# Energy system assessment and modeling of a potential future energy system on Lamu Island, Kenya

*Master thesis within the Sustainable Energy Systems program*

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A case study relevant for many regions with similar climatic conditions

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# Abstract

The energy situation on Lamu today was mapped and visualized. Based on the predictions for future demand possible scenarios for energy sector was modeled and evaluated. The methodology shows a simplified picture of the energy sector and is based on many assumptions and mainly aim to show what possibilities there are for Lamu Island to become for self-sustainable in terms of energy.

The current situation is that Lamu Island is very dependent on fossil fuels and woody biomass from outside the island for energy services, draining the local economy. A future Business-as-Usual scenario show how problems with current situation will increase if active measures are not taken. A 'Light Green' scenario demonstrates the effect of a few simple and easy actions are taken. The 'Deep Green' scenario predict what kind of investments and land use changes could be required in order to make Lamu Island energy self-sufficient.

Other environmental threats was also investigated and it was found that the most urgent issue on Lamu is fresh and waste water system, which will soon have large economic effects if not addressed. The nature of the problem is investigated and possible solutions in term on increased rain water harvesting, reduced fresh water consumption and improved waste water treatment are investigated.

Reducing the outtake from the Shella aquifer and better waste water management in Lamu town is required. Water, food, waste and energy are however interconnected systems why reduced fresh water use, better waste water treatment and energy efficiency improvements require combined solutions. These are reuse of waste water for irrigation and fertilization. Further it assist in removing use of firewood and charcoal in traditional stoves which is important for three reasons; health impacts, low energy efficiency and the global warming effect of the soot they emit.

Energy sector governance of the Republic of Kenya is briefly analyzed and evaluated. Certain policies such as lack of grid feed-in with net charge system for households and design of the power producer Feed-in-Tariff system are inhibiting renewable energy investments and thus also sustainable development on Lamu.

The goal is to provide material that will be useful for the governors and companies in order to take action and make decisions that will improve the energy, environment and economy future of Lamu Island.

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## Acronyms

AD: Anaerobic digestion

CBO: Community Based Organization

CDM: Clean Development Mechanism

GHG: Green House Gas

GWh: Giga Watt Hour

ICT: Information and Communication Technology

IPP: Independent Power Producer

KACA: Kenya Anti-Corruption Authority

ksh: Kenyan Shillings (1 USD = 83 ksh)

KPLC: Kenya Power and Lighting Company

kWh: Kilo Watt Hour

LPG: Liquid Petroleum Gas

MDG: Millennium Development Goals

NEMA: National Environment Management Authority

NGO: Non-Governmental Organization

PE: Poly Ethylene

PET: Polyethylene Terephthalate

PHES: Pumped Hydroelectric Energy Storage

PP: Poly Propylene

PPA: Power Purchasing Agreement

PVC: Polyvinyl chloride

UN: United Nations

USD: United States Dollars

TWh: Tera Watt Hour

## Preface

We humans have an incredible capability of adaptation, from the Inuit communities of the Arctic to the Tuareg of Sahara, we manage to make a living in the environment we find ourselves in. This capability comes partly from the unique creativity and drive for improved living conditions of our species. Since we have been successful in this and reached an impressively large number of individuals on this planet there have also been negative side effects of these skills. The modern globalized civilization has transformed the surface of earth on such a scale that it is now relevant to speak of new geological age; the anthropocene 'age of human being'. This transformation can be seen in the earth biodiversity as the number of species now extinct because of human activities is approaching levels of previous ice ages or major meteorite collisions. We are even threatening the future of our own kind by disturbing ecosystem services that are essential to our living. Disruptions on the nitrogen cycle, emissions of carbon dioxide and other greenhouse gases and soil degradation are some of the most challenging examples.

In Lamu, the target of this thesis, the most urgent threat is destruction of fresh water reserve by saline and nitrate contamination due to high discharge rates from the wells and inadequate sewage treatment. Sadly there are several examples of human settlements that did not see the ecologic impact of their life style and habits in time. The classic example would be the people of Easter Island in the Pacific where extensive deforestation caused a collapse of society as ecosystem services where lost. Manda and Pate islands in the Lamu Archipelago have experienced severe economic and social decline partly due to salinization of wells, with such serious examples next door one could expect that the community of Lamu would be fast to react now. As a matter of fact the technical report that unveiled the graveness of the current situation was provided to local and national policy makers already in 2008, four years earliear than this present study, and still no measures have been taken to improve the situation. But who am I, or anybody in the globalized world, to blame them. We have known about the possible consequences of greenhouse gas emissions for at least a couple of decades, and still emissions are increasing.

Electrification is an important step towards a modern energy system. However, it is good to keep in mind that electricity does not satisfy any human need in itself. Electricity on the East African coast was actually introduced long ago:

> "The first steps to use electricity to light up the night skies in the eastern parts of Africa were taken by Sultan Seyyid Bargash bin Said bin Sultan of Zanzibar in 1881. The Sultan, inspired by his travels to Europe, sought to replace the earlier elaborate illuminations of his palace and nearby streets by oil lamps with light of a different kind. He did this by installing a steam-driven electric generating plant on the Zanzibar waterfront. This plant was the first of its kind in Africa and, indeed, was quite advanced by the standards of the day." (1)

An Island is naturally a rather isolated system; it is therefore in a way simpler to analyze it. There is a good possibility of building on a sense of community in working towards a uniting target. This has been adopted by islands Samsö of Denmark and El Hierro of the Spanish Canaries Islands. Both have departed of ambitious paths to become self-sustainable of energy. Islands may become the catalysts of renewable energy systems development. What they really show is that if there is a will there is a way, break the chains of fossil fuel dependency. For me, the author of this thesis, the journey to Kenya was a way of showing this to myself. I started pedaling on my bicycle from Trondheim in Norway in the last days of June and after many new found friendships, some adventures and a few aches here and there, I arrived in Cairo in early October. From there I had to take a flight to Nairobi though, could have made it all the way had I have had more time. In Kenya I had the opportunity of doing some more travels on the bicycle in the highlands and on the coast. In the end it was a great experience, demonstrating for myself and maybe some others too, that the world is not that big, that we can travel long distances without fossil fuels and that challenges can be overcome.

I would like to thank a lot of people for making this thesis become a reality: My supervisor Germán Maldonado at Chalmers for good support and inspiration, regarding energy systems, and other aspects of society and life especially in developing countries. Assistant professor Erik Ahlgren for believing in what must have seemed to be a slightly crazy endeavor. Fredrik Kronhamn that made the journey possible after some initial problems. Magnus Johansson my compadre on the roads of eastern Europe. On Lamu I received support and assistance from Paul and Christina Aarts, they are a great resource for the island. Mohammed Mwenje helped me very much even though I had given him no notice of my project. Mama Esther and Mama Asha both helped me get hands-on understanding of the challenges on the island. Mohammed Juma, for good friendship. Coach Satan and Laura Alonso Canal for keeping me happy and sane during the final stage of the long journey. Many more friends found on the road, in Kenya and on Lamu, thank you!

A final urge to the people and institutions with influence on the future of Lamu; your home is something of a paradise, learn from history and current research in order to develop and adapt before it is too late.

Göteborg August 2012
Dan-Eric Archer

# 1. Introduction

## 1.1. Goal

The aim of this thesis is to suggest a tool for analysis and studies in developing countries. Maybe this will help local policymakers, investors and companies, assisting them to achieve a sustainable development for the island of Lamu and the region. The format is intended to be informative and educative as better knowledge about available technologies and their profitability will increase local activities in these sectors. Target group is also NGOs working towards sustainability on Lamu and also other locations with similar conditions. Providing them with information can inspire them into involving in activities and provide foundation for decisions when choosing between projects.

## 1.2. Scope

A significant part of the thesis is investigating of the current energy demand; electricity demand curve, transportation fuel and cooking habits are key data. Further local conditions of environmental importance investigated are solid waste handling, waste water treatment, water availability and agricultural situation. Energy sector governance of the Republic of Kenya is briefly analyzed and evaluated. Certain policies, or lack of them, can be inhibiting renewable energy investments and thus also sustainable development on Lamu. The perspective is broad and does not include in-depth investigations for any aspect but rather intend to provide adequate information about a wide range of issues in order to fulfill the stated goals. Cost-effectiveness of selected technologies is not investigated in depth; only rough estimation of investment costs is mentioned. In order to provide reliable economic projections significantly more investigatory work has to be but in which was not possible within this thesis.

## 1.3. Methodology

Input of information about conditions on Lamu is to a large extent interviews made by the author during January and February of 2012. These were in some cases qualitative, for example investigating cooking fuel use, but also partly qualitative, in order to get a feeling of how things function on the island, what the general mentality is. Usually interviews were 20-40 minute dialogues where questions were adapted to the person being interviewed and during which follow-up questions were improvised based on answers. In total these where 32 interviews though some of more brief nature. A lot of information also comes from a study made by Haroun Kombo during March 2011 by the initiative of the author in collaboration with the Swedish NGO; Ingenjörer Utan Gränser, (2). Data of statistical nature as well as information about governmental policies have also been retrieved from a number of public documents.

The examples of activities with good potential of creating sustainable development chosen to be investigated further are the ones found being most urgent and having largest potential benefit as estimated by the author. One could most probably find arguments that there are other aspects or technologies more important or appropriate. The knowledge about technologies themselves has been acquired through academic literature studies and in some cases contact with commercial companies.

The three future scenarios, business-as-usual, light green and deep green, each has a composition of energy sources and technologies for energy conversion that was chosen by the author based on criteria listed in respective results subchapter. The construction of the scenarios, as well as the current system modeling, is made by connecting corresponding energy sources, carriers and end use activities with each other into complete energy supply chains. As an example, one such supply chain is Fuel oil -> Lamu Power Station -> End users (hospital and LAWASCO; oil press and bakery; schools; restaurants; hotels; other commercial and domestic).

During the modeling of current energy system as well as possible future scenarios, much estimation had to be made in order to get a full spectrum of energy related issues into the scenarios, every link in each supply chain was not known. What is empirical data, its reliability, and what is estimation, as well as how these estimations are made, is described in chapters 'Current energy system' and subchapters of each renewable technology. The economic data for each scenario are not complete or accurate and only serve to show the order of magnitude of the investment required for new generating or processing capacity included in each scenario.

More sophisticated modeling that will create scenarios calculated based on economic conditions and certain policies could be made using various software tools such as LEAP rather than qualified intuition as is the current case. The opinion of the author is however that a greater benefit would be created if this effort is spent on actual implementations on the ground.

## 1.4. Development and energy

What is development? This is the first question that needs to be addressed. One of the most established definitions is the UN millennium development goals (MDGs):

- Eradicating extreme poverty and hunger
- Achieving universal primary education
- Promoting gender equality and empowering women
- Reducing child mortality rates
- Improving maternal health
- Combating HIV/AIDS, malaria, and other diseases
- Ensuring environmental sustainability
- Developing a global partnership for development (3)

Secure energy supply is, as seen above, not a goal in itself but rather a mean to achieve MDGs. For example; access to electricity can provide light in the evening that enables children to do their homework, assisting in the achievement of universal primary education. It is however important to keep in mind that electricity is often more likely to be used for a TV showing soap operas or European leagues football than for stoic academic during late nights or value adding industrial activities studies. The MDGs have therefor been supplemented with key recommendation points to priority energy interventions which national governments should take to support achieving the MDGs at the national level:

1. Place the issue of energy services at par with other MDGs.

2. Adopt legal and regulatory frameworks that will provide incentives for effective partnerships among government institutions (including local governments), private-sector utilities and other operators, and community organizations.
3. Improve the affordability, availability, and safety of cooking fuels and practices.
4. Adopt strategic, institutional, and financial measures to ensure wider access for households and small businesses in urban and peri-urban settings to services such as illumination and power, information and communication technology (ICT), refrigeration, and other beneficial uses.
5. Adopt measures to ensure reliable electricity supply to households, businesses, public institutions, commercial establishments, and industry.
6. Provide access to mechanical power (for water lifting/delivery systems and agro-processing) and electricity for public facilities (health clinics/centers, schools, government offices, and community centers) in all rural communities.
7. Take a flexible approach to selecting from a wide range of technologies as well as a wide range of institutional structures for the delivery of energy services.
8. Develop energy infrastructure and institutions that directly benefit women and the poor.
9. In order to develop and rapidly scale up energy services, enhance human capacity through energy-related education, training, and research.
10. Incorporate the cost of energy service delivery needed to support the achievement of the MDGs into all national MDG strategies (4).

'Sustainable development' is a slightly different concept that emphasizes the future more. "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" is a famous citation from an early and important text on the topic, (5).

Swedish expert on international economics and development theory, Stefan de Vylder, states following:

> "In order to achieve development there has to be a reasonable balance between different categories of resources, or what could be called capital. A breakdown of the concept capital could lead to following entities:
>
> - *Natural capital*; natural resources – arable land, rivers, minerals and such. It is difficult to imagine any commodity not dependent on any form of earth natural resources.
> - *Financial capital*; money – needed to exchange one form of capital for another. Financial capital can be used for consumption or investment, or payment of debts. [and is a market in itself]
> - *Directly productive capital*; or means of labor, could be the name for machinery any such things that assist the human to make products or services.
> - *Infrastructural capital*; are useful things like roads, harbors, bridges, sewage systems, airports, telecommunication systems etc.
> - *Human capital*; knowledge and skills that enable the human to use nature and technology for making products and services.

