site 11	(633133.0,9670073.0)	Vestas V52 (850 kW)	2	55	3.489	1.23
Turbine site 12	(633680.9,9670373.0)	Vestas V52 (850 kW)	2	55	3.507	1.51

The specific Site wind climates for each Turbine location, elevation, Weibull parameters, energy density and Rix factor are shown in table 3 below.
Site wind climates for each Turbine location, elevation, Weibull parameters, energy density and Rix factor

Site	Location [m]	Height [m a.g.l.]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]
Turbine site 1	(635338.8,9670967.0)	55	9.9	2.47	8.80	665	0.0
Turbine site 2	(636076.6,9670994.0)	55	10.2	2.47	9.05	722	0.0
Turbine site 3	(635955.1,9670292.0)	55	10.6	2.45	9.36	803	0.0
Turbine site 4	(634891.0,9669889.0)	55	10.6	2.45	9.41	819	0.0
Turbine site 5	(635266.8,9670400.0)	55	10.3	2.45	9.12	743	0.0
Turbine site 6	(635759.4,9669833.0)	55	11.4	2.43	10.09	1014	0.0
Turbine site 7	(634605.4,9670697.0)	55	9.8	2.47	8.73	650	0.0
Turbine site 8	(634410.1,9669640.0)	55	10.8	2.41	9.57	870	0.2
Turbine site 9	(634111.6,9669209.0)	55	10.6	2.43	9.41	823	0.1
Turbine site 10	(633688.6,9668919.0)	55	10.7	2.40	9.45	840	0.1
Turbine site 11	(633133.0,9670073.0)	55	9.7	2.44	8.63	631	0.0
Turbine site 12	(633680.9,9670373.0)	55	9.8	2.45	8.67	638	0.0

Turbine location, Gross AEP, Net AEP, and Efficiency factor for all sectors of the wind direction

Turbine	Location [m]	Gross AEP [MWh]	Net AEP [MWh]	Efficiency [%]
Turbine site 1	(635338.8,9670967.0)	3659.914	3545.686	96.88
Turbine site 2	(636076.6,9670994.0)	3819.735	3770.102	98.7
Turbine site 3	(635955.1,9670292.0)	4010.012	3980.585	99.27
Turbine site 4	(634891.0,9669889.0)	4027.762	3994.869	99.18
Turbine site 5	(635266.8,9670400.0)	3853.302	3791.446	98.39
Turbine site 6	(635759.4,9669833.0)	4393.706	4385.867	99.82
Turbine site 7	(634605.4,9670697.0)	3611.618	3537.747	97.95
Turbine site 8	(634410.1,9669640.0)	4095.144	4031.288	98.44
Turbine site 9	(634111.6,9669209.0)	4015.930	3991.022	99.38
Turbine site 10	(633688.6,9668919.0)	4025.520	3992.337	99.18
Turbine site 11	(633133.0,9670073.0)	3532.695	3489.415	98.77
Turbine site 12	(633680.9,9670373.0)	3560.290	3506.534	98.49
Wind farm	-	46605.623	46016.905	98.74

12 WAsP Analysis for JKIA Met. Station

The Nairobi_JKIA Met. station is located at co-ordinates (268558,9854003) UTM in the map shown in figure 27 below. The associated observed wind climate data were collected at -1.32°N 36.92°E. The site elevation is 1,620.0 m a.s.l. The roughness conditions of the site is also shown in the map.

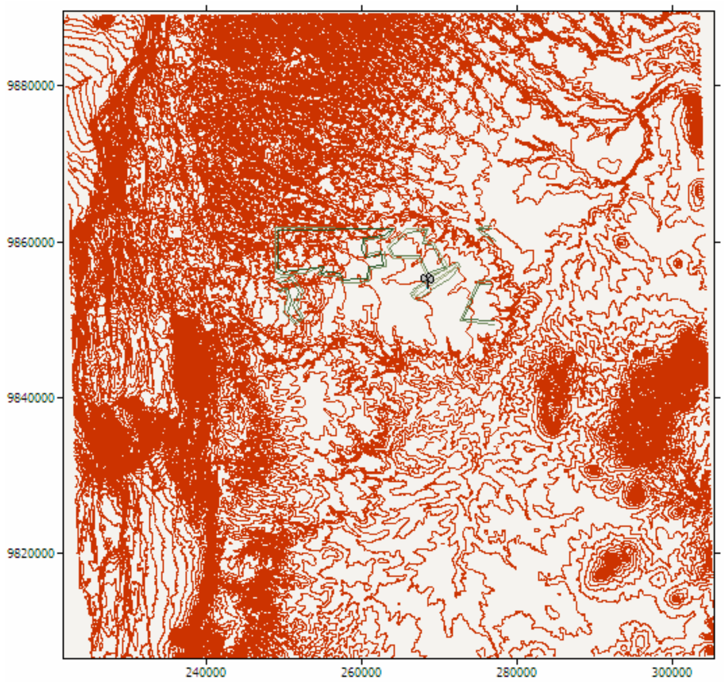


Figure 27: Position of the JKIA Met. Station at the Airport site in Nairobi.

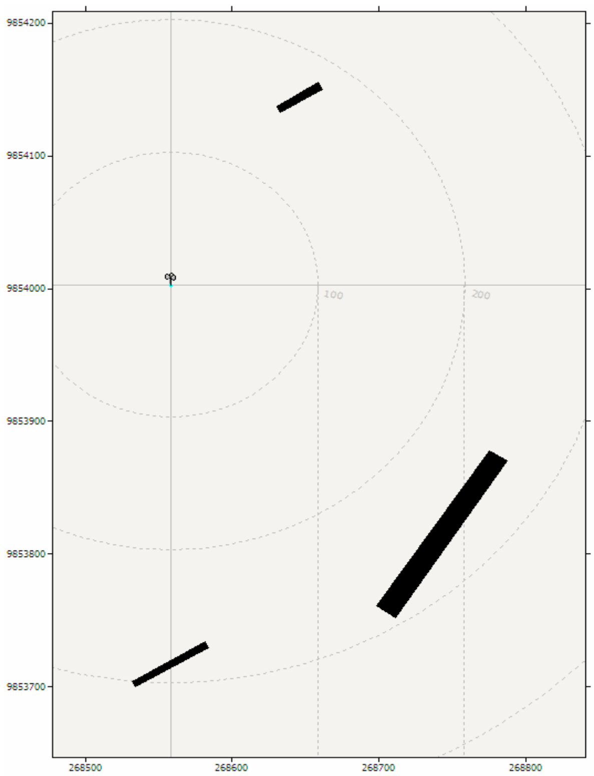


Figure 28. The obstacle Map for JKIA Met Station

Obstacle	A1 [°]	R1 [m]	A2 [°]	R2 [m]	Depth [m]	Height [m]	Porosity
1	28	152	30	150	10	33	0
2	120	250	150	280	20	15	0
3	175	274	175	270	10	58	0

The observed wind climate for the JKIA site generated using WAsP analyses are shown in the tables and figures below. Figure 8 presents the observed wind rose frequency diagram and the Weibull fit.

-	Weibull fit	Combined	Discrepancy
Mean wind speed	3.48 m/s	3.46 m/s	-0.68%
Mean power density	52 W/m²	52 W/m²	0.08%

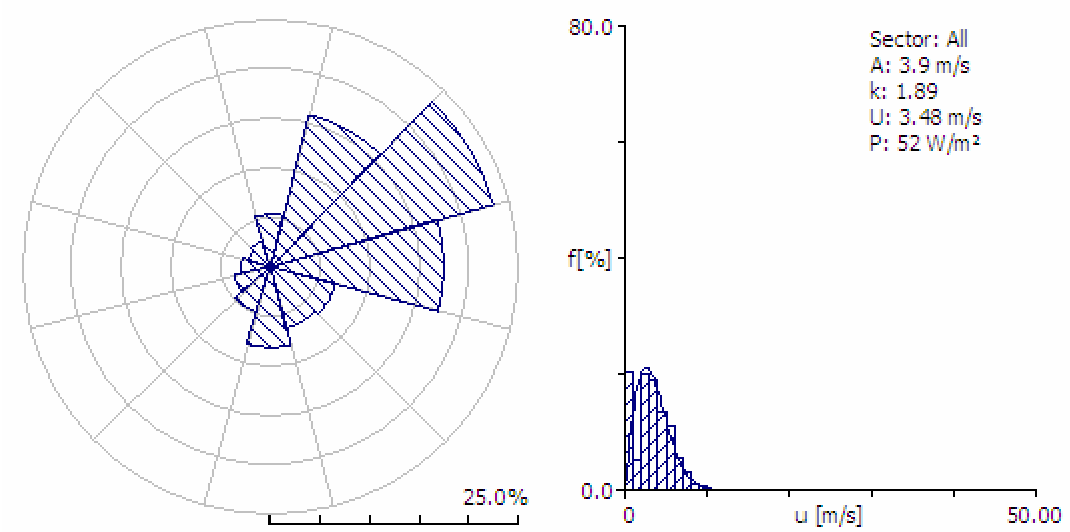


Figure 29: observed wind rose frequency diagram and the Weibull fit for JKIA_Met' Station-Position: -1.32°N 36.92°E; Anemometer height: 10.00 m a.g.l. The WAsP prediction for the met. Station is given in the table below.

-	Observed	Predicted	Discrepancy
Mean wind speed	3.48 m/s	3.45 m/s	-0.73%
Mean power density	52 W/m²	53 W/m²	1.15%

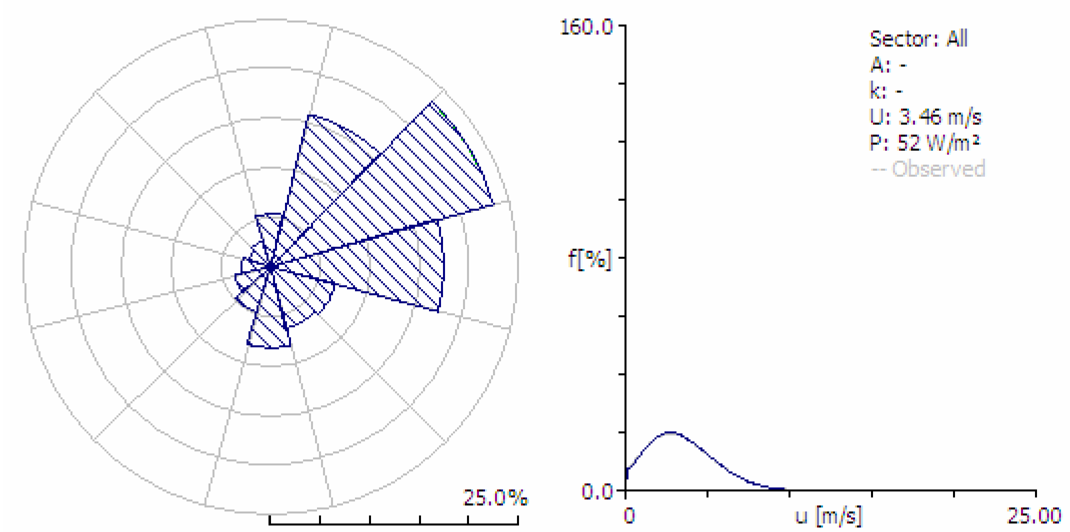


Figure 30: The WAsP predicted wind rose frequency diagram and the Weibull fit for JKIA_Met' Station- Position: -1.32°N 36.92°E; Anemometer height: 10.00 m a.g.l.