- *Institutional capital*; a scarce commodity in many developing countries. Good institutions could be anything from democratic parliament and free press to uncorrupted financial authorities, competent national statistical institutions and well-functioning tax collection, to mention a few examples.
- *Social capital;* is the invisible glue that keeps societies together." (6)

When working with development and energy issues it is important to look at a bigger socioeconomic perspective of this mainly infrastructural capital we are often talking about. A lesson to be learned from the electrification of Sweden is that the greatest benefit may actually have been, not as much the electricity distribution system itself but the creation of domestic industrial knowledge and capacity through companies like Asea, (now ABB) Vattenfall and its precursors, (7). Economic incentive for electrification has seldom been household demand but instead industrial and commercial since this is where the volume is high enough (8). When large infrastructural projects have been undertaken in developing countries by initiative of the World Bank, the IMF or more recently various Asian investors, foreign human capital have often been used. One example is how Swedish companies started building electricity infrastructure in Congo, at that time Zaire, around 50 million SEK was borrowed president Mobutu in an unsuccessful attempt of electrifying the country (9). Creative accounting did in 2011 manage to make the debt relief of this loan, with accumulated inflation and interest, become a 980 million SEK income for Sweden, (10).

Finally, some perspective it is important to keep track of orders of magnitude:

> "Achieving the MDG Energy Vision will require a substantially accelerated delivery of energy services to the poor of the world. Still we are not talking about a lot of energy. The total amount [of energy to achieve the MDG Energy Vision] is only equal to about 900 TWh annually, comparable to the amount of energy Sweden consumes in 18 months." (11)

## 1.5. Energy systems theory

Energy is a physical entity that cannot be created or destroyed but merely transformed. In energy system analysis the elements in society and nature that have impact on the energy are categorized and their internal relationships clarified. Energy forms found in nature that have not been subjected to any conversion or transformation process are called *primary energy*. It is energy contained in raw fuels and other forms of energy received as input to the energy system. They can be non-renewable or renewable. This thesis focus on renewable sources of primary energy since this is the only category that can be in the energy mix of a long term vision for sustainable development. However, there are many examples of when also renewable energy technologies have been implemented with significant negative impacts; every new plant or practice has to be evaluated individually, renewable does not guarantee sustainable. It is also of great importance not to look solely on impact in form greenhouse gas emissions but also a range of aspects like acidification, eutrophication, toxic emissions in air, soil and water, biodiversity and resource depletion. Further the concept of sustainable development also includes aspects economic and social sustainability that need to be taken in account besides the environmental.

Energy can also take the shape of carriers that are to varying extent are suitable for providing the services which the users are interested in. These are categorized as *secondary energy*. Hydrocarbon fluids are dominant in the transport sector where they also can be considered the most suitable alternative, at least with the infrastructure of today, thanks to high energy concentration. Dominant source of hydrocarbons are fossil deposits of petroleum and gas which is transformed into natural gas, LPG, petrol, diesel, kerosene, heavy oils and more products. For many developing countries the import of fossil fuels causes a relatively large loss of financial capital from the economy. Fuel imports share of GDP for Kenya is about twice that of Sweden (12). Renewable hydrocarbon fluids, biofuels, are primarily derived from biomass. Different type of biomass can through refining processes be converted into a variety of biofuels, Figure 1 (13).

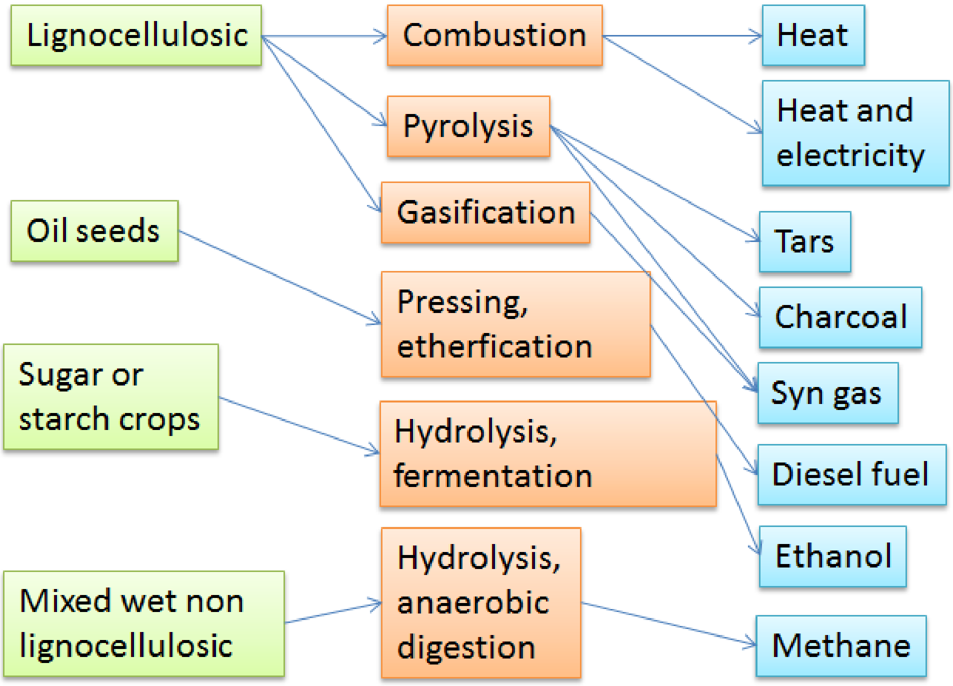


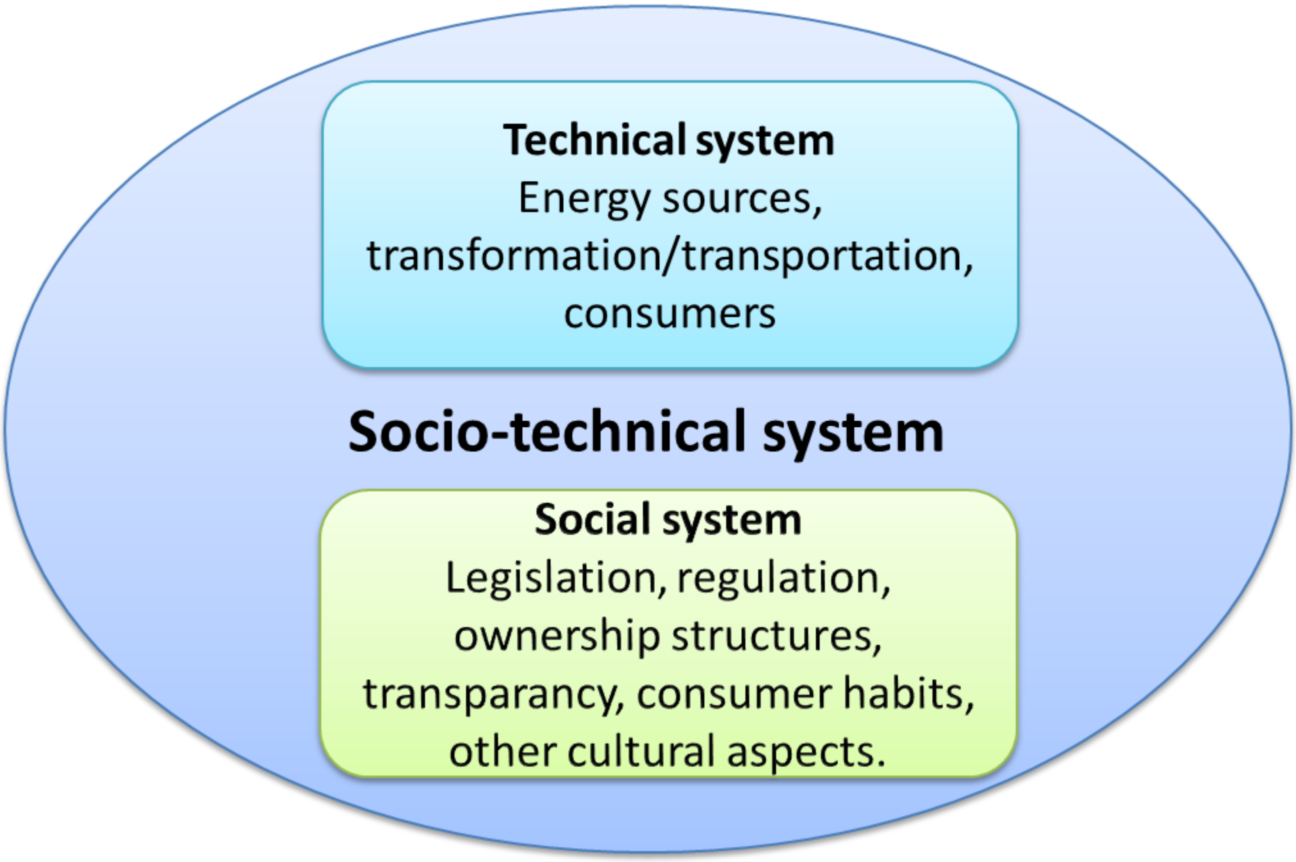

**Figure 1 Examples of biomass to bioenergy conversion options.**

Solid fuels are in many developing countries the main fuel for cooking stoves while electricity generating plants are in some regions large consumers of solid fuels, fossil and renewable. Common cooking stove fuels are unprocessed firewood, charcoal or fossil coal. Globally 3 billion people rely on solid fuels for cooking. Many of these, especially in rural areas, have primitive stoves causing unhealthy indoor air conditions causing annually over two million deaths in respiratory diseases (14).

Electricity is an energy carrier with the special characteristic having to be consumed at the same moment as it is produced unless storage in the form of batteries or other solutions are installed. Electrification seems to have positive socioeconomic impact on the MDG in a variety of ways, for example lighting for educational institutions, increased economic growth and modern medical equipment (15) (16). According to research it does not however initiate development by itself but stimulate development already taking place (17).

The third level of energy is the service that is actually provided by it which we will call *final energy use*. Primary energy, energy carriers and final energy use are components of the technical system which is a subsystem of the whole energy system that should also include social aspects such as legislation, regulation, ownership structure, consumer habits and culture. This thesis focuses mostly on the technical part of the energy system of Lamu. However, any implementation of suggested technologies must be made taking the whole sociotechnical system account.

> "…it is difficult to change the direction of large electric power systems – and perhaps that of large sociotechnical systems in general – but such systems are not autonomous. Those who seek to control and direct them must acknowledge the fact that systems are evolving cultural artifacts rather than isolated technologies. As cultural artifacts, they reflect the past as well as the present. Attempting to reform technology without systematically taking in account the shaping context and the intricacies of internal dynamics may well be futile. If only the technical components of a system are changed they may snap back into their earlier shape like a charged particle in a strong magnetic field. The field must also be attended to; values may need to be changed, institutions reformed, or legislation recast." (18)




It is also interesting to distinguish between fundamental needs and demand created 'artificially' by the market. In many large cities today one could say that there is a need for less energy use in the transport sector, changing cars for bicycles and public transport would improve health by improved air quality and physical activation of its inhabitants, it would make transports more time efficient thanks to reduced congestion. Large part of the world today, both in so called developing and developed countries, are built into a system of created needs; some kind of institutional and behavioral trap that becomes a very real problem when energy prices today are rising rapidly due to increasing demand and stagnant supply. Not to mention all the environmental degradation related to high energy consumption. It is important that authorities are active informants on effects of life style and habits also adopting policies to avoid these traps. On Lamu an example is the donkeys doing most of heavier transports on Lamu, no cars are needed, and neither is there much desire for it. (19)

# 2. Background

## 2.1. Kenyan history and culture

There is not much written account of pre-colonial history of the lands northeast of Lake Victoria, today known as Kenya. The dominant ethnic groups of today are of Bantu and Nilot origin. The Bantu peoples include Kikuyu, Kamba, Luhya, and Meru. Their languages are related to those spoken in what today is Niger, Congo and between. They came to East Africa about two thousand years ago and have a history of being skilled farmers (20). The Nilotic peoples are Kalenjin, Lou, Maasai and Turkana. As the term Nilotic suggests their origin is area of the Nile, more exactly the land that today is South Sudan. They have a common tradition of being pastoralist but the various tribes adopted to regions they settled in; the Lou being farmers and fishermen by Lake Victoria, the Kalenjin farming the fertile lands of western Kenya, the Maasai and Turkana, living on more arid lands, keeping more of a nomadic pastoralist lifestyle (21). The Cushitic peoples came from the north, todays Ethiopia and Somalia, and are mainly pastoralist herdsmen (22). They consist of tribes Somali and Oromo. Somali is the main group and also the name of their language. It was more than 2000 years ago since members of this ethnic group started coming south but has been ongoing, especially in periods of draught or conflict in the traditional land. Because of the last 30 years history of violence in Somalia there are now many Somalis living under bad humanitarian conditions in refugee camps such as the one at Dadaab (23). Many Somali communities have lived in Kenya for generations and are known to be successful entrepreneurs. The coast of Kenya (as well as Somalia and Tanzania) was for a long time dominated by Arab people, mainly Omanis, which created trade centers that became cities (24). A mix of Bantu and Arab culture became what is now known as Swahili, a language and group of tribes such as Giriama and Bajun. Swahili is spoken all over East Africa, at least as a second or trade language. Though only mother tongue few tribes in Kenya it is the official state language together with English.

From the arrival of Vasco da Gama in 1498, the next 200 years was dominated by conflicts between the Portuguese and the Arab sultans. From the early 18$^{th}$ century the Portuguese are leaving and another period of calmer Arab rule begins. During the 19$^{th}$ century an increasing number of missionaries arrive to the region, and after them adventurers with economic interests. In 1885 a protectorate named British East Africa is established. During early 20$^{th}$ century an increasing amount of British and Indian settlers are arriving. The railroads of today's Kenya are built. There is during this time severe segregation and suppressing of the native African population. They are forced to live in certain reserves, 'paying hut taxes' and are not allowed to grow tea and coffee which proves to be profitable for the colonizers. During several years of the fifties the Mau Mau rebellion is fought between groups of the Kikuyu community and the British and loyalist Africans. Though the conflict was relatively settled when the general pressure on Britain to let go of governance led to the Kenyan independence on 12$^{th}$ December 1963 it still had an impact when independence was gained. First president, and still regarded as the founding father of the nation, was Jomo Kenyatta, previously imprisoned as a Mau Mau rebel. Since independence Kenya gained reputation as a positive example of post-colonial nation building. There where however causes of disagreement within from the start. Many communities felt that Kenyatta was favoring his own ethnic group, the Kikuyu, when land left by or confiscated from British settlers where distributed back to Kenyans. After his death in 1978 the vice president Daniel Arap Moi became president. Moi was from the Kalenjin community from west of the Rift Valley and now was the time when his community was favored, at least according to many of the others. All forms of corruption were present both during Kenyatta and Moi. Up to 1991 only one political party was allowed but this then changed thanks to internal and external pressure. It was however not until the 2002 election when the ruling KANU party of Moi was defeated. The winning Rainbow Alliance let by Mwai Kibaki had promised to deal with corruption and ethnic conflicts. However there have been reports (25) showing corruption not decreasing despite installation of the Kenya Anti-Corruption Authority (KACA) and many not from the presidents Kibaki's community, again Kikuyu, will say that ethnic inequalities have increased.

After the general elections in late 2007 there were ethnical conflicts between mainly Kikuyu, backing the sitting president Mwai Kibaki, and other communities like Kalenjin and Luo, backing Raila Odinga. Kibaki was declared winner of the elections though the opposition leader Odinga had been clearly ahead in previous polls. Many claimed results been falsified and refused to accept the outcome by violent protests that ended up in what could be called a small civil war (26). In late 2011 five people were charged for various crimes by the International Criminal Court situated in the Hague due to events during the post-election violence; Former Minister of Higher Education, Science and technology William Samoel Ruto, Head of operations at Kass FM in Nairobi Joshua Arap Sang, Member of the Parliament Henry Kiprono Kosgey, Former Head of the Public Service Francis Kirimi Muthaura, Deputy Prime Minister and former Minister for Finance Uhuru Muigai Kenyatta (27). Despite of ambitious efforts to normalize relations between ethnic groups by for example the Kenyan National Dialogue and Reconciliation group there are significant distrust between communities of the central province, mainly Kikuyu, and other ones dominant in western and coastal provinces.

Nairobi is the trade hub of East Africa, weather it is Somali pirate loot, Congolese minerals or NGO project headquarters; it is the place where the deals are made. Signs of this are the increasing amount of gated communities with electric fencing and 24 hour security staff, high end shopping malls, found in the wealthier parts of the city. This said it is also obvious how income inequalities are growing since the situation in the slums, of Nairobi and other cities, is not improving much. Because of general increase in world market prices on base commodities like sugar, petroleum and chemical fertilizer, the situation for many poor people have actually deteriorated. Mombasa has the most important port of the region, Kilindini Harbour, handling about 20 million tons of gods (28). Though some there is competition with Tanzania's port in Dar Es Salaam and Kismayo port in Somalia, it can still be considered the main port of the region, serving the landlocked countries like Uganda, Rwanda, South Sudan and Burundi as well as the important resource rich Kivu region of Congo. During much of 2011 there was significant congestion in gods handling at the Mombasa port due to overload and/or mismanagement (29). The organization, by several nations defined as a terrorist group, Al-Shabaab, control the ports of Kismayo since 2009 and was also before this a safe haven for smugglers bringing goods and contraband into East Africa. This is a threat to Kenya because of loss of revenue, standard import tax is 42 %, as well as increased drug and weapon availability (30). Kismayo is also an export for large quantities of charcoal designated for mainly shisha smokers in the Persian Gulf and Arabian Peninsula despite some countries imposing bans, (31).

Near Mombasa is also where a recently built undersea telecom cable connects East Africa with the rest of the world. Expectation is it will generate activities such as call-centers and other ICT related business.

"The East African telecommunications and broadband market is undergoing a revolution following the arrival of fiber optic cables to the coast of Kenya in 2009 and 2010.This has brought broadband connectivity to the region and contributed to the expansive growth rate seen during recent years, on average by as much as 40%." (32)

## 2.2. Economy

The current government of President Mwai Kibaki has been maintaining liberal economic policies opening up for investors and it has seen some years of significant GDP growth. One does however have to keep in mind the effect of growing population in combination with inflation for the US dollar which means that the inflation adjusted GDP per capita has only increased marginally since the early eighties. There have also been improvements in infrastructure investments, roads being built in a more proper way nowadays. (not with only a 1 cm asphalt layer as during Moi presidency) Many infrastructure projects today are financed by Chinese capital and contracted to Chinese companies.

Tax revenues in 2010 amounted to USD 6.29 billion or almost one billion less than government spending in Table 1. This budget deficit was partly made up for by development assistance aid received though relatively large share of this was spent on debt service (33). Large share of the debt has been claimed to be illicit because the loans mostly ended up as private property of the presidents and cabinet members, and that the lenders where aware of this (34). Lending interest rate charged by banks on loans to prime customers within the country was 14.4 % and significantly higher for average citizen. When looking at the key economic figures it becomes obvious that incoming and outgoing capital does not add up. This is partly because public and private lending is increasing but this is not even close to cover the whole gap. This 'dark matter' is probably made up of revenues from unaccounted business with capital going in but mostly out of the landlocked countries South Sudan, Uganda, Rwanda and eastern part of the Democratic Republic of Congo. There is however no reference for this statement.

**Table 1 Some economic figures from year 2010**

| **Economic activities** | **Billion current USD** |
|---|---|
| GDP | 33,6 |
| Agriculture, value added | 7,1 |
| Manufacturing, value added | 3,2 |
| Industry, value added | 5,6 |
| Services, etc., value added | 15,5 |
| **Debts** | **Billion current USD** |
| IBRD loans and IDA credits | 3,2 |
| External debt stocks, total | 8,4 |
| Present value of external debt | 5,9 |
| Net bilateral aid flows from DAC donors | 1,3 |
| Debt service on external debt, total | 0,4 |
| **Import/export** | **Billion current USD** |
| Imports of goods and services | 12,2 |
| Exports of goods and services | 8,9 |
| **Inerest rates** | **Percent** |
| Deposit interest rate | 4,6 |
| Lending interest rate | 14,4 |
| **Income inequalities** | **Percent** |
| Income share held by lowest 20% | 4,8 |
| Income share held by highest 20% | 53,2 |

The import-export ratio is 2:1 and large share of this difference is oil imports, Figure 2, though refined oil products are also sold to other countries in the region. The most important export commodities are tea, cut flowers, coffee, petroleum products, fish and cement see appendix, (35). Main industries are small-scale consumer goods (plastic, furniture, batteries, textiles, clothing, soap, cigarettes, flour), agricultural products, horticulture, oil refining; aluminum, steel, lead; cement, commercial ship repair and tourism. Majority of population lives of subsistence farming (36).

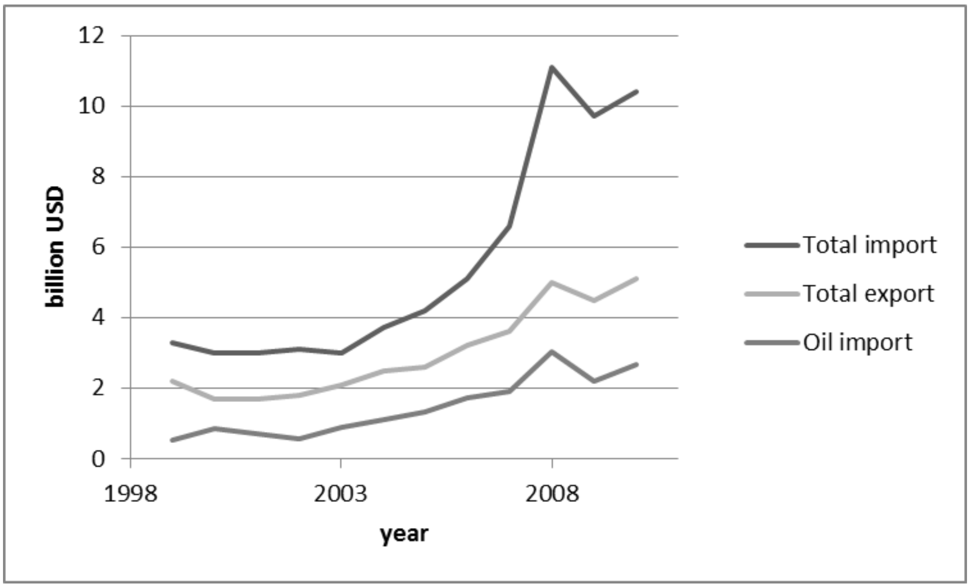



**Figure 2 Import, export and oil import is billion current USD**

## 2.3. Energy

Energy use in Kenya is dominated by solid biomass fuel; this is collected firewood and locally made charcoal used mainly for cooking but also space heating in the colder highlands. Around 75 percent of total primary energy use goes under this category though it is difficult to have precise data since the mayor share of it is collected by an informal sector, households themselves or small businesses that are not registered or paying tax (37) (38). In year 2000 the consumption of wood fuel was 34.3 million tons while the estimated sustainable supply is only 15 million, in other words forests are being cut down faster than the regrowth. Further, the wood fuel demand is estimated to grow at 2.7% per year while the sustainable supply at a slower rate of 0.6% per year (39). In practice this means forest cover is declining, 6.1% or about 3467000 ha of Kenya is forested. On an average between this was reduced by 11 percent per year between 2005 and 2010 (40). The use of solid biofuels, especially with primitive stoves that are still common, create an indoor air pollution that cause many cases of acute respiratory infections. Traditional huts are often ill ventilated and it is mostly women and children, that spend a lot of time in the kitchen, that suffer from the smoke (41).

## 2.4. Electricity Sector

The Kenyan electricity market has a number of key stakeholders. The Ministry of Energy is the legislative authority with, according to website, vision and mission to:

> "[Provide] Affordable quality energy for all Kenyans. [And] To facilitate provision of clean, sustainable, affordable reliable and secure energy for national development while protecting the environment."

Kenya Power and Lighting Company Limited (KPLC) is the company that transmits, distributes and retails electricity throughout Kenya. It is a public company listed at the Nairobi Stock Exchange (NSE). The Kenyan government is the largest owner with slightly more than 50 percent of shares (42). Costumer billing is constituted of several parts: The non-fuel tariff for electrical energy is depending on consumption and type of costumer, domestic or commercial. Slightly odd is that for domestic costumers the price per kWh is actually lower at lower consumption; KSh 2.00 per kWh for 0-50 kWh per month, ksh 8.10 per kWh for 51-1500 per month, ksh 18.57 per kWh consumption above 1500kWh. For commercial customers the per kWh price also vary with consumption but not as much and not increasing with demand. There is also en interruptible of-peak option when all customers can buy electricity at a reduced cost. For all costumers there is a fixed charge of ksh 120 per month. On top of this there is a fuel charge which is basically a fuel cost average for the plants connected to the grid and compensated for transmission losses. There is a positive trend for transmission losses, during 2010 at 15.4 percent, down from 16.4 in 2008. Since nearly all fossil fuel is imported there is an exchange rate factor on the fuel charge, a rather large share of total electricity cost based on primarily diesel fuel price, as well as an inflation adjustment. Finally there is VAT of 16 percent on the total price, a fee for the Rural Electrification Program at 5 percent and a ksh 3 per kWh levy that go to the Energy Regulatory Commission.

During the time period January 2009 to January 2012 the total electricity price for a common costumer has varied between ksh 14.5 and 22.7 per kWh for a domestic costumer with medium (51-1500 kWh/month) consumption (43). In an international perspective this is a medium electricity price. With the last two year average price being USD 0.21 per kWh in Kenya, is about the same as in Sweden, almost double that of USA and just over half of the price per kWh in Denmark (44).

Owners of generating capacity, KenGen or IPPs, has to negotiate a Power Purchasing Agreement (PPA) with KPLC to determine what fixed price the produced electricity will have. These contracts are usually for 20 years but are also often renegotiated before end (45). Current plants and their capacity are listed in Table 2.