The wind atlas was computed using 4 reference roughness lengths, i.e. 0.000 m, 0.030 m, 0.100 m, 0.400 m and 5 reference heights (10 m, 25 m, 50 m, 100 m, 200 m) above ground level. The roses of Weibull parameters had 12 sectors each. These parameters represent the regional wind climate and were as summarized in table 5 below.

Regional wind climate summary

Height	Parameter	0.00 m	0.03 m	0.10 m	0.40 m
10.0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	6.61 2.11 5.85 223	4.48 1.85 3.98 80	3.87 1.86 3.44 51	3.02 1.85 2.68 24
25.0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	7.24 2.15 6.41 287	5.37 1.96 4.76 129	4.79 1.95 4.24 92	3.98 1.92 3.53 53
50.0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	7.77 2.19 6.88 350	6.22 2.12 5.51 185	5.62 2.09 4.98 138	4.80 2.04 4.26 89
100.0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	8.43 2.14 7.46 455	7.39 2.21 6.54 299	6.70 2.22 5.94 222	5.80 2.22 5.14 144
200.0 m	Weibull A [m/s] Weibull k Mean speed U [m/s] Power density E [W/m²]	9.31 2.07 8.25 635	9.19 2.14 8.14 590	8.27 2.16 7.32 427	7.09 2.17 6.28 268

12.1 *Wind Resource Grid for JKIA*

The structure and the computational Grid Setup is shown in the table

Structure: 17 columns and 17 rows at 5010 resolution gives 289 calculation sites.
Boundary: (220434, 9804787) to (305604, 9889957)
Nodes: (222939, 9807292) to (303099, 9887452)

The WAsP modeled mean wind speeds at 50m above the ground is shown in figure 31 while figure 11 gives the resulting wind power density for the same region.

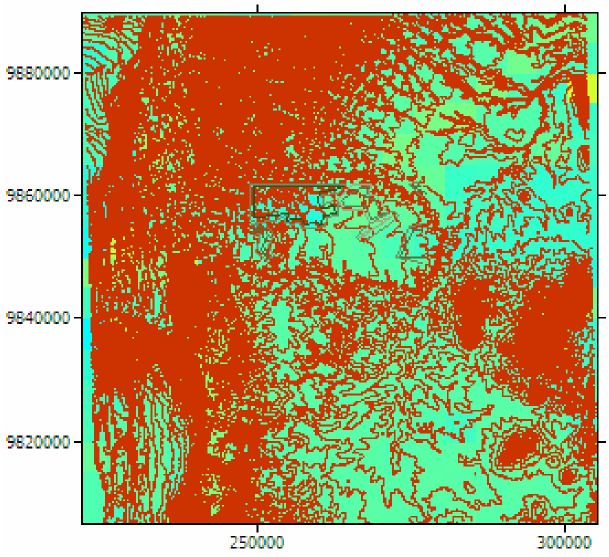


Figure 31: Modeled wind speeds at 50m a.g.l.

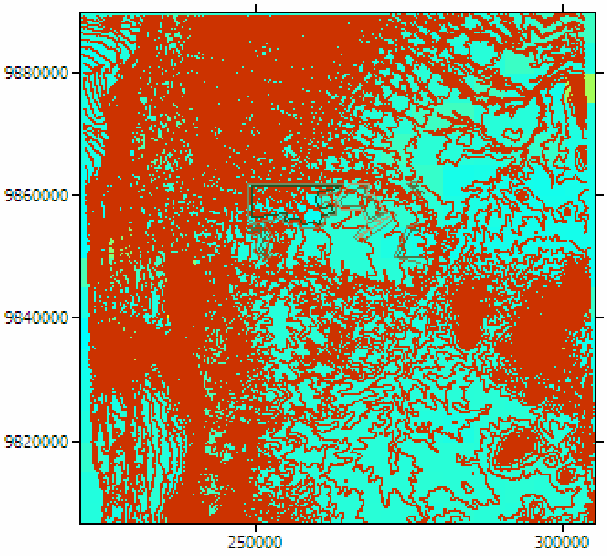


Figure 32: Modeled wind power density [W/m²] at 50m a.g.l.

The tables below show the attributes of the wind speed and power density for the area

Maximum Value:	8.26 m/s at (240474, 9844867)
Minimum Value:	3.96 m/s at (240474, 9844867)
Mean Value:	5.40 m/s at (240474, 9844867)

Mean Speed [m/s]

Maximum Value:	764 W/m² at (240474, 9844867)
Minimum Value:	69 W/m² at (240474, 9844867)
Mean Value:	179 W/m² at (240474, 9844867)

Mean Power Density [W/m²]

12.2 *Wind farm Analysis for Ng'ong Hills in Nairobi*

The wind farm map is shown in figure 33 below. The figure shows the position of the fifteen turbines both at higher grounds of Ng'ong Hills in Nairobi.

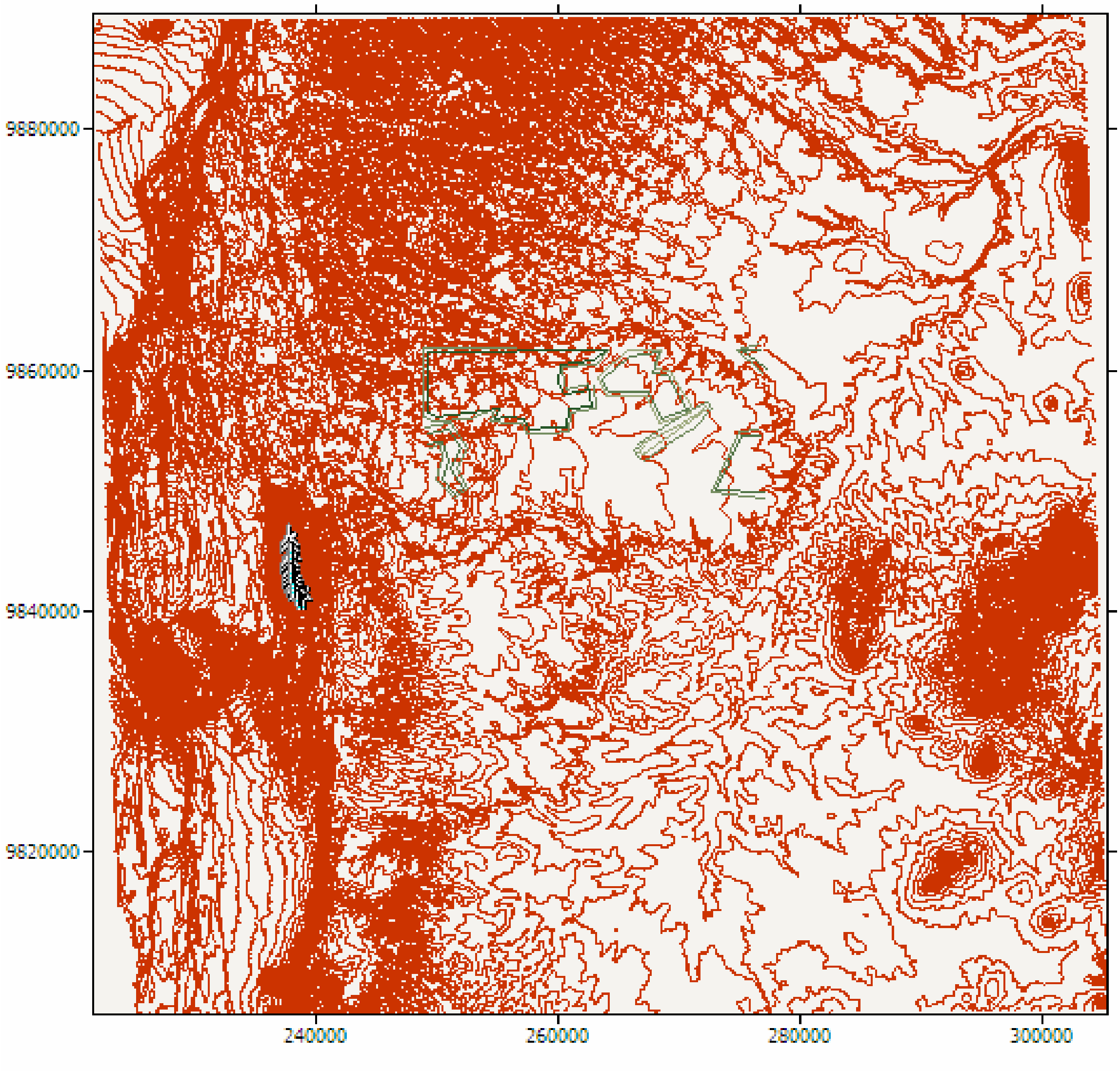


Figure 33: Position of the 15 wind turbine generators

12.3 *Ng'ong Hills wind farm*

12.4 *Summary results of a Ng,ong Hills wind farm*

Parameter	Total	Average	Minimum	Maximum
Net AEP [GWh]	53.315	3.554	3.158	3.897
Gross AEP [GWh]	53.668	3.578	3.161	3.919
Wake loss [%]	0.66	-	-	-