**Table 2 Plants selling electricity to KPLC with installed capacity and year 2010 generated electricity**

| Plant | Type | Installed capacity (MW) | 2010 generation (GWh) | Plant factor |
|---|---|---|---|---|
| *KenGe:* | | | | |
| Tana | Hydro | 20 | 50 | 0,29 |
| Kamburu | Hydro | 94 | 408 | 0,50 |
| Gitaru | Hydro | 225 | 802 | 0,41 |
| Kindaruma | Hydro | 40 | 191 | 0,55 |
| Masinga | Hydro | 40 | 201 | 0,57 |
| Kiambere | Hydro | 164 | 899 | 0,63 |
| Turkwel | Hydro | 106 | 455 | 0,49 |
| Sondu Miriu | Hydro | 60 | 364 | 0,69 |
| Small hydros | Hydro | 13,7 | 57 | 0,47 |
| Kipevu I | Thermal | 75 | 223 | 0,34 |
| Kipevu III | Thermal | 115 | 268 | 0,27 |
| Embakasi Gas Turb | Thermal | 60 | 1 | 0,0019 |
| Garissa & Lamu | Thermal | 8,9 | 23 | 0,30 |
| Other off-grid | Thermal | 9,1 | 21 | 0,26 |
| Olkaria I | Geothermal | 45 | 235 | 0,60 |
| Olkaria II | Geothermal | 1053 | 846 | 0,092 |
| Ngong | Wind | 5,3 | 18 | 0,39 |
| | | | | |
| *Independent Power Producer:* | | | | |
| Iberafrica | Thermal | 109 | 722 | 0,76 |
| Tsavo | Thermal | 74 | 368 | 0,57 |
| Mumias | Thermal | 26 | 87 | 0,38 |
| OrPower 4 | Geothermal | 48 | 372 | 0,88 |
| Rabai Power | Thermal | 90 | 394 | 0,50 |
| Imenti | Hydro | 0,3 | 0,4 | 0,15 |

Kenya Electricity Generating Company Limited (KenGen) is the largest electric power generation company in Kenya, producing about 80 percent of electricity consumed in the country. 70 percent of shares are owned by the government. The company has various sources to generate electricity ranging from hydro, geothermal, thermal (mainly Diesel) and wind. Hydro is the leading source, with an installed capacity of 766.88 MW, which is 65 per cent of the company's installed capacity. Main hydropower capacity is in the Tana river which is vulnerable to draughts. One can in Figure 4 clearly see how the severe 1999/2000 draught, affecting 4.4 million Kenyans, reduced the output from hydropower (46).

The planned investments future investments of KenGen (Table 3) include a lot of renewable energy installations but also a large coal (thermal) plant that will have a negative impact on $CO_2$ emissions. It also reflects the very large growth plans for the sector with plan for new capacity of 1395 MW until

2016 compared todays 1140 MW (47). The coal is to be mined in the Mui basin of the Eastern Province where only the first block to be exploited is estimated to hold 400 million tons of coal (48). This is enough to provide the planned thermal power plant with fuel for 250 years.

**Table 3 KenGen planned new capacity**

| Project | Type | Capacity (MW) | Status |
|---|---|---|---|
| Eburru | Geothermal | 2,3 | Commissioning in Nov 2011 |
| Muhoroni MSD | Thermal | 80 | Commissioning in 2013 |
| Sang'oro Hydro | Hydro | 21 | Commissioning in March 2012 |
| Ngong Wind I Phase II | Wind | 6,8 | Commissioning in April 2013 |
| Ngong Wind II | Wind | 13,6 | Commissioning in April 2013 |
| Kindaruma 3rd unit & Updating Unit 1&2 | Hydro | 32 | Unit 3 Commissioning in June 2012<br>Unit 2 Commissioning in December 2012<br>Unit 1 Commissioning in June 2013 |
| Olkaria I Unit 4&5 | Geothermal | 140 | Commissioning in 2014 |
| Olkaria IV | Geothermal | 140 | Commissioning in 2014 |
| Isiolo Wind | Wind | 50 | Commissioning in July 2013 |
| Marsabit Wind | Wind | 150 | Feasibility ongoing |
| Olkaria I Unit 6 & Olkaria IV Unit 3 | Geothermal<br>Geothermal | 140 | Commissioning in June 2016 |
| Olkaria IV Unit 4&5 | Geothermal | 170 | Commissioning in Jule 2016 |
| Kilifi Coal | Thermal | 600 | Commissioning in July 2016 |
| LNG | Thermal | 300 | Feasibility ongoing |

Individual Power producers (IPP) are companies selling power to the grid other than KenGen. There are currently four of them: Westmont, 46 MW gas turbine. Iberafrica, 56 MW diesel. Tsavo, 75 MW diesel. OrPower4, 13 MW geothermal. Rabai Power, 90MW diesel. In total 280 MW installed capacity (49) (50).

Kenya Petroleum Refineries Limited (KPRL) refines crude oil mainly imported from the gulf region for costumers without actually owning the petroleum product themselves. KPRL's main products include LPG, petrol, automotive gasoil, diesel, fuel oil and special products like bitumen and grease (51).

National Oil Corporation of Kenya (National Oil) is a distributor of petroleum products 100 percent owned by the Kenyan government.

Kenya Pipeline Company Limited (KPC) own and manage the petroleum pipeline network of Kenya. Currently there are lines from the ports of Mombasa to Nairobi and then onwards to Eldoret and Kisumo in western Kenya. 4.3 million cubic meters of products were transported through the pipelines in 2009 which is 93 percent of the total imports of 4.6 million cubic meters per year (52). Connecting to oil fields in Uganda and eastern DRC are proposed with an extension of the current pipelines to Eldoret and Kisumo. Preparatory work on a pipeline from the already developed oilfields of South Sudan to Lamu has already commenced (53).

Energy Regulatory Commission (ERC) is a regulatory agency responsible for economic and technical regulation of electric power, renewable energy, and petroleum sectors. This includes tariff setting and review, licensing, enforcement, dispute settlement and approval of power purchase and network service contracts (54).

Rural Electrification Authority (REA) was established by the Energy Act (55) to manage the Rural Electrification Program, REP. The authority has a substantial budget since 5 percent of all electricity sales in the nation are dedicated to the program. There is also plenty of activity, as of 18 January 2012, 3180 projects had been finished or initiated (56). Today only 15 percent of Kenyans have access to the national electrical grid with a breakdown of 51.3% and 5% for urban and rural areas, respectively (57).

Energy Tribunal (ET) is the authority to settle disputes within the energy sector.

Geothermal Development Company (GDC) is a 100% state-owned company, formed to develop electricity production from geothermal sources in the country. A formulated vision is to develop 5000 MW production capacity from geothermal resources by 2030. The company has gained some momentum and has today 200 MW installed capacity and another 500 MW planned to be ready by 2016 (58).

Kenya Electricity Transmitting Company (KETRACO) plan, design, builds, operate and maintain electricity transmission lines and substations of the Kenyan national transmission grid. It is 100 percent state-owned.

Electricity mix in the national grid of Kenya was for a long time mainly based on the hydro power in Tana River and diesel generators for remote, back up and peak load power. However, lately the share of geothermal capacity, with rather good load factor, has increased a lot and is a very interesting feature of the Kenyan energy sector. The share of diesel power has also increased, mainly from IPPs. The PPAs for these new diesel plants have been criticized for involving corrupt procedures and overpricing (59) (60) (1).

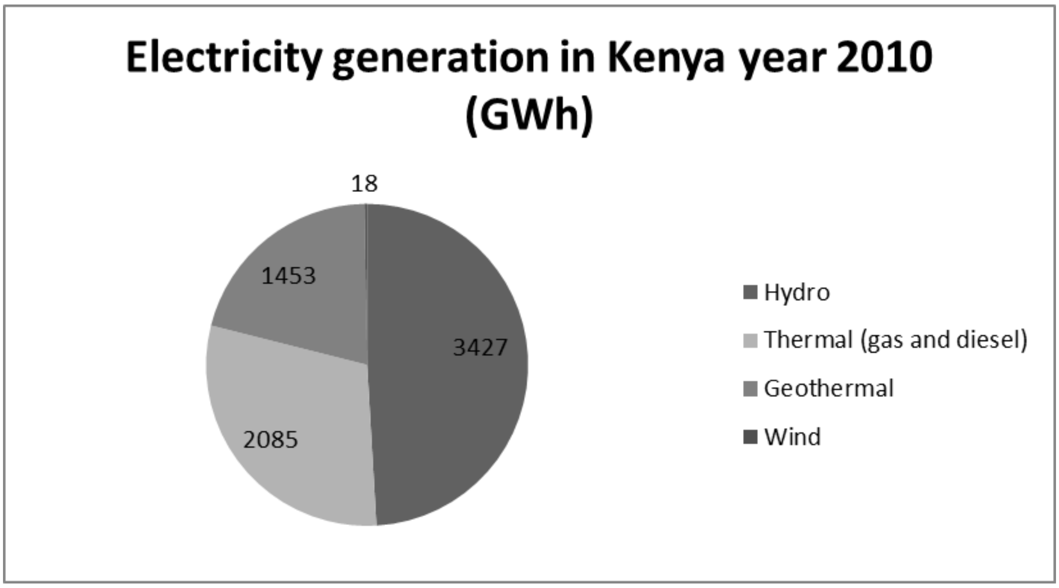



**Figure 3 Primary energy in Kenyan electricity mix.**

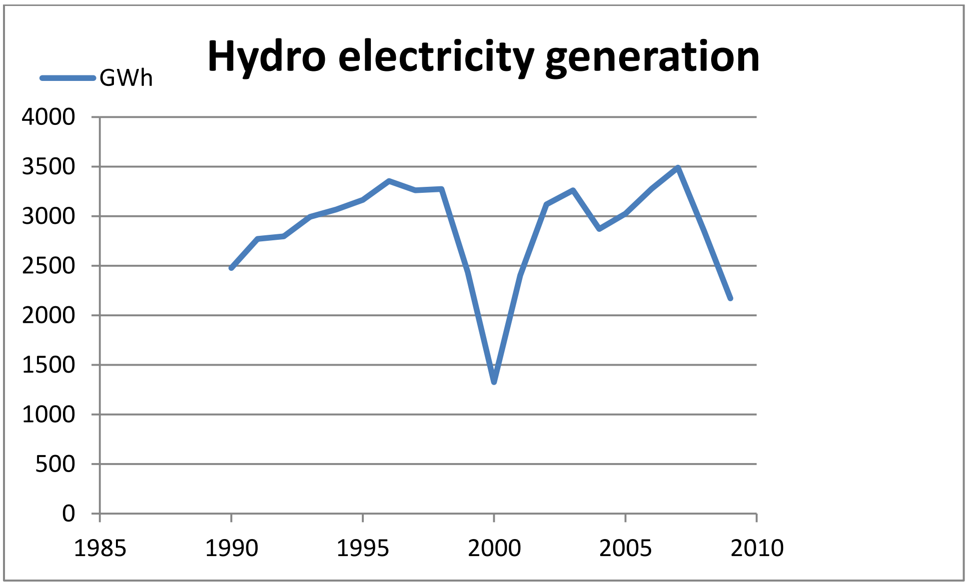



**Figure 4 Electricity generated from hydropower 1990-2009 where draught of year is clearly visible.**

There is today marginal import/export of electricity with Uganda and Tanzania that will possibly increase as higher capacity transmission lines are built. A 500 kV connection to Ethiopia under construction and will make possible import from the giant Gibe III dam that will have an 1870 MW generating capacity (61). It has however been strongly criticized by various organizations including UNESCO that in 2011 urged construction to be stopped until better investigation on the dams effect on Lake Turkana could be made, (62).

The only current wind generating capacity in Kenya is a 6x850 kW farm on top of Ngong Hills outside Nairobi. Wind energy has been used in Kenya primarily for water pumping since the beginning of the 19th century though use declined as diesel fueled pumps became cheap and available. More than 220 Kijito wind pumps have been constructed for use in remote areas.

Roughly 30,000 small (20–100 W) photo voltaic (PV) systems are bought per year by Kenyan households. Solar electric systems are a growing market that includes at least ten import and manufacturing companies, plus many related small businesses. In 2003, the cumulative sales were estimated to be in excess of 220,000 units (more than 4 MW). About 140,000 $m^2$, or an annual estimated output of 150 GWh, of solar thermal panels are in use for mainly drying of agricultural produce and water heating (38).

Extraordinary in the Kenyan electricity mix (Figure 3) is the large share of geothermal energy. The country is fortunate to have great geothermal resources mainly located in the Rift Valley. It is estimated that the Kenyan part of the Rift hold a potential of more than 4000 to 7000 MW of geothermal power capacity. The high load factor of geothermal plants, in Kenya around 95 percent, is uncommon for renewable energy sources and makes it good base load capacity (63).

## 2.5. Future

The Kenya Vision 2030 is a strategy with a goal to achieve large economic growth transforming Kenya into a newly-industrializing, middle-income country. Importantly it also aims to accomplish a high standard of living for all Kenyans in a clean and secure environment. Concretely is state that the

Millennium Development Goals (MDGs) should be reached by 2015. Infrastructure, including energy, is identified as one of the key areas of its implementation.

> “A key element in attaining Vision 2030, is reaching an average annual economic growth rate of 10 per cent between 2012 and 2030. This high economic growth will require modern, efficient infrastructure facilities to expand the productive sectors of the economy and improve access to markets. To upgrade the infrastructure platform, the MTP calls for rehabilitating the road network, upgrading the railways, improving urban public transport, and expanding access to electricity and safe water. In an effort to improve equity of opportunity, the overall program gives a special emphasis to expanding the access of the rural and urban poor to basic services such as electricity, water, and sanitation.” (64)

The 2030 vision include a projection of rapid growth in electric power demand:

> “The current electricity demand is 1,191 MW while the effective installed capacity under normal hydrology is 1,429 MW. Generation capacities from Hydro, Geothermal, bagasse (cogeneration) and wind are 52.1%, 13.2%, 1.8% and 0.4% respectively while fossil based thermal contributes at 32.5%. The peak load is projected to grow to about 2,500MW by 2015 and 15,000 MW by 2030.” (65)

It would maybe have been more interesting to envision the electric energy used instead of installed capacity. If applying simple exponential regression analysis to historical data of electric energy use in Kenya (Figure 5) nothing near the 12 fold increase, as for generating capacity in the Vision 2030, is achieved. However, the Vision also target a sustained economic growth of 10 percent, significantly higher than past 20 years average of about 4 percent, which would imply a significantly increased growth rate for electricity demand too. It is normal, for any country, that increase of energy demand decrease after a while of rapid increase; this cannot be seen in the planning of the Kenyan government.

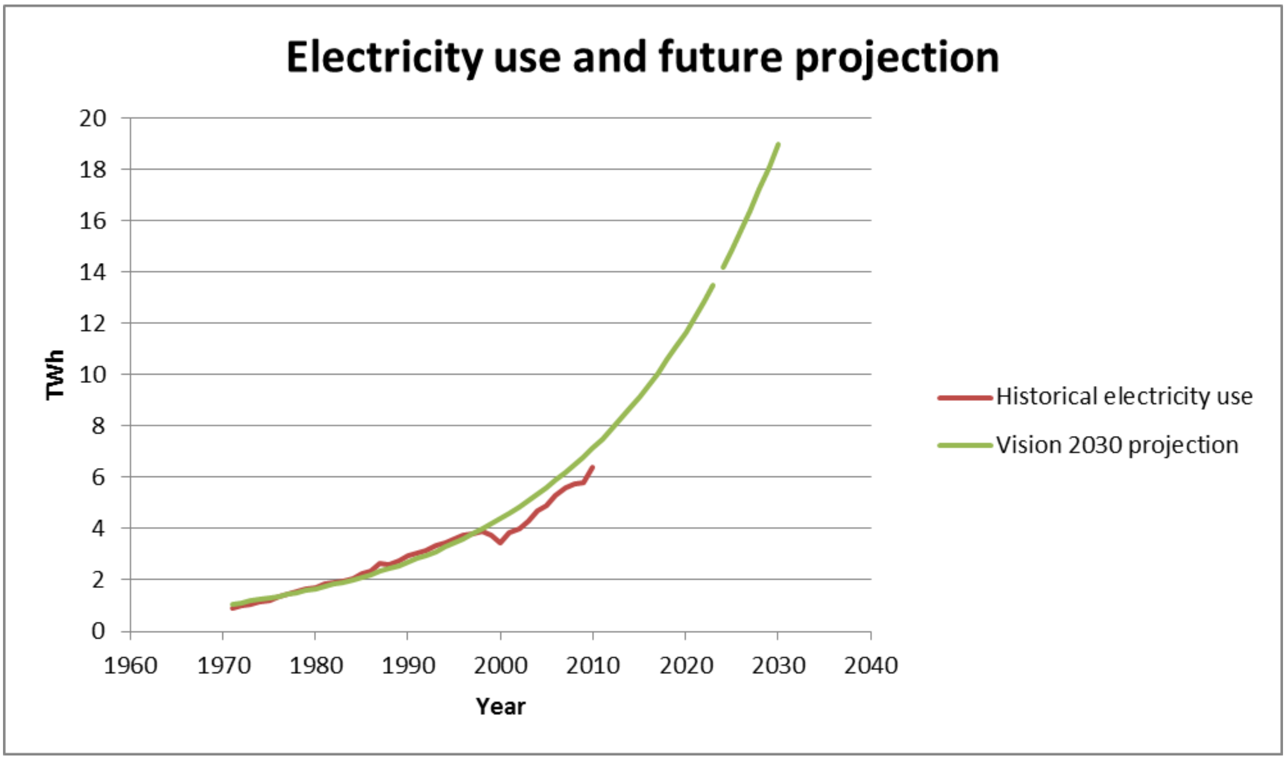



**Figure 5 Current and by the government projection of future electric energy demand in Kenya. Vision 2030 is basically an exponential regression analysis of the 1970-1998 historical data by the goverment.**

The government's intention to achieve the goals of the Vision 2030 are very optimistic but possible, Kenya is a country with rich in resources as solar irradiation, wind, biomass geothermal potential and various minerals. The location is strategic as landlocked petroleum and mineral rich nations need Kenyan infrastructure to export their goods. Despite of the violence of last election the country is politically relatively stable but ethnic tensions are a risk factor. The public sector rather well developed regarding administrative civil servants offices, though corruption is a big issue. Level of education is improving, especially since primary school fees were dropped in 2003. However, it is still not compulsory and many schools face severe lack of staff and material, not uncommon with classes of up to 100 pupils and 10 pupils per textbook. Another concern is growing income differences, within the more developed regions as central and western provinces, and between regions.

> "Within a country, the adoption of energy-using assets typically follows an S-shaped pattern: among the very poor, we see little increase in the number of households owning refrigerators, vehicles, air conditioners, and other assets as incomes go up; above a first threshold income level, we see rapid increases of ownership with income; and above a second threshold, increases in ownership level off. A large share of the world's population has yet to go through the first transition, suggesting there is likely to be a large increase in the demand for energy in the coming years." (66)

East Africa is most certainly below the first threshold mentioned in (66) but will surly at some point reach the second one where energy use growth decrease, this is, it seems not yet taken into account by the authorities within the energy sector of Kenya.

# 3. Lamu background

## 3.1. Introduction

Lamu district is one of the 46 districts in Kenya, located in the Coastal Province, just south of the border with Somalia. The district is organized into seven divisions, Figure 6. Lamu is also the name of the island where the town which can be considered to be the cultural center of the district is located; Lamu Town. Mpeketoni, on the mainland, is the other larger urban center of the district with a more agriculture based economy rather than tourism as Lamu Island.

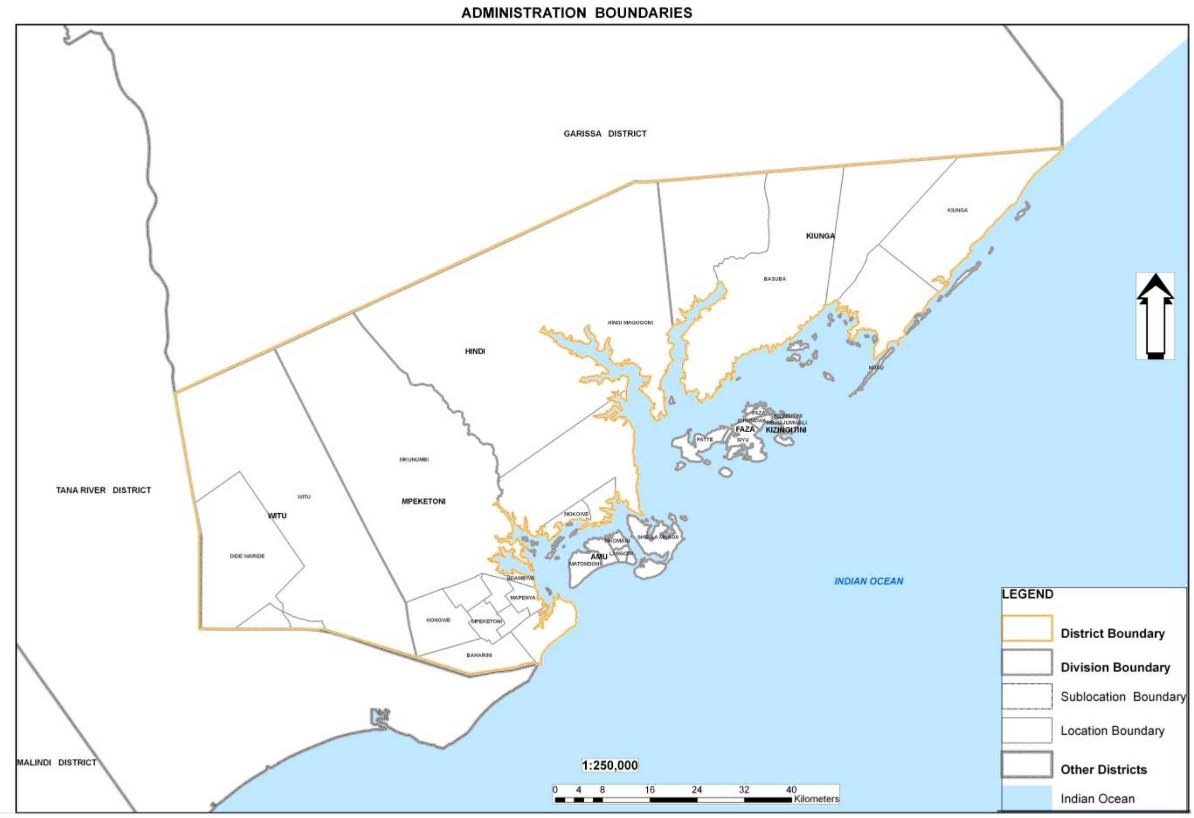



**Figure 6 Lamu district with divisions**

As the rest of the East African coast, Lamu was for a long period influenced by Arab, Portuguese and Indian traders, before the time of English colonization. The economy was for a long period based on slave trade until its abolition in 1907. Other traditional exports included ivory, timber, turtle shells and rhinoceros. Competition from the port of Mombasa significantly diminished Lamu's trade. During the second half of the twentieth century tourism has gradually restored the local economy. Contributing to the attention of tourists is the status as UNESCO World Heritage Site that Lamu Town received in 2001. As the best preserved settlement of Swahili culture, with unique architecture using materials as coral stone and mangrove timber. Special features are the jetty with its dhows, the donkeys, the courtyards and elaborately carved wooden doors (67).

Historically there have also been important cultural centers at neighboring Manda and Pate Islands. However, because of too high extraction rate of ground water, on both islands the wells turned saline and the large population could no longer be maintained. Today population there relies on water catchment from rooftops or djabias, (semi-underground tanks for water harvesting (68)) desalinization equipment and water transported there from other locations. Those who do not afford this do sometimes drink saline water.


**Figure 7 Areal image of Lamu Island with names and locations of some populated areas**

Lamu Island covers a surface of about 50 $km^2$ and holds a population of 22500 permanent residents plus a few hundred tourists depending on season (69). Main urban center is Lamu Town that, together with Wiyoni and other unofficial settlements in its perimeter has the majority of the islands population. Shella and estates on the seafront between Lamu Town and Shella are mainly high end hotels and villas owned by wealthy non-islanders. Kipungani and Matondoni are small villages mainly inhabited by local people. In the interior there are many shambas, (small farms) either larger estates with employed workers or subsistence farmers renting from land owners or cultivate unclaimed land without holding title deeds. The densely populated areas around Lamu Town consist of many buildings of poor quality without electricity, water or sewage access. Majority do not hold title deeds or building permits for their homes.

The climate is tropical; temperatures ranging from $23^{o}$ to $33^{o}C$. One long rain period from April to June and one short in November, but it does not rain every day during these and sometimes not at all. Average annual rainfall is 550 to 1100 mm. Air humidity is high. Soils are sand only or possibly loamy sand in some locations. Terrain is a mix of flat areas and sand dunes up to 20 m high. Most land is covered with some vegetation; bush, palms and some trees, though not dense since the water availability for plants is limited. East and north shores are covered with mangrove forest.

### 3.2. Lamu Port Project

There are long gone plans, and even initial construction taking place, to undertake a transport and communication corridor called 'Lamu Port-South Sudan-Ethiopia Transport' (LAPSSET). LAPSSET will consist of a standard gauge railway line, a port, a super highway, a regional international airport, a tourist resort, an oil pipeline, and a fiber optic cable constructed to link Juba and Addis Ababa with Lamu and the rest of the world (70).