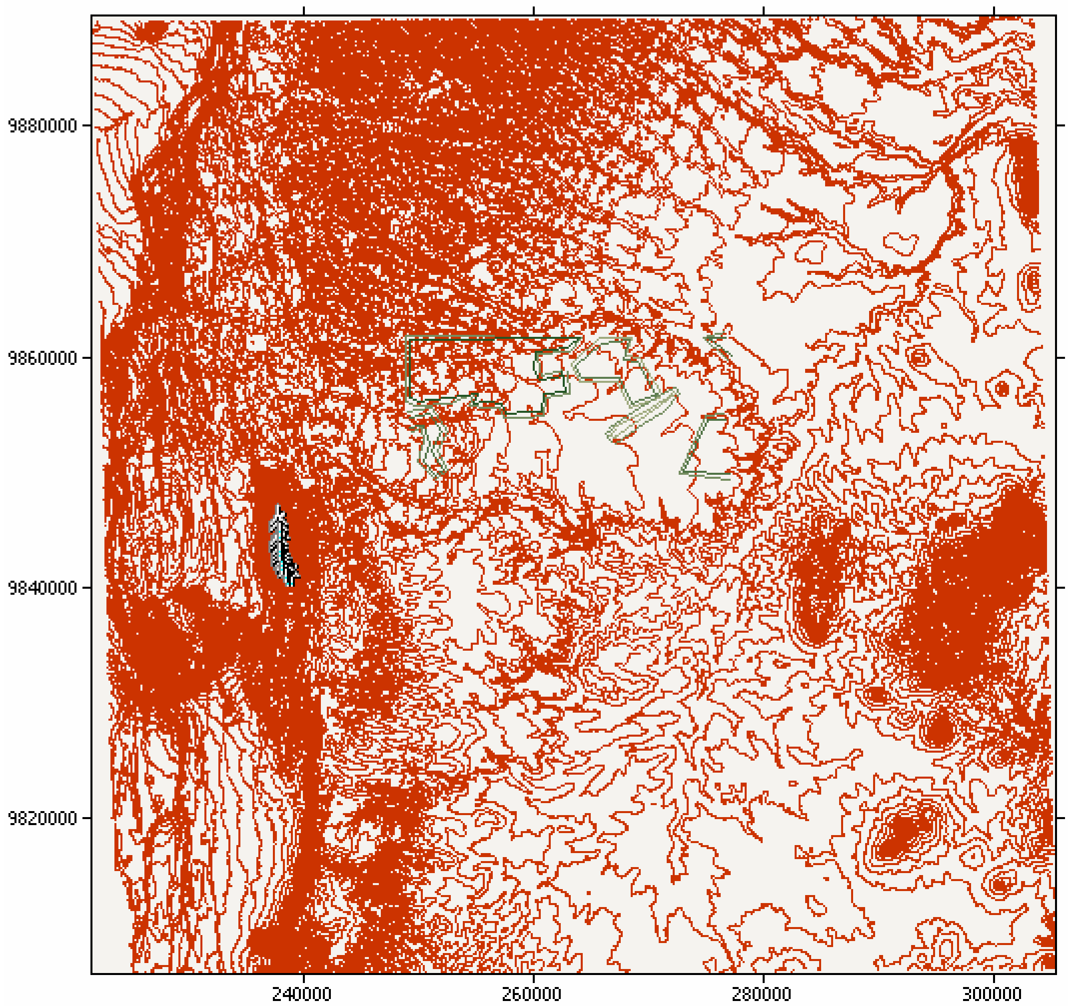
Site results

Site	Location [m]	Turbine	Elevation [m a.s.l.]	Height [m a.g.l.]	Net AEP [GWh]	Wake loss [%]
Turbine site 1	(238805.6,9840268.0)	Vestas V52 (850 kW)	2220	55	3.158	0.07
Turbine site 2	(238414.9,9840373.0)	Vestas V52 (850 kW)	2221	55	3.361	0.87
Turbine site 3	(238309.7,9840658.0)	Vestas V52 (850 kW)	2242	55	3.445	0.54
Turbine site 4	(238114.3,9840989.0)	Vestas V52 (850 kW)	2301	55	3.585	1.03
Turbine site 5	(238212.0,9840816.0)	Vestas V52 (850 kW)	2264	55	3.475	0.81
Turbine site 6	(238009.2,9841312.0)	Vestas V52 (850 kW)	2340	55	3.621	0.8
Turbine site 7	(237941.5,9841545.0)	Vestas V52 (850 kW)	2325	55	3.309	0.85
Turbine site 8	(237956.6,9841860.0)	Vestas V52 (850 kW)	2364	55	3.442	0.65
Turbine site 9	(237836.3,9842123.0)	Vestas V52 (850 kW)	2380	55	3.570	0.75
Turbine site 10	(237731.1,9842461.0)	Vestas V52 (850 kW)	2383	55	3.475	0.6
Turbine site 11	(237716.1,9842776.0)	Vestas V52 (850 kW)	2420	55	3.650	1.27
Turbine site 12	(237836.3,9843595.0)	Vestas V52 (850 kW)	2420	55	3.812	0.4
Turbine site 13	(237806.3,9843107.0)	Vestas V52 (850 kW)	2460	55	3.897	0.56
Turbine site 14	(237731.2,9844279.0)	Vestas V52 (850 kW)	2420	55	3.692	0.33
Turbine site 15	(237716.1,9844722.0)	Vestas V52 (850 kW)	2420	55	3.822	0.31

Site wind climates

Site	Location [m]	Height [m a.g.l.]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]
Turbine site 1	(238805.6,9840268.0)	55	9.2	1.96	8.17	650	14.5
Turbine site 2	(238414.9,9840373.0)	55	9.8	1.82	8.74	865	12.6
Turbine site 3	(238309.7,9840658.0)	55	10.1	1.76	8.98	975	14.7
Turbine site 4	(238114.3,9840989.0)	55	10.5	1.80	9.32	1059	17.8
Turbine site 5	(238212.0,9840816.0)	55	10.2	1.77	9.07	999	15.8
Turbine site 6	(238009.2,9841312.0)	55	10.5	1.85	9.31	1024	19.6
Turbine site 7	(237941.5,9841545.0)	55	9.8	1.69	8.77	952	18.1
Turbine site 8	(237956.6,9841860.0)	55	10.1	1.77	8.98	970	20.2
Turbine site 9	(237836.3,9842123.0)	55	10.7	1.69	9.54	1231	22.6
Turbine site 10	(237731.1,9842461.0)	55	10.3	1.70	9.21	1098	21.7
Turbine site 11	(237716.1,9842776.0)	55	10.6	1.85	9.44	1070	22.8
Turbine site 12	(237836.3,9843595.0)	55	11.3	1.78	10.03	1338	24.1
Turbine site 13	(237806.3,9843107.0)	55	12.1	1.72	10.76	1723	25.5
Turbine site 14	(237731.2,9844279.0)	55	10.9	1.77	9.71	1224	21.0
Turbine site 15	(237716.1,9844722.0)	55	11.4	1.75	10.19	1434	21.3

The wind farm lies in a map called 'New_Nairobi_JKIA'.



The wind farm is in a project called 'WAsP project 1'
A wind atlas called 'JKIA' was used to calculate the predicted wind climates

12.5 *Calculation of annual output for 'JKIA'*

Decay constants: 0.075

Sector 1 (0°)

Turbine	A [m/s]	k	Freq. [%]	U [m/s]	MWh (free)	MWh (park)	Eff. [%]
Turbine site 1	4.8	2.42	4.33	4.29	25.091	24.956	99.46
Turbine site 2	4.3	2.26	3.50	3.77	13.657	12.828	93.93
Turbine site 3	4.0	2.26	3.23	3.56	10.045	9.650	96.07
Turbine site 4	4.5	2.44	3.59	3.99	15.956	13.898	87.1
Turbine site 5	4.1	2.33	3.34	3.66	11.207	10.619	94.75
Turbine site 6	4.8	2.50	3.84	4.28	21.545	18.445	85.61
Turbine site 7	3.4	2.17	3.24	2.99	5.083	2.396	47.13
Turbine site 8	3.9	2.17	3.58	3.49	10.874	9.805	90.17
Turbine site 9	3.6	2.17	3.19	3.20	6.784	5.082	74.92
Turbine site 10	3.6	2.17	3.25	3.18	6.717	3.217	47.89
Turbine site 11	5.1	2.50	3.86	4.50	25.771	22.257	86.37
Turbine site 12	4.8	2.50	3.50	4.23	18.708	16.873	90.19
Turbine site 13	4.6	2.50	3.24	4.11	15.649	12.784	81.69
Turbine site 14	5.1	2.50	3.67	4.49	24.350	20.950	86.04
Turbine site 15	4.6	2.50	3.37	4.12	16.424	16.424	100.0
Sector 1 total	-	-	-	-	227.862	200.184	87.85

Sector 2 (30°)

Turbine	A [m/s]	k	Freq. [%]	U [m/s]	MWh (free)	MWh (park)	Eff. [%]
Turbine site 1	8.4	2.32	13.81	7.48	368.989	368.989	100.0
Turbine site 2	8.6	2.10	11.41	7.62	316.048	316.048	100.0
Turbine site 3	8.3	1.96	9.66	7.40	254.389	254.389	100.0
Turbine site 4	8.8	2.13	10.86	7.78	312.024	312.024	100.0
Turbine site 5	8.4	2.02	9.98	7.48	267.406	267.406	100.0
Turbine site 6	8.9	2.23	11.73	7.89	345.743	345.743	100.0
Turbine site 7	7.1	2.04	9.39	6.33	181.465	181.465	100.0
Turbine site 8	7.8	2.15	10.89	6.92	251.604	251.604	100.0
Turbine site 9	7.7	2.03	9.20	6.84	208.719	208.719	100.0
Turbine site 10	7.5	2.11	9.64	6.60	202.351	202.351	100.0
Turbine site 11	8.6	2.36	11.76	7.63	326.517	304.466	93.25
Turbine site 12	8.8	2.27	10.60	7.79	305.999	305.999	100.0
Turbine site 13	9.0	2.21	9.66	8.00	291.155	291.155	100.0
Turbine site 14	8.0	2.42	10.97	7.12	264.558	264.558	100.0
Turbine site 15	8.7	2.26	10.18	7.72	288.777	288.777	100.0
Sector 2 total	-	-	-	-	4185.743	4163.693	99.47

Sector 3 (60°)

Turbine	A [m/s]	k	Freq. [%]	U [m/s]	MWh (free)	MWh (park)	Eff. [%]
Turbine site 1	11.8	2.79	27.42	10.47	1260.566	1260.566	100.0
Turbine site 2	13.1	2.69	33.58	11.65	1703.171	1703.171	100.0
Turbine site 3	13.5	2.62	35.89	11.95	1843.059	1843.059	100.0
Turbine site 4	13.5	2.61	30.91	12.03	1593.172	1593.172	100.0
Turbine site 5	13.4	2.60	33.98	11.94	1740.702	1740.702	100.0
Turbine site 6	13.3	2.65	28.43	11.80	1449.950	1449.950	100.0
Turbine site 7	12.2	2.38	27.69	10.79	1262.212	1262.212	100.0
Turbine site 8	12.7	2.52	27.82	11.28	1343.770	1343.770	100.0
Turbine site 9	13.2	2.37	27.72	11.70	1350.706	1350.706	100.0
Turbine site 10	12.5	2.37	25.59	11.10	1194.032	1194.032	100.0
Turbine site 11	12.7	2.61	23.20	11.25	1130.038	1130.038	100.0
Turbine site 12	13.5	2.50	24.15	12.00	1222.947	1222.947	100.0
Turbine site 13	14.3	2.39	23.63	12.65	1212.113	1212.113	100.0
Turbine site 14	12.2	2.47	19.71	10.81	909.728	909.728	100.0
Turbine site 15	13.5	2.44	23.38	12.01	1174.633	1174.633	100.0
Sector 3 total	-	-	-	-	20390.797	20390.797	100.0

Sector 4 (90°)