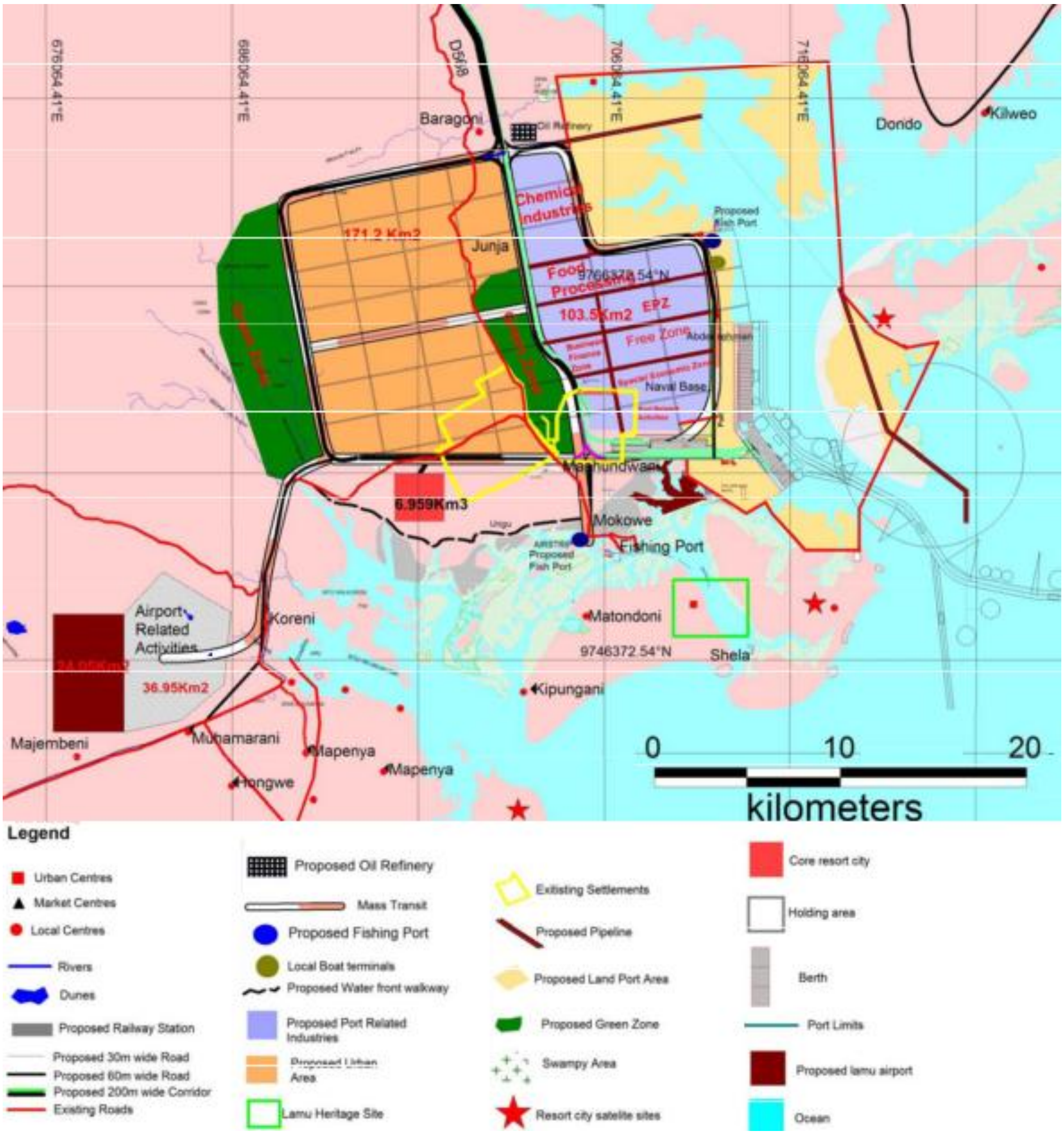



**Figure 8 Sketch of the proposed port project**

The port will serve Kenya, the East African Community, Southern Sudan, Ethiopia, the Central Africa Republic, DR Congo, Congo-Brazzaville and Chad. It is planned to become the largest port on the continent, with ability to handle post-panamax ships thanks to its natural 18 meters deep channel. The port project is estimated to cost $3.5 billion (64). The main consultants involved are Japan Port Consultants and BAC Engineering & Architecture Ltd.

The strategic background for the port is that the entire East African region can be considered to be a 'hotspot' for current oil and gas prospecting: Southern Sudan already have capacity of 375,000 barrels per day, though not producing much until conflict with (northern) Republic of Sudan is resolved or possibly the pipeline to Lamu finished (71). The Ogaden province of Ethiopia has 4 trillion cubic feet of natural gas or USD 85 billion at today's market price of natural gas reserves according to some sources (72). Uganda has (at least) 1 billion barrels oil proven reserves (73). Eastern Democratic Republic of Congo's Kivu district holds vast resources of coltan and other minerals and possibly also petroleum. Anglo-Irish firm Tullow Oil have announced oil discovered in the Turkana District of northern Kenya after test drilling in 2011, it is said to be a large find though not yet known how big (74). The Lamu basin itself also seems to have promising conditions for oil and gas exploitation (75) (76).

Within the LAPSSET corridor project there is also a plan to open the Tana River region for large scale irrigation projects. The Tana and Athi River Development Authority has already developed infrastructure to irrigate over 250,000 hectares of land along this corridor. Further, there are plans for a new dam which will allow for irrigation of an additional 200,000 thousand hectares. Some of the proposed agricultural development projects are:

- Multipurpose sugar cane based ethanol, power generation and sugarcane plant along the
- Sabaki-Galana river or in lower tana river.
- Sorghum and cassava based Bio-fuel production in Galana area
- Fruit production and processing plant in the Tana delta
- Horticultural production and processing in the upper Tana river and in with the water from the high grand falls dam
- Irrigated cereals production (maize, and rice) in the Tana delta
- Beef production in Laikipia area (77)

There is substantial local and international concern regarding the sustainability of the project. Environmental Impacts; Lamu is endowed with rich biodiversity and has some of the richest marine ecology on the Kenyan coastline with coral reefs and mangrove forests. To date, no Environmental Impact Assessment (EIA) has been carried out. The local initiative Save Lamu has the objective to inform about mainly negative social consequences of the LAPSSET project:

1. Community Participation; only a sensitization meeting with stakeholders has been carried out, none with the affected communities even though work has started.
2. Access to information; despite the scale of the project, there has been limited information provided to the people and local governance of Lamu.
3. Lamu is one of the poorest Counties in Kenya with a small population. The 2010 feasibility study predicts that the population in Lamu will increase to over 1.25 million over the period of construction. Because of this Lamu's unique cultures that form the core of its designation as a UNESCO World Heritage Site is threatened.

4. Land Tenure Insecurity; individuals in positions giving access to the project plans have been by doubtful methods obtained title deeds for land at the proposed development sites where locals have sometimes been living for generations without being able to acquire this (78).

Economically there are many large concerns, it is not certain how much oil is left in the field of South Sudan and the political situation is very unstable, there may be now oil extraction for long periods.

# 5. Current energy system

## 5.1. Electricity Supply

All of the electricity in the current local grid is produced in the Lamu power station managed by KenGen. The plant has six engines running on fuel oil with a total maximum power output of 2396 kW: (79)

**Table 4 Engines at Lamu Power Station**

| Model | Power | Inst. year |
|---|---|---|
| CUMMINS KTA 19 G4 | 400 kW | 1997 |
| CATERPILLAR C-18 | 500 kW | 2007 |
| CUMMINS KTA 19 G1 | 289 kW | 1989 |
| CUMMINS KTA 19 G1 | 289 kW | 1989 |
| CUMMINS KTA 19 G4 | 400 kW | 2001 |
| CATERPILLAR C-18 | 500 kW | 2007 |

The fuel oil for the station is delivered by road from Mombasa to Mokowe by truck. At Mokowe, the barrels are transported by boat to the power station. The boat can carry maximum of 80 barrels of 200 liters each per trip. Kenol Kobil is contracted for fuel delivery. There is an environmental risk of transporting fuel by sea by use of 200 liter drums. There is no jetty at the power station, so in order to bring the barrels to the shore they are simply thrown into the water and rolled up onto the embankment with ropes. For the maintenance of the plant is approximately ksh 46,000,000 annually. (80) More data of the power station are listed in Table 3 (81).

**Table 5 Lamu Power Station data**

| | |
|---|---|
| AVERAGE AVAILABLITY | 82,70% |
| AVERAGE SFC* | 0.258 Kg/kWh |
| TOTAL UNIS SENT | 6,971,142 kWh |
| TOTAL GENERATION | 7,049,894 kWh |
| INTERNAL USE | 35,743 kWh |
| FUEL USED | 2,123,224 LITRES |
| FUEL RECEIVED | 2,139,592 LITRES |
| OIL USED (LUBRICANTS) | 19056 LITRES |
| FUEL COST PER LITER | 103 ksh |

*Specific Fuel Consumption

These data give a specific electricity cost of about ksh 38.5 per kWh, not taking the plant depreciation into account, meaning that the annual electricity subsidy to the local Lamu grid will be in the vicinity of ksh 110 million.

The local grid is owned and maintained by KPLC who state that corrosion and falling poles are causing some blackouts but that it is more common with interruptions by the production side, KenGen. Independent Power Producers (IPP) would be allowed to sell electricity too but there are none on Lamu at the moment (82).

A connection to national grid is currently being built by KENTRACO:

- 96 km of a 220 kV single circuit line from Rabai to Malindi and a 220kV bay at Rabai and 220/33kV substation at Malindi;
- 116 km of a 220kV single circuit line from Malindi to Garsen and a 220/132/33 kV substation at Garsen.
- 108 km of 132 kV line to Lamu and 132/33 kV substation at Lamu.

> "A number of positive and negative anticipated impacts to the environmental and social wellbeing have been identified thus far. The route of the proposed transmission line crosses two major rivers: the Tana and Athi Rivers (Galana Sabaki) and as such, potentially significant impacts include the construction of corridors crossing aquatic habitats that may disrupt these watercourses and wetlands; and removal of riparian vegetation. It is important to note that sediment and erosion from construction activities and storm water runoff may increase turbidity of surface watercourses. The proposed route also passes through important forests (lowland rainforests) especially the Witu forest which is a lowland rain forest." (83)

Though it is not yet clear what will happen to the Lamu Power Station after grid connection has been finished. Suggestions are; to keep as reserve capacity because otherwise there will be power shortages, that it can be used only for backup power or that it shall be moved to Mokowe. There are large numbers of domestic and commercial houses not connected to the local grid that have their own generating capacity. These are mostly small diesel generators but also a few wind turbines and PV solar panels. Many households do not have access to any electricity; neither local grid nor own generation.

## 5.2. Electricity Demand

Average power demand in the local grid is 800 kW with peaks at around 1200 kW, lower during rainy season, May to July, and higher during peak tourist season, December to January, Figure 9, (80). Electricity sold on Lamu by KPLC is currently at about 7 GWh per year. Larger consumers are hotels and local business such as the bakery, oil press and water pumping (84) (85).

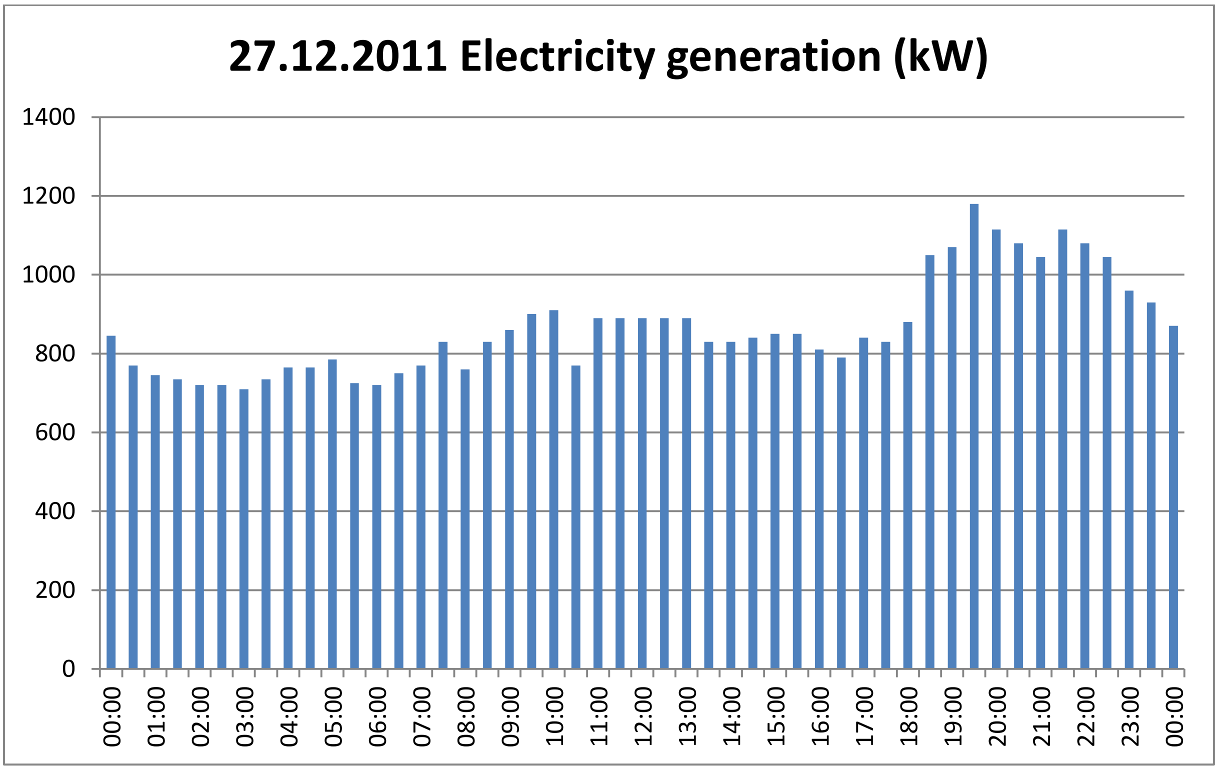



**Figure 9 Electricity generation at Lamu power station on December 27th 2012**

The demand can be expected to grow significantly. Even if it is not located on the island, the construction of Lamu Port and related infrastructure will affect. A majority of households on Lamu Island do today not have a connection to the local grid and as income level of the poor hopefully increases so will also electricity demand do. Electricity demand growth in Kenya has historically been 5 percent per year which would for Lamu mean a current increase of 350 MWh per year (37).

There are hotels and households with their own generating capacity on Lamu. No reliable data of its volume has been acquired. Commonly it is small diesel or petrol generators. With increasing petroleum prices and decreasing prices renewables as small scale wind and solar PV systems could prove to become an important share of future electricity generation growth. More about the specific technologies can be found in respective chapter.

Electricity use for the common Lamu citizen is often limited to a few light sources, mobile phone charging and a radio; at most, many do not have access to electric appliances at all. For higher income households can be added; computer, TV, refrigerator and air conditioning could also be added, these are also common appliances in hotels. This step however rather high, few households on Lamu own a refrigerator. There is little private ownership of private computers also but computer/internet availability is still pretty good, at least in Lamu Town, since there are many cybercafés. The two banks are also relatively large consumers of electricity with many computers and air conditioned office space. Energy intensive industry is limited, the oil press and the bakery are the only ones found during this survey.

## 5.3. Transportation

There are few motorized vehicles on Lamu, only a couple of tractors, one ambulance and a handful motorcycles. There is a clear consensus that more cars or motor vehicles are not desired on the Island, among all groups such as farmers, employed by tourist industry, local governance and tourists (19). Instead of cars for overland transports there are donkeys, around 5000 of them. Since they eat almost anything; fruit peels, other organic waste or corrugated paper (which seem to be a favorite) they are actually part of the waste management of the island. The problem is however not solved since the dung coming out the other end of the donkeys need to be taken care of.

As an island community boats and shipping is of course an important sector. Ship activities are passenger and goods transports, fishing and recreational use. (Mostly for tourists) Most common ship type is still the traditional sailing dhow. Because of limited capability of tacking many carry an outboard engine. Dhow building is an old and respected craft and still important industry on the entire coast. They come in varying shape and size; the bigger ones are mostly used with internal engine. Traditionally all trade along the coast was made using dhows. During the time of the northern Kaskazi, November to March, the dhow journey down to Mombasa take only 2 days while coming back to Lamu may take two weeks, if sailing by wind only.

Locally made glass fiber motorized boats are almost as common. There are a few imported sailing and motor boats to. Fuels used are diesel and petrol though no reliable data on share of each or quantity have been acquired. Data of total fuel sales on the island have been gathered through interviews (86) but this also includes diesel and petrol for generators and kerosene for cooking and lighting. Furthermore, many ship owners purchase fuel in Mokowe or elsewhere on the mainland because prices are lower. Sales of diesel and petrol on Lamu are 50 to 70 drums of 200 liter of both fuels respectively per week. Major part of it is used for boats but some also for electric generators. The cost of petrol was as of February 2012 ksh 120 per liter diesel and ksh 130 per liter petrol. This does however vary a lot.

## 5.4. Cooking fuel

As in the rest of Kenya, main cooking fuels are traditional biomass as agricultural waste; coconut shells, dung or maize stems, firewood; mostly easily collected branches or sticks and charcoal. Though cheap and renewable these fuels have issues. Deforestation because of charring is not a very urgent issue in Lamu district yet, population density is not very high, though if all charcoal consumed on Lamu were produced there the island would have large problem with deforestation. It is on the mainland, north of Mokowe, where charring mainly take place. Since the stoves are often primitive, without proper chimney, and kitchens are badly ventilated, respiratory diseases caused by smoke are common. In Lamu district they are the most common cause of death, though not all respiratory disease cases are caused by kitchen smoke (87).

Most of the charcoal comes through Mokowe though there are some additional sources like manufacturing on the island itself and smuggling. Some of the charcoal sold in Mokowe is also used there or transported to other places like Manda Island. Quantities are about 700 bags per week during normal season and 350 bags per week during rainy season. Commonly charring is done in remote areas where the raw material timber can be cut without any cost for the manufacturer. The normal method is to make 8-15 bags at once in one or several large dirt kilns, a process that take four to six days. Some make use of power saw but most do not afford this. One bag weighs 45 to 50 kg and is sold to an intermediate at about ksh 350 the woven bag itself cost ksh 20 but is commonly recycled. At arrival by Lamu Town jetty a fee of ksh 20 must be paid to the County Council, though smuggling during night and through other landing sites do occur. Transport by donkey or hand pulled cart to costumers within the town cost two shillings per bag. Shop owners buy charcoal from intermediate at about ksh 500 per bag or during rainy season ksh 700 per bag. Restaurants and hotels buy charcoal directly from the intermediate while most households buy smaller quantities from the shops. Normally two kg containers that sell at about 30 ksh each, or slightly higher during rainy season. The reason prices are higher during rainy season is that people are busy plowing and planting in the shambas and do not have time to make charcoal (88).

Kerosene used as cooking fuel but also for lighting and some generator and boat engines. The sale of kerosene on the island is 15 to 25 drums of 200 liters each per week. The price is around ksh 110 per liter.

Several hotels, restaurants and households that can afford it use LPG as cooking fuel. It is mainly bought in 13 kg containers at ksh 3200 each, though this is also a volatile price. Demand is 100 to 150 containers per week, depending on tourist season since these are behind large share of consumption.

A visualization of the islands energy system has been made from data collected at interviews, extrapolations of these and authors own estimations, Figure 10.

| | | Fuel oil [* = L] | Kerosene [* = L] | Diesel [* = L] | Petrol [* = L] | LPG [* = kg] | Charcoal [* = kg] | Firewood [* = kg] | Electricity [* = kWh] |
|---|---|---|---|---|---|---|---|---|---|
| Annual consumption | [*] | 2100000 | 208000 | 640000 | 620000 | 85000 | 2030000 | 2080000 | 7600000 |
| Price | [ksh/*] | 103 | 110 | 120 | 130 | 246 | 40 | 5 | 18 |
| Energy dispersity | [*/GWh] | 87800 | 97400 | 99200 | 101500 | 70600 | 112500 | 190000 | 1000000 |
| Energy price | [ksh/kWh] | 9 | 10 | 12 | 13 | 17 | 5 | 1,9 | 18 |
| Annual energy use | [GWh] | 24 | 2 | 6,5 | 6,1 | 1,2 | 18 | 22 | 7,6 |
| Island import balance | [Mksh] | -216 | -20 | -78 | -79 | -20 | -70 | 0 | 0 |

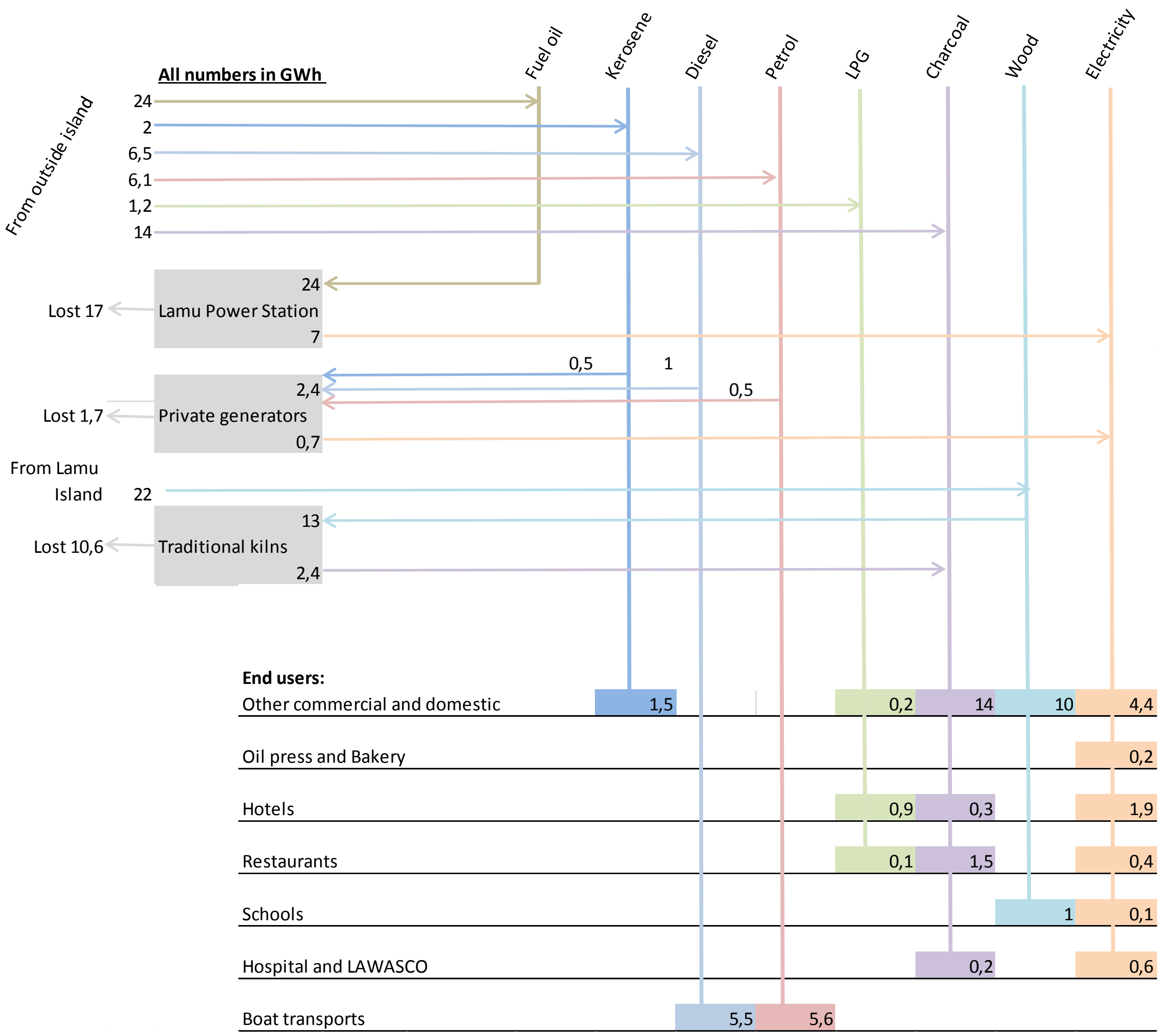



**Figure 10 Current energy system**

# 6. Environmental issues

## 6.1. Solid Waste

There is no public waste management system on the island. The only action taken by the County Council is the Kashmir dumping site where people are supposed to throw their own waste and once a month arranging a public clean-up day when school children take part in the work of cleaning the streets. Kashmir is however not functional as a landfill since it is under dimensioned and not protected by wind, plastic bags blow all over.

In Shella Town there is a positive example of a cooperative waste management solution called Shella Environmental Resident Group, SERG. It was started by the initiative of the Peponi Hotel, management and today several workers are employed as well as a manager dedicated to the project (89). Basically the households' place their trash outside which is collected by two workers using one donkey for transport each plus a four people that are cleaning the streets from litter and donkey dung. The treatment of collected waste still leaves space for improvements though. Metals are sold or given to local dealers. PET bottles are being accumulated for eventual recycling in the future. Other plastics are burned in the open just as mean of disposal; no energy is used from this. Glass is crushed, put in used cement bags and dumped into the deep sea, (90). People living in Shella have the opinion it is working rather well, they get the service they expect for what they pay, waste is removed. A key factor is participation; about 95 percent of all household are members. The fee is adapted to what the households' income level, some may pay as little as ksh 150 per month while the larger hotels pay several thousand shillings per months. Participation makes villagers build more concern for their local environment. Shella is however a lot smaller than Lamu Town and hold a larger share of high income households.

In Lamu Town there is a similar initiative that has not quite gained momentum yet; Lamu Safi employ a handful workers to clean a selected number of main streets on a daily basis and collect waste directly from the sponsors, a few hotels, and dispose it at Kashmir dumpsite, (91). Participation of common households are however almost non-existing why these usually dispose their waste wherever convenient. (for example the dock between Lamu Town and Wiyoni) The main perceived environmental issue on Lamu, by both residents and tourists, is waste; plastic bags, bottles and donkey dung, lying on the beach and other open surfaces. Both for increasing the wellbeing and attractively for tourism, the most important source of income to the local economy, it is essential that this issue is addressed. Following the example of organizing collection should not be impossible for Lamu Town. Best and easiest would of course be if the County Council would use authority and resources support waste collection. The current standard of activity of the Council is however of a nature that makes it difficult to see this happen. Regarding treatment of collected waste please see respective chapters below.

## 6.2. Waste Water

The waste water handling in Lamu Town can be separated in two parts; grey and black water.

The grey water, that is water from showers, clothes washing facilities, kitchens etc., is transported by a network of open drainage trenches to the sea. There are about 25 exit points evenly distributed along the seafront embankment for the grey water. Current problems include:

- Clogging by donkey dung or other waste falling into it (which become breeding ground for mosquitos)
- Flooding during rainy season because of insufficient capacity when storm water is added
- Eutrophication of Lamu canal due to detergents, donkey dung and urine in the grey water
- Toxic emissions due to strong detergents, dyes, oil spills and other chemicals in the grey water

The treatment of black water is basically non-existing. Commonly a concrete septic is made under the house. Overflow from septic goes directly down into the soil. When full with solids, which may take 10 to 15 years, they are emptied in a deep pit dug beside house, (92). For the informal settlements on the solution is often a pit latrine or simply doing the business in the bush. The problem with current situation is that Lamu Town ground water, which used to be of good quality, is rapidly deteriorating by increasing levels of nitrates and pathogens. The increased use of flushing toilets is probably accelerating the negative impacts because the higher volume of sewage makes compounds dissipate faster into the groundwater. One positive example is the Subira House hotel that employ urine separating toilets so that urine can easily be transported to their shamba for use as fertilizer and the feces be composted and then also used as soil improver, (93). Outside Lamu Town there is usually no grey/black water separation.

## 6.3. Fresh Water

Many households rely on their local wells in Lamu Town and elsewhere on the island. Especially in the town the water quality can be doubted since sewage is going into the soil. Those who can afford it use the local well water only for flushing toilets and such things and not for drinking. Good quality water is bought from Lamu Water and Sanitation Company, LAWASCO.

LAWASCO is a public company supplying water from the Lamu reservoir, Figure 11, to costumers on Lamu and Manda Islands. An average day 1500 $m^3$ of water are sold. The company pays a fee of ksh 0.5 per $m^3$ water taken out of the reservoir; the Shella sand dunes aquifer. Water is sold at a tariff scale starting at ksh 33 per $m^3$ if buying 6 $m^3$ per month to ksh 68 per $m^3$ if buying 100 $m^3$ per month. The pump house located near Shella Beach has two 18.5 kW pumps, one 11 kW and one 1.5 kW. There is one 450 $m^3$ storage tank located on the highest hill of Lamu Town, 22 meters above sea level and roughly 20 meters above the water table in the aquifer. Monthly electricity use is about 40,000 kWh. To prevent risk of over outtake the wells are fitted with an automatic level control electrode that stops pumping when depth is 0.5 m. The level is about 1.5 m when full. There are two pipelines to Manda Island that are privately owned but water transported in them sold is by LAWASCO. Average daily sales are 1500 m3. This gives an energy use of about one kWh electricity per cubic meter of water (94).