Turbine	A [m/s]	k	Freq. [%]	U [m/s]	MWh (free)	MWh (park)	Eff. [%]
Turbine site 1	12.6	3.12	18.32	11.23	931.881	931.881	100.0
Turbine site 2	13.4	2.89	17.17	11.91	906.456	885.343	97.67
Turbine site 3	13.9	2.82	17.51	12.34	943.305	943.305	100.0
Turbine site 4	15.0	2.99	19.88	13.36	1146.939	1146.939	100.0
Turbine site 5	14.3	2.88	18.67	12.71	1033.776	1033.776	100.0
Turbine site 6	15.0	3.07	20.45	13.42	1192.626	1192.626	100.0
Turbine site 7	14.9	2.99	24.51	13.27	1409.114	1409.114	100.0
Turbine site 8	14.9	3.05	22.00	13.36	1277.658	1277.658	100.0
Turbine site 9	16.2	2.99	24.80	14.44	1471.524	1471.524	100.0
Turbine site 10	15.7	3.00	25.77	13.99	1518.261	1518.261	100.0
Turbine site 11	15.5	3.07	23.78	13.83	1406.335	1406.335	100.0
Turbine site 12	16.7	3.03	25.26	14.92	1515.875	1515.875	100.0
Turbine site 13	18.2	2.98	27.38	16.21	1618.653	1618.653	100.0
Turbine site 14	16.1	2.96	26.80	14.39	1583.088	1583.088	100.0
Turbine site 15	17.1	3.00	26.55	15.26	1587.356	1587.356	100.0
Sector 4 total	-	-	-	-	19542.845	19521.733	99.89

Sector 5 (120°)

Turbine	A [m/s]	k	Freq. [%]	U [m/s]	MWh (free)	MWh (park)	Eff. [%]
Turbine site 1	9.5	2.47	6.30	8.43	208.743	208.743	100.0
Turbine site 2	8.5	2.27	5.34	7.55	145.587	138.266	94.97
Turbine site 3	8.2	2.10	5.04	7.28	128.470	122.199	95.12
Turbine site 4	9.8	2.26	5.82	8.71	201.343	199.366	99.02
Turbine site 5	8.7	2.15	5.30	7.73	150.762	147.016	97.52
Turbine site 6	10.6	2.35	6.29	9.38	243.265	243.265	100.0
Turbine site 7	9.9	2.19	6.23	8.77	216.672	216.672	100.0

Turbine site 8	10.5	2.32	6.43	9.33	246.178	246.178	100.0
Turbine site 9	10.7	2.18	6.18	9.47	237.858	237.858	100.0
Turbine site 10	10.9	2.23	6.66	9.69	265.008	265.008	100.0
Turbine site 11	12.4	2.41	7.55	10.96	350.428	350.428	100.0
Turbine site 12	12.4	2.31	7.14	10.98	327.558	327.558	100.0
Turbine site 13	13.0	2.23	7.01	11.53	329.791	329.791	100.0
Turbine site 14	13.9	2.40	8.89	12.35	451.558	451.558	100.0
Turbine site 15	12.7	2.28	7.25	11.23	337.415	337.415	100.0
Sector 5 total	-	-	-	-	3840.635	3821.320	99.5

Sector 6 (150°)

Turbine	A [m/s]	k	Freq. [%]	U [m/s]	MWh (free)	MWh (park)	Eff. [%]
Turbine site 1	7.9	2.60	5.11	7.01	117.969	117.969	100.0
Turbine site 2	6.3	2.60	4.01	5.60	52.049	52.049	100.0
Turbine site 3	5.8	2.60	3.73	5.18	38.217	29.828	78.05
Turbine site 4	7.4	2.60	4.28	6.55	84.082	51.763	61.56
Turbine site 5	6.3	2.60	3.90	5.61	50.619	27.643	54.61
Turbine site 6	8.2	2.60	4.72	7.29	118.495	98.558	83.17
Turbine site 7	7.1	2.47	4.52	6.32	82.420	63.325	76.83
Turbine site 8	8.0	2.55	4.76	7.06	112.064	108.403	96.73
Turbine site 9	7.7	2.47	4.48	6.79	97.258	76.665	78.83
Turbine site 10	7.7	2.38	4.79	6.86	107.137	93.351	87.13
Turbine site 11	9.4	2.46	5.69	8.32	184.512	181.480	98.36
Turbine site 12	9.0	2.43	5.17	7.97	155.605	155.294	99.8
Turbine site 13	9.1	2.34	4.95	8.03	150.662	150.096	99.62
Turbine site 14	9.8	2.24	6.13	8.70	211.244	211.011	99.89
Turbine site 15	9.0	2.37	5.15	7.94	153.864	153.701	99.89
Sector 6 total	-	-	-	-	1716.196	1571.135	91.55

Sector 7 (180°)

Turbine	A [m/s]	k	Freq. [%]	U [m/s]	MWh (free)	MWh (park)	Eff. [%]
Turbine site 1	6.9	2.75	6.61	6.10	105.865	105.865	100.0
Turbine site 2	6.2	2.75	5.52	5.54	67.182	67.182	100.0
Turbine site 3	5.9	2.75	5.09	5.21	51.396	48.545	94.45
Turbine site 4	6.3	2.76	5.47	5.65	70.435	69.908	99.25
Turbine site 5	6.0	2.75	5.19	5.30	55.318	55.209	99.8
Turbine site 6	6.7	2.78	5.78	5.96	86.616	81.186	93.73
Turbine site 7	4.9	2.77	4.99	4.38	27.954	21.386	76.51
Turbine site 8	5.7	2.77	5.54	5.11	52.381	35.839	68.42
Turbine site 9	5.3	2.77	4.93	4.69	35.044	30.940	88.29
Turbine site 10	5.2	2.77	5.00	4.66	34.775	31.198	89.71
Turbine site 11	7.0	2.78	5.80	6.27	99.812	81.266	81.42
Turbine site 12	6.6	2.78	5.26	5.88	75.950	62.931	82.86
Turbine site 13	6.4	2.78	4.88	5.72	64.898	52.402	80.74
Turbine site 14	7.0	2.78	5.52	6.25	94.450	85.715	90.75
Turbine site 15	6.4	2.78	5.07	5.73	67.977	56.404	82.98
Sector 7 total	-	-	-	-	990.052	885.977	89.49

Sector 8 (210°)

Turbine	A [m/s]	k	Freq. [%]	U [m/s]	MWh (free)	MWh (park)	Eff. [%]
Turbine site 1	6.3	2.49	5.51	5.57	71.427	71.427	100.0
Turbine site 2	6.4	2.56	6.02	5.67	81.333	81.333	100.0
Turbine site 3	6.2	2.54	5.78	5.49	71.342	71.342	100.0
Turbine site 4	6.5	2.55	5.45	5.76	76.876	76.876	100.0
Turbine site 5	6.2	2.54	5.63	5.53	71.002	71.002	100.0
Turbine site 6	6.6	2.54	5.26	5.86	78.176	78.176	100.0
Turbine site 7	5.4	2.44	4.85	4.81	41.050	41.050	100.0
Turbine site 8	6.1	2.50	5.08	5.37	59.235	59.235	100.0
Turbine site 9	5.8	2.43	4.83	5.18	51.421	51.421	100.0
Turbine site 10	5.7	2.47	4.63	5.04	44.901	44.901	100.0
Turbine site 11	6.3	2.46	4.36	5.60	57.890	57.890	100.0
Turbine site 12	6.5	2.53	4.48	5.74	62.890	62.890	100.0
Turbine site 13	6.6	2.53	4.36	5.83	63.866	57.814	90.52
Turbine site 14	5.7	2.40	3.55	5.06	35.450	35.450	100.0
Turbine site 15	6.4	2.53	4.34	5.65	58.487	58.487	100.0
Sector 8 total	-	-	-	-	925.344	919.293	99.35

Sector 9 (240°)

Turbine	A [m/s]	k	Freq. [%]	U [m/s]	MWh (free)	MWh (park)	Eff. [%]
Turbine site 1	5.3	1.88	4.95	4.68	46.712	46.712	100.0
Turbine site 2	6.0	1.89	6.43	5.28	83.613	83.613	100.0
Turbine site 3	6.2	1.92	7.09	5.50	101.191	101.191	100.0
Turbine site 4	6.3	1.96	6.02	5.60	88.830	88.830	100.0
Turbine site 5	6.2	1.94	6.70	5.53	96.464	96.464	100.0
Turbine site 6	6.2	1.97	5.44	5.49	76.262	76.262	100.0
Turbine site 7	5.9	2.00	5.62	5.23	68.892	68.892	100.0
Turbine site 8	6.0	1.98	5.39	5.36	70.999	70.999	100.0
Turbine site 9	6.4	2.01	5.65	5.69	85.752	85.752	100.0
Turbine site 10	6.1	2.00	5.22	5.38	68.806	68.806	100.0
Turbine site 11	5.9	1.97	4.47	5.23	55.488	55.488	100.0
Turbine site 12	6.4	1.99	4.84	5.66	72.752	72.752	100.0
Turbine site 13	6.8	2.00	4.91	6.05	86.205	86.205	100.0
Turbine site 14	5.7	1.97	3.94	5.06	44.621	44.621	100.0
Turbine site 15	6.4	1.99	4.77	5.70	73.011	73.011	100.0
Sector 9 total	-	-	-	-	1119.599	1119.599	100.0

Sector 10 (270°)

Turbine	A [m/s]	k	Freq. [%]	U [m/s]	MWh (free)	MWh (park)	Eff. [%]
Turbine site 1	3.3	1.19	3.28	3.13	16.164	14.986	92.71
Turbine site 2	3.2	1.10	3.36	3.09	17.648	17.648	100.0
Turbine site 3	3.2	1.07	3.52	3.14	19.675	19.675	100.0
Turbine site 4	3.7	1.13	3.77	3.54	26.557	26.557	100.0
Turbine site 5	3.4	1.09	3.67	3.29	22.490	22.490	100.0
Turbine site 6	3.9	1.17	3.76	3.67	27.985	27.985	100.0
Turbine site 7	4.0	1.19	4.57	3.76	35.434	35.434	100.0
Turbine site 8	4.0	1.19	4.04	3.75	31.078	31.078	100.0
Turbine site 9	4.4	1.19	4.63	4.10	43.385	43.385	100.0
Turbine site 10	4.4	1.24	4.71	4.11	43.386	43.386	100.0
Turbine site 11	4.6	1.30	4.12	4.24	39.399	39.399	100.0
Turbine site 12	4.8	1.27	4.51	4.49	49.499	49.499	100.0
Turbine site 13	5.3	1.27	4.95	4.91	64.830	64.830	100.0
Turbine site 14	5.2	1.38	4.49	4.70	52.082	52.082	100.0
Turbine site 15	5.0	1.28	4.75	4.66	55.847	55.847	100.0
Sector 10 total	-	-	-	-	545.459	544.282	99.78

Sector 11 (300°)

Turbine	A [m/s]	k	Freq. [%]	U [m/s]	MWh (free)	MWh (park)	Eff. [%]
Turbine site 1	1.7	0.92	2.19	1.77	3.419	2.839	83.03
Turbine site 2	1.6	0.96	1.93	1.68	2.308	2.308	100.0
Turbine site 3	1.6	0.96	1.87	1.66	2.099	2.044	97.35
Turbine site 4	1.9	0.96	2.12	1.96	3.977	3.977	100.0
Turbine site 5	1.7	0.97	1.96	1.76	2.644	2.637	99.72
Turbine site 6	2.0	0.96	2.26	2.07	5.090	5.090	100.0
Turbine site 7	1.9	0.97	2.32	1.96	4.285	4.285	100.0
Turbine site 8	2.0	0.96	2.35	2.03	4.944	4.944	100.0
Turbine site 9	2.1	0.97	2.31	2.12	5.358	5.358	100.0
Turbine site 10	2.1	0.97	2.47	2.16	6.054	6.054	100.0
Turbine site 11	2.4	0.95	2.70	2.40	9.116	9.116	100.0
Turbine site 12	2.5	0.97	2.60	2.48	9.286	9.286	100.0
Turbine site 13	2.7	0.99	2.60	2.67	10.855	10.855	100.0
Turbine site 14	2.7	0.96	3.20	2.74	14.747	14.747	100.0
Turbine site 15	2.5	0.98	2.66	2.57	10.201	10.201	100.0
Sector 11 total	-	-	-	-	94.382	93.738	99.32

Sector 12 (330°)

Turbine	A [m/s]	k	Freq. [%]	U [m/s]	MWh (free)	MWh (park)	Eff. [%]
Turbine site 1	2.4	1.22	2.19	2.28	3.882	3.454	88.98
Turbine site 2	1.9	1.22	1.72	1.82	1.310	0.913	69.66
Turbine site 3	1.8	1.22	1.60	1.68	0.873	0.244	27.93
Turbine site 4	2.3	1.22	1.83	2.11	2.496	1.935	77.53
Turbine site 5	1.9	1.22	1.67	1.82	1.272	0.437	34.37
Turbine site 6	2.6	1.24	2.04	2.40	4.231	3.455	81.66
Turbine site 7	2.4	1.37	2.08	2.20	2.460	2.380	96.71
Turbine site 8	2.5	1.31	2.13	2.34	3.551	2.324	65.43
Turbine site 9	2.6	1.37	2.07	2.38	3.264	2.725	83.5
Turbine site 10	2.8	1.42	2.27	2.51	4.060	4.060	100.0
Turbine site 11	3.7	1.46	2.72	3.34	12.298	12.298	100.0
Turbine site 12	3.5	1.47	2.48	3.21	9.836	9.836	100.0
Turbine site 13	3.7	1.51	2.43	3.31	10.148	10.148	100.0
Turbine site 14	4.3	1.61	3.14	3.82	18.896	18.896	100.0
Turbine site 15	3.6	1.51	2.52	3.28	10.225	10.225	100.0
Sector 12 total	-	-	-	-	88.802	83.329	93.84

All Sectors

Turbine	Location [m]	Gross AEP [MWh]	Net AEP [MWh]	Efficiency [%]
Turbine site 1	(238805.6,9840268.0)	3160.706	3158.385	99.93
Turbine site 2	(238414.9,9840373.0)	3390.360	3360.700	99.13
Turbine site 3	(238309.7,9840658.0)	3464.060	3445.471	99.46
Turbine site 4	(238114.3,9840989.0)	3622.687	3585.247	98.97
Turbine site 5	(238212.0,9840816.0)	3503.661	3475.400	99.19
Turbine site 6	(238009.2,9841312.0)	3649.985	3620.741	99.2
Turbine site 7	(237941.5,9841545.0)	3337.042	3308.611	99.15
Turbine site 8	(237956.6,9841860.0)	3464.338	3441.837	99.35
Turbine site 9	(237836.3,9842123.0)	3597.072	3570.135	99.25
Turbine site 10	(237731.1,9842461.0)	3495.489	3474.626	99.4
Turbine site 11	(237716.1,9842776.0)	3697.604	3650.462	98.73
Turbine site 12	(237836.3,9843595.0)	3826.904	3811.738	99.6
Turbine site 13	(237806.3,9843107.0)	3918.824	3896.846	99.44
Turbine site 14	(237731.2,9844279.0)	3704.770	3692.403	99.67
Turbine site 15	(237716.1,9844722.0)	3834.214	3822.479	99.69
Wind farm	-	53667.713	53315.076	99.34

The tables below gives Summary results of the wind farm analysis for Ng'ong Hills as well as the position of the various turbines. The net Annual Energy production from the 15 turbines is 35.592 GWh.

Parameter	Total	Average	Minimum	Maximum
Net AEP [GWh]	35.592	2.373	2.038	2.645
Gross AEP [GWh]	35.738	2.383	2.039	2.654
Wake loss [%]	0.41	-	-	-

The specific locations of each turbine, their elevation, net annual energy output and wake losses are shown in table below.

Turbine location, elevation, net annual energy output and wake losses.

Site	Location [m]	Turbine	Elevation [m a.s.l.]	Height [m a.g.l.]	Net AEP [GWh]	Wake loss [%]
Turbine site 1	(238805.6,9840268.0)	Vestas V44 (600 kW)	2220	40.5	2.038	0.05
Turbine site 2	(238414.9,9840373.0)	Vestas V44 (600 kW)	2221	40.5	2.223	0.55
Turbine site 3	(238309.7,9840658.0)	Vestas V44 (600 kW)	2242	40.5	2.295	0.32
Turbine site 4	(238114.3,9840989.0)	Vestas V44 (600 kW)	2301	40.5	2.403	0.64
Turbine site 5	(238212.0,9840816.0)	Vestas V44 (600 kW)	2264	40.5	2.316	0.48
Turbine site 6	(238009.2,9841312.0)	Vestas V44 (600 kW)	2340	40.5	2.411	0.5
Turbine site 7	(237941.5,9841545.0)	Vestas V44 (600 kW)	2325	40.5	2.197	0.49
Turbine site 8	(237956.6,9841860.0)	Vestas V44 (600 kW)	2364	40.5	2.288	0.41
Turbine site 9	(237836.3,9842123.0)	Vestas V44 (600 kW)	2380	40.5	2.397	0.47

Turbine site 10	(237731.1,9842461.0)	Vestas V44 (600 kW)	2383	40.5	2.313	0.36
Turbine site 11	(237716.1,9842776.0)	Vestas V44 (600 kW)	2420	40.5	2.429	0.79
Turbine site 12	(237836.3,9843595.0)	Vestas V44 (600 kW)	2420	40.5	2.570	0.28
Turbine site 13	(237806.3,9843107.0)	Vestas V44 (600 kW)	2460	40.5	2.645	0.37
Turbine site 14	(237731.2,9844279.0)	Vestas V44 (600 kW)	2420	40.5	2.486	0.23
Turbine site 15	(237716.1,9844722.0)	Vestas V44 (600 kW)	2420	40.5	2.581	0.2

The specific Site wind climates for each Turbine location, elevation, Weibull parameters, energy density and Rix factor are shown in table below.

Site wind climates for each Turbine location, elevation, Weibull parameters, energy density and Rix factor

Site	Location [m]	Height [m a.g.l.]	A [m/s]	k	U [m/s]	E [W/m²]	RIX[%]
Turbine site 1	(238805.6,9840268.0)	40.5	9.0	1.91	7.96	620	14.5
Turbine site 2	(238414.9,9840373.0)	40.5	9.7	1.76	8.61	861	12.6
Turbine site 3	(238309.7,9840658.0)	40.5	10.0	1.70	8.90	990	14.7
Turbine site 4	(238114.3,9840989.0)	40.5	10.4	1.74	9.27	1086	17.8
Turbine site 5	(238212.0,9840816.0)	40.5	10.1	1.71	8.98	1014	15.8
Turbine site 6	(238009.2,9841312.0)	40.5	10.3	1.79	9.20	1025	19.6
Turbine site 7	(237941.5,9841545.0)	40.5	9.7	1.63	8.65	959	18.1
Turbine site 8	(237956.6,9841860.0)	40.5	9.9	1.72	8.87	967	20.2
Turbine site 9	(237836.3,9842123.0)	40.5	10.6	1.63	9.50	1266	22.6
Turbine site 10	(237731.1,9842461.0)	40.5	10.2	1.63	9.11	1117	21.7
Turbine site 11	(237716.1,9842776.0)	40.5	10.5	1.79	9.30	1058	22.8
Turbine site 12	(237836.3,9843595.0)	40.5	11.3	1.73	10.04	1390	24.1
Turbine site 13	(237806.3,9843107.0)	40.5	12.4	1.67	11.04	1936	25.5
Turbine site 14	(237731.2,9844279.0)	40.5	10.9	1.71	9.74	1284	21.0
Turbine site 15	(237716.1,9844722.0)	40.5	11.5	1.69	10.28	1531	21.3

Turbine location, Gross AEP, Net AEP, and Efficiency factor for all sectors of the wind direction

Turbine	Location [m]	Gross AEP [MWh]	Net AEP [MWh]	Efficiency [%]
Turbine site 1	(238805.6,9840268.0)	2039.048	2038.052	99.95
Turbine site 2	(238414.9,9840373.0)	2235.453	2223.079	99.45
Turbine site 3	(238309.7,9840658.0)	2302.379	2295.125	99.68
Turbine site 4	(238114.3,9840989.0)	2418.138	2402.674	99.36
Turbine site 5	(238212.0,9840816.0)	2327.471	2316.199	99.52
Turbine site 6	(238009.2,9841312.0)	2423.094	2410.928	99.5
Turbine site 7	(237941.5,9841545.0)	2208.033	2197.283	99.51
Turbine site 8	(237956.6,9841860.0)	2297.282	2287.944	99.59
Turbine site 9	(237836.3,9842123.0)	2408.349	2397.056	99.53
Turbine site 10	(237731.1,9842461.0)	2321.791	2313.318	99.64
Turbine site 11	(237716.1,9842776.0)	2448.150	2428.816	99.21
Turbine site 12	(237836.3,9843595.0)	2576.906	2569.746	99.72
Turbine site 13	(237806.3,9843107.0)	2654.294	2644.604	99.63
Turbine site 14	(237731.2,9844279.0)	2491.908	2486.300	99.77
Turbine site 15	(237716.1,9844722.0)	2585.956	2580.713	99.8
Wind farm	-	35738.247	35591.840	99.59

13 WAsP Analysis for Marsabit Met. Station

The Marsabit Met. station is located at co-ordinates (386418,259148) UTM as shown in figure 35 below. The associated observed wind climate data were collected at 2.32°N 37.98°E. The site elevation is 1,361.0 m a.s.l. The roughness conditions of the site is also shown in the map.

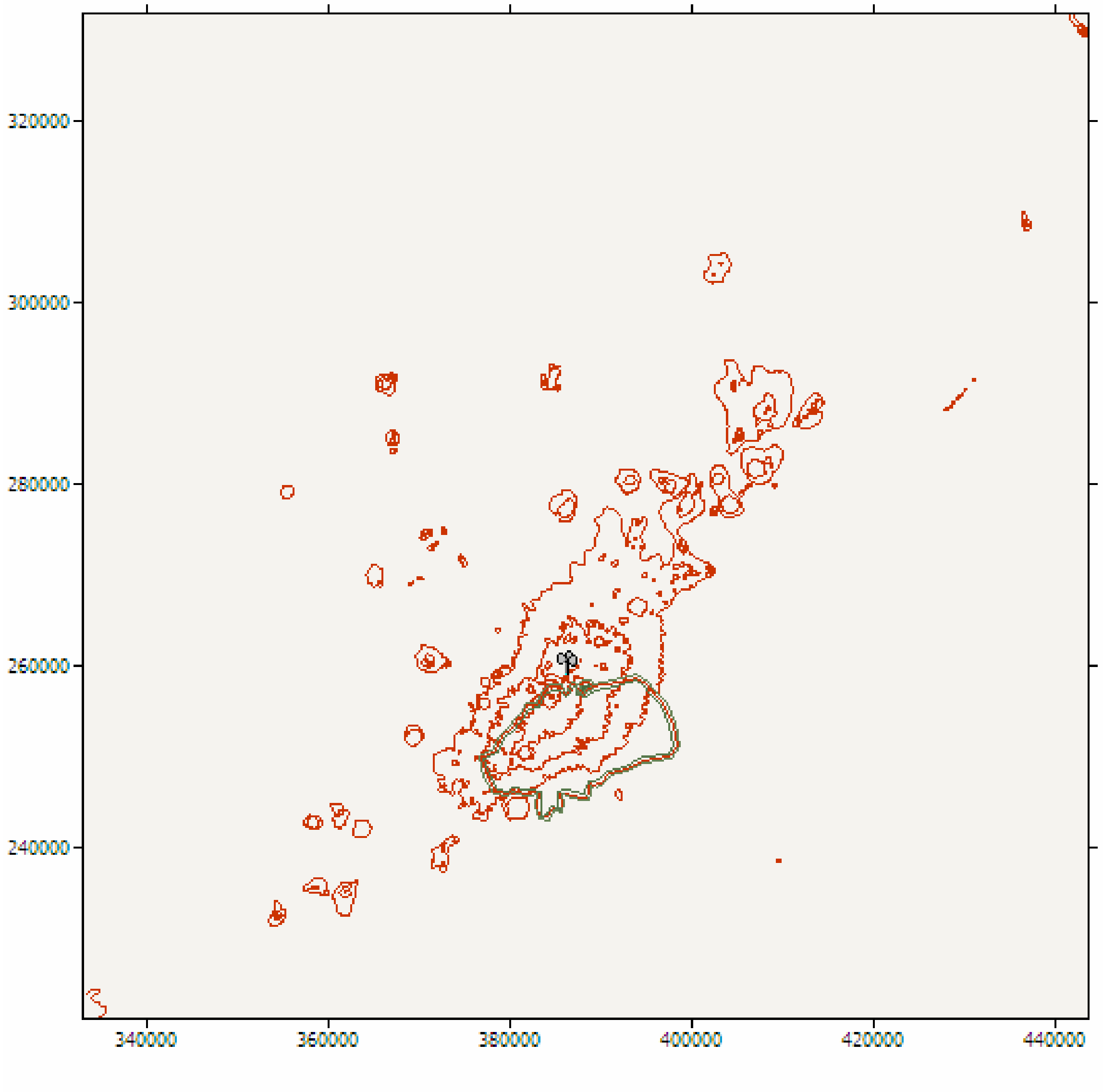


Figure 35: Position of the Marsabit Met. Station site.

The observed wind climate for the Marsabit site generated using WAsP analyses are shown in the tables and figures below. Figure below presents the observed wind rose frequency diagram and the Weibull fit.

-	Weibull fit	Combined	Discrepancy
Mean wind speed	11.27 m/s	11.26 m/s	-0.11%
Mean power density	1298 W/m²	1297 W/m²	-0.03%

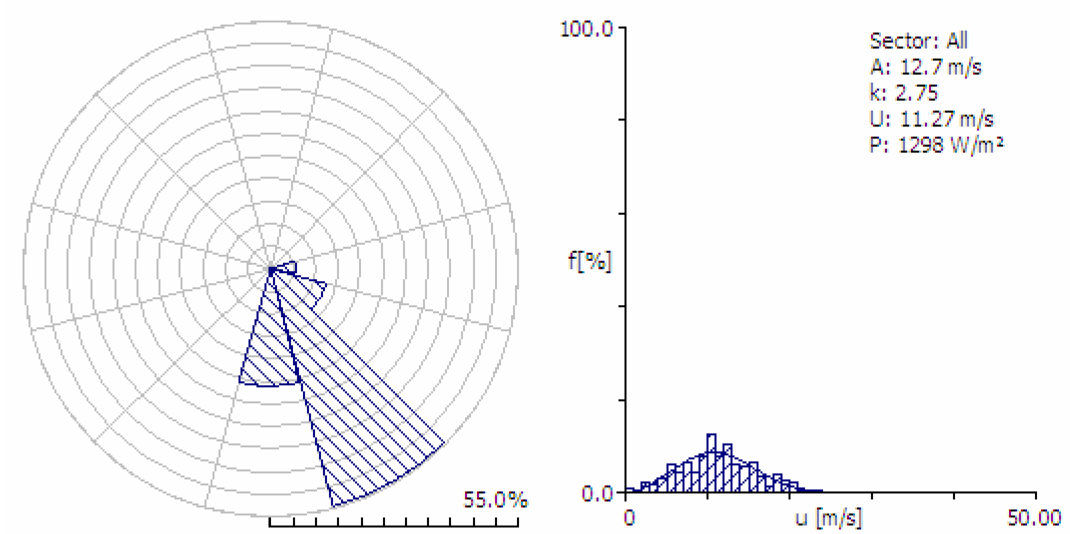


Figure 36: The observed wind rose frequency diagram and the Weibull fit for Marsabit Met -Position: 2.32°N 37.98°E; Anemometer height: 10.00 m a.g.l.

The WAsP prediction for the met. Station is given in the table below.

-	Observed	Predicted	Discrepancy
Mean wind speed	11.27 m/s	11.21 m/s	-0.52%
Mean power density	1298 W/m²	1278 W/m²	-1.54%

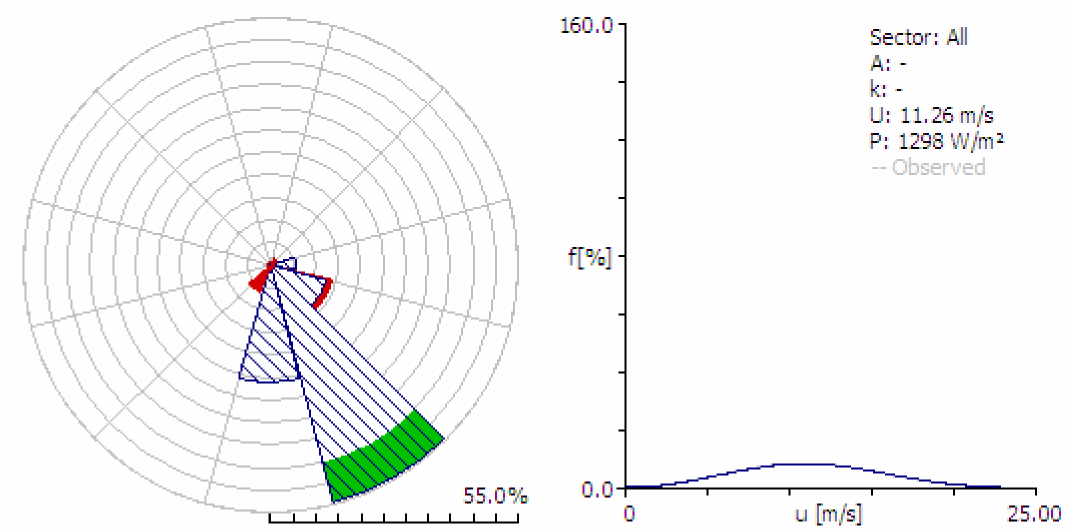


Figure 37: The WAsP predicted wind rose frequency diagram and the Weibull fit for Marsabit_Met' Station-Position: 2.32°N 37.98°E; Anemometer height: 10.00 m a.g.l.

The wind atlas was computed using 4 reference roughness lengths, i.e. 0.000 m, 0.030 m, 0.100 m, 0.400 m and 5 reference heights (10 m, 25 m, 50 m, 100 m, 200 m) above ground level. The roses of Weibull parameters had 12 sectors each. These parameters represent the regional wind climate and were as summarized in table 9 below.

Regional wind climate summary

Height	Parameter	0.00 m	0.03 m	0.10 m	0.40 m
10.0 m	Weibull A [m/s]	21.13	15.04	12.94	10.05
	Weibull k	2.44	2.39	2.39	2.42
	Mean speed U [m/s]	18.73	13.33	11.47	8.91
	Power density E [W/m²]	6475	2365	1507	699
25.0 m	Weibull A [m/s]	22.93	17.45	15.54	12.93
	Weibull k	2.44	2.41	2.40	2.44
	Mean speed U [m/s]	20.34	15.47	13.78	11.47
	Power density E [W/m²]	8264	3680	2603	1486
50.0 m	Weibull A [m/s]	24.32	19.32	17.55	15.14
	Weibull k	2.45	2.44	2.42	2.46
	Mean speed U [m/s]	21.57	17.13	15.56	13.43
	Power density E [W/m²]	9832	4953	3726	2369
100.0 m	Weibull A [m/s]	25.73	21.27	19.62	17.40
	Weibull k	2.47	2.48	2.46	2.49
	Mean speed U [m/s]	22.83	18.86	17.41	15.44
	Power density E [W/m²]	11603	6527	5151	3565
200.0 m	Weibull A [m/s]	27.22	23.37	21.82	19.75
	Weibull k	2.47	2.53	2.51	2.54
	Mean speed U [m/s]	24.15	20.74	19.36	17.53
	Power density E [W/m²]	13735	8558	6988	5137

13.1 *Wind Resource Grid for Marsabit*

The structure and the computational Grid Setup is shown in the table

Structure: 9 columns and 10 rows at 6620 resolution gives 90 calculation sites.
Boundary: (355300, 243270) to (414880, 309470)
Nodes: (358610, 246580) to (411570, 306160)

The WAsP modeled mean wind speeds at 50m above the ground is shown in figure 16 while figure 17 gives the resulting wind power density for the same region.

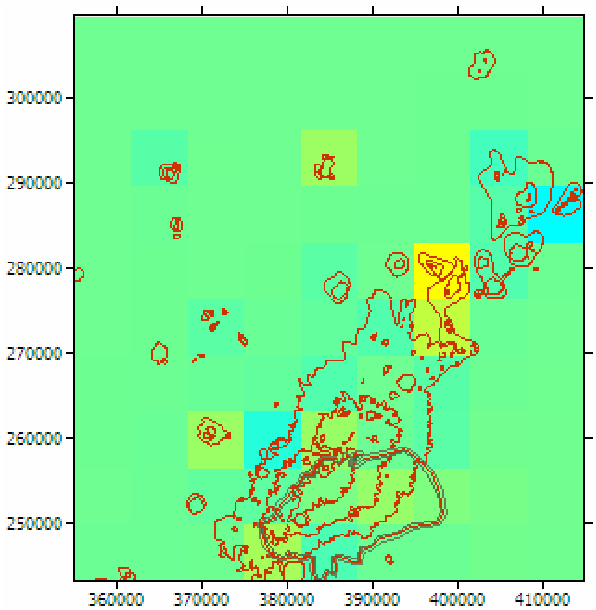


Figure 38: Modeled wind speeds at 50m a.g.l.

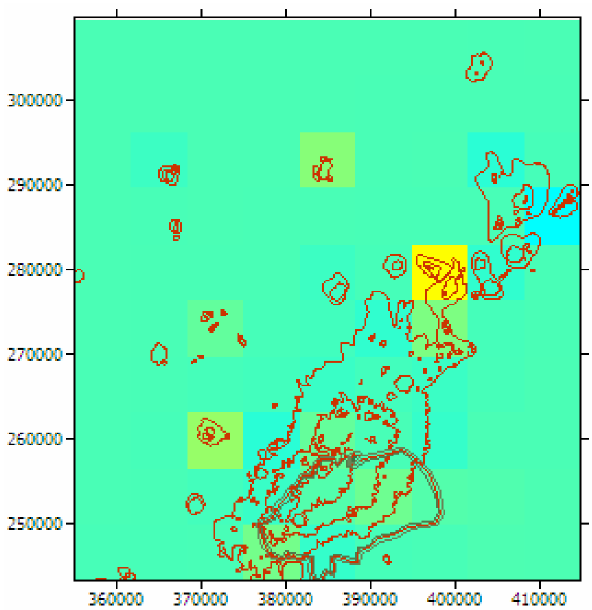


Figure 39: Modeled wind power density [W/m²] at 50m
a.g.l.

Maximum Value:	17.55 m/s at (401640, 282990)
Minimum Value:	11.92 m/s at (401640, 282990)
Mean Value:	14.31 m/s at (401640, 282990)

Mean Speed [m/s]

Maximum Value:	367 W/m² at (620012, 9664978)
Minimum Value:	219 W/m² at (620012, 9664978)
Mean Value:	287 W/m² at (620012, 9664978)

Mean Power Density [W/m²]

13.3 *Marsabit Wind farm analysis*

Summary results for Marsabit wind Farm

Parameter	Total	Average	Minimum	Maximum
Net AEP [GWh]	80.114	5.007	3.920	5.534
Gross AEP [GWh]	80.181	5.011	3.919	5.543
Wake loss [%]	0.08	-	-	-

13.4 *Site results*

Site	Location [m]	Turbine	Elevation [m a.s.l.]	Height [m a.g.l.]	Net AEP [GWh]	Wake loss [%]
Turbine site 1	(398200.4,279683.7)	Vestas V52 (850 kW)	1200	55	4.939	0.09
Turbine site 2	(399358.3,277402.2)	Vestas V52 (850 kW)	1241	55	5.085	0.02
Turbine site 3	(397334.4,277528.7)	Vestas V52 (850 kW)	1093	55	5.275	0.04
Turbine site 4	(370976.0,260371.9)	Vestas V52 (850 kW)	1370	55	3.920	-0.01
Turbine site 5	(400876.3,279881.6)	Vestas V52 (850 kW)	1210	55	4.052	0.0
Turbine site 2	(396177.1,277336.0)	Vestas V52 (850 kW)	1070	55	5.473	0.07
Turbine site 3	(400787.0,277694.6)	Vestas V52 (850 kW)	1119	55	5.046	0.0
Turbine site 4	(395664.8,279000.8)	Vestas V52 (850 kW)	1070	55	5.496	0.15
Turbine site 5	(400966.3,282125.5)	Vestas V52 (850 kW)	1070	55	5.476	0.04
Turbine site 6	(399839.4,280486.3)	Vestas V52 (850 kW)	1070	55	5.473	0.1
Turbine site 7	(395229.4,280537.5)	Vestas V52 (850 kW)	1070	55	5.351	0.22
Turbine site 8	(396228.2,280921.7)	Vestas V52 (850 kW)	1120	55	4.638	0.16
Turbine site 9	(397406.3,281434.0)	Vestas V52 (850 kW)	1070	55	5.534	0.17
Turbine site 10	(398866.2,282125.5)	Vestas V52 (850 kW)	1070	55	5.517	0.16
Turbine site 11	(372050.8,260585.8)	Vestas V52 (850 kW)	1133	55	4.647	0.06
Turbine site 12	(373024.0,260150.4)	Vestas V52 (850 kW)	1220	55	4.193	0.0

Site wind climates for marsabit

Site	Location [m]	Height [m a.g.l.]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]
Turbine site 1	(398200.4,279683.7)	55	20.8	2.24	18.45	6615	2.2
Turbine site 2	(399358.3,277402.2)	55	20.9	2.58	18.57	6051	1.4
Turbine site 3	(397334.4,277528.7)	55	17.9	2.33	15.90	4096	1.4
Turbine site 4	(370976.0,260371.9)	55	26.6	2.39	23.61	13135	7.4
Turbine site 5	(400876.3,279881.6)	55	25.5	2.77	22.74	10604	7.8
Turbine site 2	(396177.1,277336.0)	55	16.9	2.45	14.99	3308	1.3
Turbine site 3	(400787.0,277694.6)	55	18.7	2.18	16.53	4873	2.8
Turbine site 4	(395664.8,279000.8)	55	16.9	2.47	15.00	3286	2.1
Turbine site 5	(400966.3,282125.5)	55	16.9	2.43	14.97	3305	0.6
Turbine site 6	(399839.4,280486.3)	55	16.0	2.45	14.23	2823	1.5
Turbine site 7	(395229.4,280537.5)	55	17.2	2.36	15.28	3602	0.6
Turbine site 8	(396228.2,280921.7)	55	17.9	1.84	15.88	5121	1.4
Turbine site 9	(397406.3,281434.0)	55	15.1	2.63	13.45	2270	2.9
Turbine site 10	(398866.2,282125.5)	55	16.9	2.48	14.96	3258	1.9
Turbine site 11	(372050.8,260585.8)	55	20.6	2.13	18.24	6683	1.3
Turbine site 12	(373024.0,260150.4)	55	25.0	2.17	22.13	11755	5.2

The wind farm lies in a map called 'marsabit_cont'.

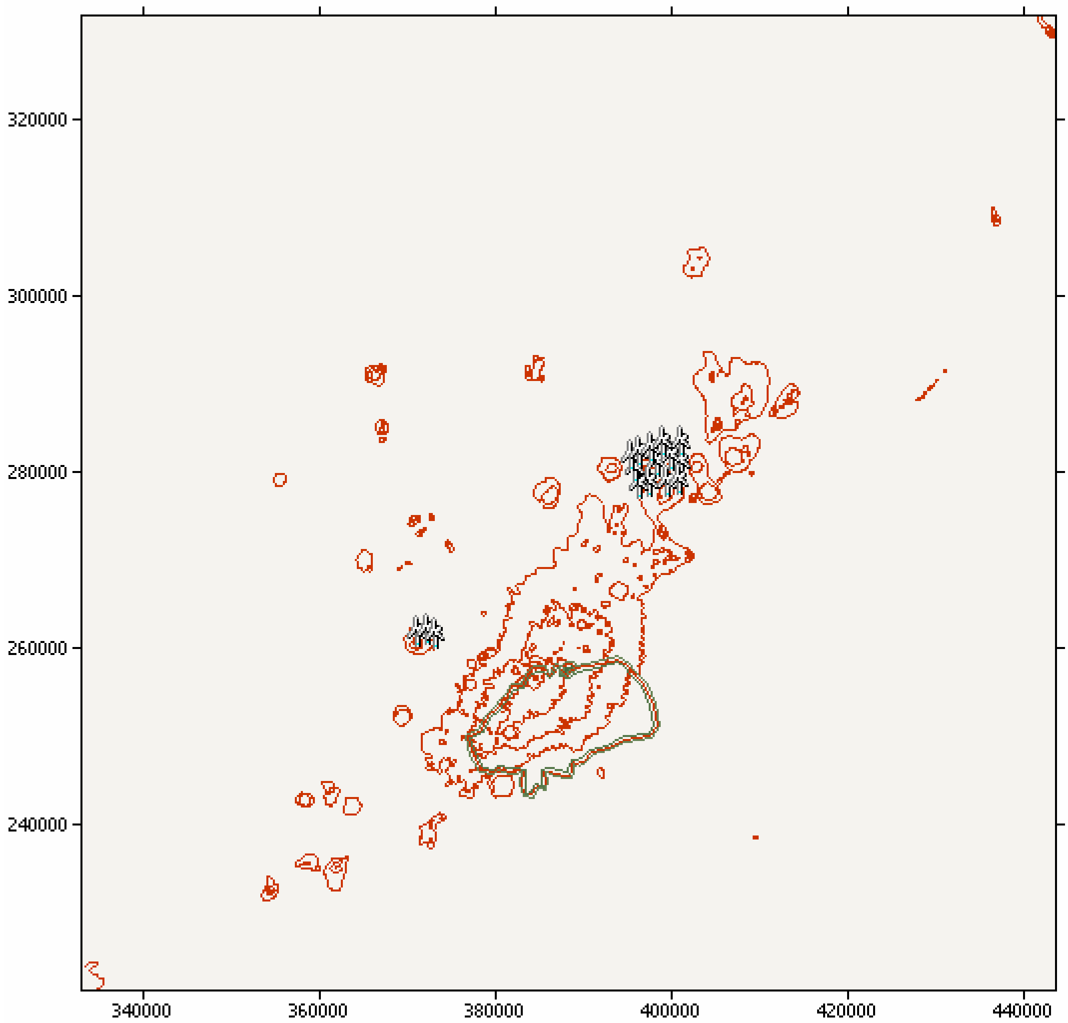


Figure 40: The wind farm is in a project called 'WAsP project 1'
A wind atlas called 'Wind atlas 2' was used to calculate the predicted wind climates

Validation

Year	Malindi Obs	Validated (50m)	Marsabit Obs	Validated (50m	JKIA Obs	Validated (50m
Mean	4.3	5.9	11.6	7.9	3.2	3.5

The results of the validation are in good agreement with the observed except for Marsabit station that shows slightly decreased wind speeds at 50m a.g.l.

14 Wind Energy analysis using Ret Screen

The wind investment analysis is based on a number of parameters. First as a result of wind analysis being done at 50 m a deliberate effort was made to identify a turbine whose hub is close to the do meter and moderately big enough to provide a sizeable amount of energy form a given amount of wind energy resource. The table below shows the operational features of the Vestas V-52-55 a medium sized turbine whose hub height is around 55 meters and has a swept are of 2,124 square meters from a 52 meter diameter rotor.

14.1 *An example of a RETScreen window*

Measured at	m	10.0	10.0
Wind shear exponent		0.142857143	
Air temperature - annual	°C	26.1	26.1
Atmospheric pressure - annual	kPa	102.0	100.6
Wind turbine			
Power capacity per turbine	kW	850	
Manufacturer		Vestas	
Model		VESTAS V52 - 55m	
Number of turbines		12	
Power capacity	kW	10,200	
Hub height	m	55.0	6.4 m/s
Rotor diameter per turbine	m	52	
Swept area per turbine	m²	2,124	
Energy curve data		Standard	
Shape factor		2.0	

Show data

Wind speed m/s	Power curve data kW	Energy curve data MWh
0	0	
1	0	
2	0	
3	0	201.9
4	26	564.7
5	67	1,098.1
6	125	1,731.7
7	203	2,385.1
8	304	3,002.8
9	425	3,556.8
10	554	4,036.8
11	671	4,440.2
12	759	4,766.7
13	811	5,017.3
14	836	5,195.2
15	846	5,305.6
16	849	
17	850	
18	850	
19	850	
20	850	
21	850	
22	850	
23	850	
24	850	
25 - 30	850	

Array losses	%	1.0%
Airfoil losses	%	1.0%
Miscellaneous losses	%	1.0%
Availability	%	98.0%
Summary		
Capacity factor	%	24.5%
Electricity exported to grid	MWh	21,872

From the table above a summary of the wind resource and the turbine conversion shows that at Ras Ngomeni a turbine will yield gross production of 1917 MWh at a specific yield of 858 kWh per square meter. The wind available provide a capacity factor of 24.5% considered a conservative assessment compared with the operational history of the two turbine farm on Ng’ong Hills near Nairobi.

14.2 *The RETScreen analysis of the three sites*

Assumption made/

A number of assumptions have been used to model the wind farm over and above the choice of the turbine.

1. A project life of 20 years
2. the fuel escalation rate is about 5.5% while the long term inflation is assumed at 6.5%
3. assuming a debt venture of 80% and a discount rate of 15%.
4. A debt payment rate of 7.5% payable for ten years
5. cost of CER about USD 22 per ton

The energy Tariff applicable - USD 90/MWh

14.2.1 Ras Ngomeni Wind farm results of the analysis

a) Project development cost allocation

Feasibility study	-	0.2 %
Development phase	-	0.1 %
Engineering	-	0.6 %
Power Systems	-	76.5%
Balance of Systems	-	22.2 %

b) Financial viability indicators

Pre Tax IRR on equity	-	44.5%
Pre Tax IRR on Assets	-	12.2%
Simple Pay back period	-	5 years
Equity payback	-	2.5%
Net Present Value	-	USD 7.1 Million

c) Economic indicators

Clean Energy Produced	-	21.872 GWh
Energy Production Cost	-	US Cents 5.018 per kWh
Total initial cost	-	USD 11981187
Annual costs and debt payment	-	USD 1474504
O&M	-	USD 78077

d) Green House Gas Emission Reduction

Carbon CERs	-	8130 tCO2 per year upto yr 9
	-	7323 tCO2 form yr 10 - 20

d) Risk analysis

A risk analysis of the investment was performed using the Monte Carlo simulation which perfumes several hundred computations to assess the project risks

The Risk factors for Ras Ngomeni are as follows
The most sensitive indicators are initial investments and tarries and to a lesser extent debt terms and debt interest rate.

14.2.2 Ng'ong Hills Wind farm results of the analysis

a) Project development cost allocation

Feasibility study	-	0.2 %
Development phase	-	0.1 %
Engineering	-	0.5 %

Power Systems	-	76.1%
Balance of Systems	-	22.1 %

e) Financial viability indicators

Pre Tax IRR on equity	-	80.6 %
Pre Tax IRR on Assets	-	19.6%
Simple Pay back period	-	3.5 years
Equity payback	-	1.2 years
Net Present Value	-	USD 17.25 Million

f) Economic indicators

Clean Energy Produced	-	38.62 GWh
Energy Production Cost	-	US Cents 3.55 per kWh
Total initial cost	-	USD 14,946,993
Annual costs and debt payment	-	USD
O&M		- USD 98128

d) Green House Gas Emission Reduction

Carbon CERs	-	14367 tCO2 per year upto yr 9
	-	12930 tCO2 form yr 10 - 20

g) Risk analysis

A risk analysis of the investment was performed using the Monte Carlo simulation which perfumes several hundred computations to assess the project risks

The Risk factors for Ng'ong Hills are as follows

Like Ras Ngomeni the most sensitive indicators are initial investments and tariffs and to a lesser extent debt terms and debt interest rate.

14.2.3 Marsabit Hills Wind farm results of the analysis

a) Project development cost allocation

Feasibility study	-	0.2 %
Development phase	-	0.1 %
Engineering	-	0.3 %
Power Systems	-	82.6 %
Balance of Systems	-	16.8 %

h) Financial viability indicators

Pre Tax IRR on equity	-	50.7 %
Pre Tax IRR on Assets	-	13.8 %
Simple Pay back period	-	4.5 years
Equity payback	-	2.2 years
Net Present Value	-	USD 16.42 Million

i) Economic indicators

Clean Energy Produced	-	46.9 GWh
Energy Production Cost	-	US Cents 4.725 per kWh
Total initial cost	-	USD 23150900
Annual costs and debt payment	-	USD
O&M		- USD 159535

d) Green House Gas Emission Reduction

Carbon CERs - 17444 tCO2 per year upto yr 9

- 15699 tCO2 form yr 10 - 20

j) Risk analysis

The most sensitive indicators are initial investments and tariffs and to a lesser extent debt terms and debt interest rate.

k) Conclusion

A close comparison of the three sites show that Marsabit and Ng'ong hills are the best options and notice that for Marsabit a line construction costs has been factored in covering a distance of 225 km from Isiolo to Marsabit.

The IRR of return appears above the market interest rates and the three sites would have pay back period of less than 7 years considered good for an energy project.

15 Availability of wind energy during dry hydrology

An analysis of the wind and hydro power resource availability for energy can easily be demonstrated by data from a site on river Maragwa at Gachocho in Maragwa District of central Kenya and a 15 turbine wind farm with a 850 kW machines on Ng’ong Hills to the west of Nairobi.

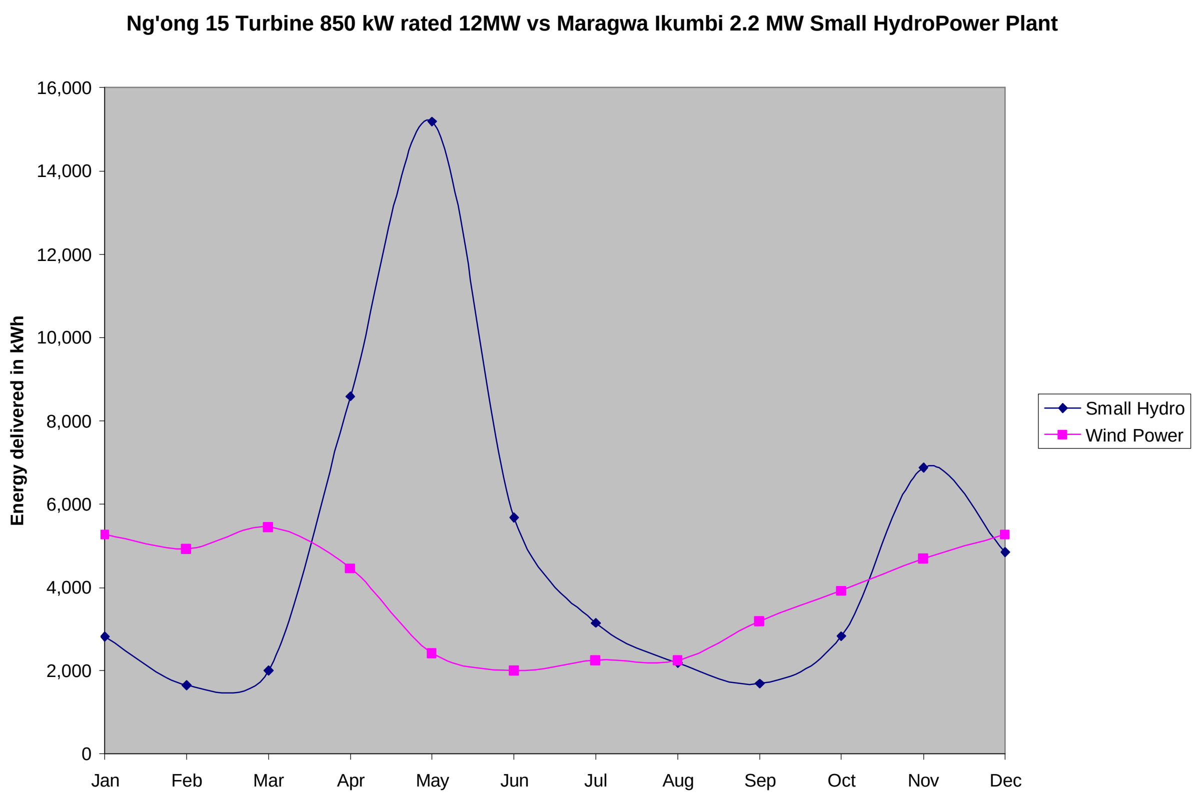


Figure: 41 Graph showing energy dissipation at tow site powered by wind and hydro power respectfully.

The Maragwa river is one of the main tributaries of the Tana river system that serves the seven forks system. Although energy from the hydro power is much higher, it is also evident that the wind regime at Ng’ong is readily available during the dry months of January, February and March . the wind dies down during the rainy seasons and gradually picks again form august to January.

Two important features of this comparison are the relative availability during the dry hydrology and the build up of wind during the least quarter of the month.

16 Conclusion and Recommendation

SWERA work has demonstrated the immense potential of solar and wind energy in Kenya. Investors, planners and users will fond this document and the National Solar and Wind atlases important in making decisions pertinent in their applications. The planners will for example fine the solar direct normal irradiance maps and the wind maps useful in identifying areas for detailed feasibility studies and also identify areas for a wider range least cost power development.

The wind investors on the other hand will find the report useful in identifying the areas for investment without wasting more resources in pre investment studies.

An analytical toolkit using the arcview platform will help users to interactively engage with maps and process the maps further to details needed.

In order to have a full interpretation of the maps and an in depth understanding of some of the analysis carried out in this report, It is highly recommended that further reading be done especially on arcview, RETScreen software notes and technical briefs , notes and references on solar energy and technologies and wind energy and its related technologies

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