Most important institution for water issues in Kenya is Water Resource Management Authority (WRMA) who has classified Shella sand dunes as a strategic aquifer. (http://www.wrma.or.ke)

An extensive study of the aquifer was conducted in 2008, (95). Some alarming results were:

- On operation status only 13 out 30 wells were operational (44%), 23 % on stand-by (with water level dropped below pump or electrode level)
- 33% not operational due to power supply relate problems.
- 75% of the operational wells could not sustain a water column more than 1 meter high.
- All wells had pumping regime lasting less than 30 minutes indicating a very low recharge.
- Four wells numbers were found to be dry pumping i.e. no water in the well.
- The southern wells (close to the beach) showed a progressive increase in mean values of the salinity through measured electric conductivity.
- It was concluded that the wells are pumped above the safe yield; discharge supersedes recharge into the aquifer.

Recommended actions are of course to reduce the rate of discharge from the aquifer but also to perhaps extend the field of wells towards the south west so that the discharge load is distributed over a larger uptake area. The history of lost fresh water on Manda and Pate islands should serve as example of what can happen.

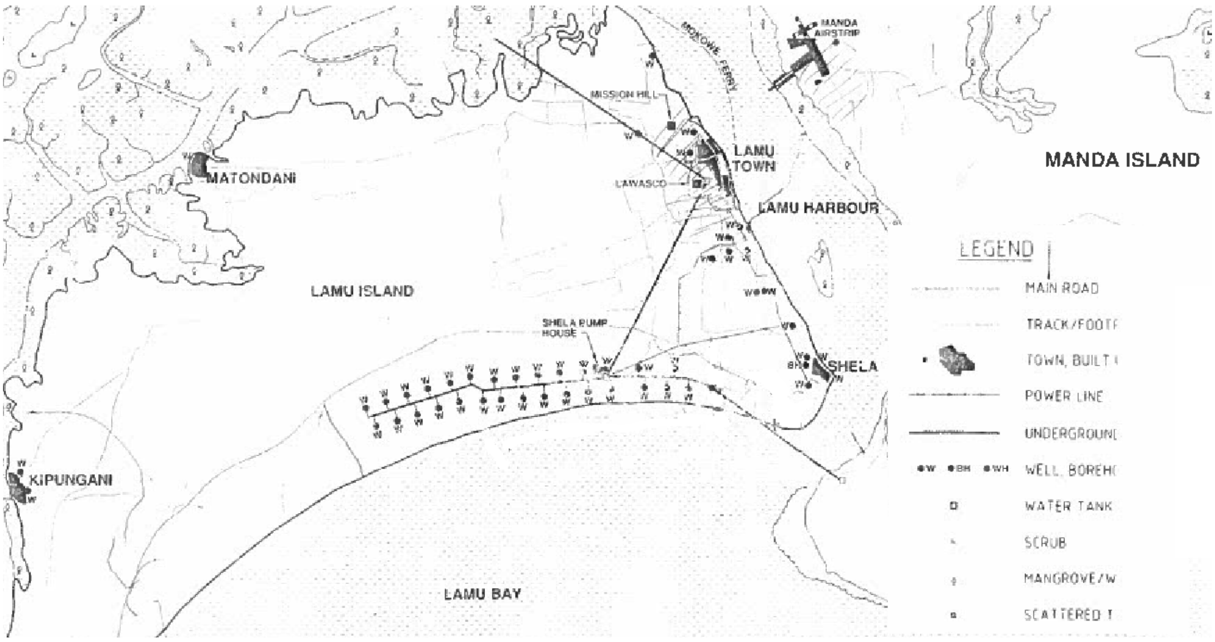



**Figure 11 Wells at Shella sand dunes aquifer**

Private wells are common all over the island and a water taken out of these are not regulated in any way. One may feel that every person should be free to dig his or her well. However, as population increase and also irrigation of crops this will quickly become unsustainable. For managing private water consumption a CBO called Lamu Island Water Resource Users Association has been founded. The aim of this organization is to be a monitor so that LAWASCO to not discharge too much water out of the reservoir and that an agreement on management on privately owned wells are reached, (96).

Fresh water can also be provided by more direct rainwater harvesting; from roofs or so called djabias. These methods are more efficient in taking up rainwater since less are los in evaporation. The mean annual rainfall vary between 550 and 1100 mm implying that a few square meter of collection area is sufficient for providing drinking water for one person. However, this rainfall is concentrated to a couple of months of rainy season why water storage tank has to be rather big and measures to preserve water freshness have to be made.

Another study by a student at KTH University in Sweden drew the conclusion that:

> "The postcolonial era has been depicted by un-maintained water system causing frequent water loss, health risks and damage to historic buildings. It then becomes necessary to revert and compliment the current water system with the traditional forms of administration in a bid to aim at enhancing community participation and consequently efficient management of water supplies. The options analyzed towards achieving this are by decentralization strategies, people empowerment and private sector incorporation as strategies of subsidizing and improving the existing administrative system." (97)

## 6.4. Agriculture

Roughly 80 percent of Lamu District population does agricultural activities. On the mainland agriculture is the back bone of life while people on the island do more fishing and activities related to tourism so that there is less agriculture. On Lamu Island just about 20% are doing agricultural activities. Staple food crops produced in the Lamu District are; maize, cow peas, cassava, millet, mchicha, sorghum. Cash crops are; coconut, cashew nuts, sesame, cotton, oranges, bananas, mangoes, limes and lemons.

On Lamu Island most common crop is coconut palms in the poor sandy soils but but in some shambas also maize, cassava, cashew, mchicha (plant also called amaranth, grown for mostly for the leaves used as spinach) and various types of beans. (98) Estimated coconut production of the island today is 500 tons of fruit per year. Some is consumed locally and some processed locally into oil but major share is transported to processing plants in Mombasa. Common use of the coconut palms is also production of alcoholic beverage called Mnazi which is made very easily from the sap of the palm tree.

Animals kept are dairy cows, donkeys, poultry goats and sheep. Dairy cattle, sheep and goats are usually held in free range. Poultry is kept in special rooms or houses. Beef cattle are brought from the mainland. Pork is not eaten much since it is a Muslim society. Donkeys are free range grazing and also fed by their owners on left over fruit leaves, maize husks or often whatever they find at the dumpsites.

Organic fertilizer use is limited, only a few farmers make their own organic fertilizers from animals dung like cows, goats, donkeys and chicken. They use it in small quantities that have not been measured. Chemical fertilizers are common on the mainland. Standard use is 50 kg of NPK per acre. The price of NPK fertilizer is ksh 3400 per 50 kg bag.

On the mainland the majority of farmers use tractor or ox for plowing. Tractor costs ksh 2000 to 2500 per acre and ox plowing costs ksh 1700 per acre. On the islands it is common with traditional slash and burn method of farming. The slashing costs between ksh 3000 to 3500 per acre.

Commonly crop residues are burned, only few use crop residues for soil improvement. Also leaves and branches collected from spaces like schoolyards and public surfaces are burned often without even making use of the heat. In order to increase nutrient uptake and reduce water losses by evaporation and infiltration, soil carbon must be added. This carbon can be created by composting all forms of organic material that do not have a higher value as for example animal feed.


**Figure 12 Aerial photo showing agricultural area near Lamu Town taken during rainy season why it is greener than usual and a pond of water on the school football pitch.**

Ulimwenguni Organic Farm is a positive example of how the sandy soil of Lamu Island can be used for more than coconut production. The farm grows mchicha, beans, oranges, coconut, moringa and mango. Livestock include around 20 dairy cattle, 10 ducks, 20 turkeys and soon a tilapia fish farm. (Though this may not be optimal because of high evaporation rate)

Cattle dung provides soil texture and nutrients for the plants though it is not an enclosed system since the cattle are fed with evergreen climber plants collected from uninhabited and unclaimed land on the island. Requesting about 100 kg per day, this is a full time job for two persons. Cattle and other animals are also fed restaurant waste brought in from Mombasa every day. (The farm owner have worked out a special deal with a bus company driving between Mombasa and Lamu) This amounts to about 100 kg per day, mostly potato peel. Small amount of commercial animal feed also used but less than 10 kg per day, (99).

Introduced on the farm during the period of the survey was a 3 $m^3$ soft PE plug flow reactor (PFR) for anaerobic digestion (AD) of cow dung. This will provide biogas to be used for cooking in the school kitchen. Jatropha was planted in tree nursery to be transplanted as a living fence around the compound for future use as biofuel.

# 7. Future energy system

## 7.1. Load control

Renewable electricity production from sources such as wind, solar or tidal is intermittent and need to be complemented with other controllable production capacity or electricity storage capacity. However, since the local electricity grid of Lamu Island will soon be connected with the national one via a 220 kW link the issue of load control will be resolved through the capacity of the national grid and the relatively nearby hydroelectric plants of Tana River. This will open up potential for investments in renewable energy in Lamu District. According to the Cordisons Ltd wind power company, the connection will be rigid enough to support 50 MW of wind generation capacity in the district (45).

Pumped hydroelectric energy storage (PHES) is a technology that could increase the regulating capacity of Tana River turbines further. PHES uses electricity to pump water uphill when demand is low and/or production high and then using the stored energy when situation is opposite. Total efficiencies reach 80 to 85 percent. Investment cost estimations have been made in a recent study, (100), though variations due to local conditions can affect cost by at least a factor 10.

A potentially useful tool for local load control is the LAWASCO pumps and water storage. The water pumps stand for about seven percent of the energy use on the island. The maximum power input of the pumps is only 50 kW or ten percent of the normal difference between minimum and maximum electricity demand meaning that the pumps are running fairly continuously and so there is little potential of using them for this purpose. However, the combined pumping capacity of all households on the island (it is common to have a pump for lifting water to a roof top tank in houses) would have a significant potential of regulating a future 'smart-grid' based on intermittent renewable energy. This would however require increased rooftop storage capacity of water for many houses and substantial investments in automatic control hard- and software.

## 7.2. Bioenergy

### 7.2.1. Biogas

Dung, primarily available from donkeys, is not used today and ends up on the dumpsites. It has value as organic fertilizer and an energy potential if used in AD to produce biogas. Since there is 4000 donkeys on the island the volume of dung is substantial (19). If each donkey produces two kilograms of dung per day the resource base would be 3000 tons per year. However, it is only realistic to make use of dung from the hard made streets of Lamu Town and Shella. Infrastructure to collect donkey dung is already in place by Lamu Safi and SERG. Daily around five 20 kg wheelbarrows of waste; dung mixed with sand and other waste, are collected from Lamu Town and Shella. Assuming half of this being dung and that more dung can be collected if number of cleaned streets are increased plus dung from for example the Donkey Sanctuary are also added then 100,000 kg per year is available. Only one study of biogas yield from donkey dung has been found and is shows that a batch 75 liter digester of 10 percent dry content gives a total of around 240 liter of biogas with around 55 percent methane content after full digestion (The study also noted benefit of co-digestion with poultry manure) (101). Assuming 50 percent dry content in collected dung the overall potential would be 1600 $m^3$ of biogas per year equivalent of 10,500 kWh or 730 kg of LPG worth ksh 180,000. This is a conservative estimation since it assume only 3.5 percent of all dung is collected. With substantial change in animal and dung management routine one could speculate on a tenfold increase, 35 percent dung collected and digested, which would then approach a potential of 10 percent of the current LPG consumption on the island.

Black water, human feces and urine, is another potential substrate for AD which is also commonly done in public sewage treatment plants. In the city of Göteborg in Sweden currently about 85 kWh of biogas per year is produced for every person connected to the sewage grid, (102). The full potential is even higher if black water is co-digested with kitchen waste, 130 kWh of biogas per person and year (103). Since a food intake and food waste is lower on Lamu than in Holland, where this potential was calculated, one can assume that a maximum of 100 kWh of biogas potential per person and year is more realistic. Further, there are several obstacles regarding how this sewage can be collected to the digester. Lamu Town and nearby informal settlements is where majority of population live is built in a way with very little space between houses. Streets in between are only one to three meters wide. Furthermore the sandy soils make buildings move if digging nearby make an establishment of a sewage grid. Result is that it will be very difficult to have a conventional sewage grid built anytime soon, (104).

One potential way of introducing biogas from sewage in a simple way is to install this kind of system for schools; a lot of people using the same toilet facility so that a digester can be economically feasible. Additionally the system is a pedagogic feature for the students. This has been tested with positive results in Central Province of Kenya (105). Investment of biogas digester for a school is about ksh 1000 per person it is to serve and usually a new toilet facility has to be built to which is more expensive, around ksh 2000 per person. With 5000 school children on the island the potential from the relatively simple investment of building biogas digester for the school is then 150,000 kWh, assuming 30 kWh per person and year since all toilet visits are not made at school and digester efficiency less than optimal. This is equivalent of 10,400 kg of LPG worth ksh 2.5 million. The biogas potential of all sewage on the island would be 2.3 GWh per year, equivalent of nearly twice the amount of LPG used annually today.

One major obstacle is however cultural reluctance of using gas from human feces as cooking fuel, though there are no real hygienic concern and very little smell if treated the right way. An important part of AD systems is to make use of the digester effluent. (This is described further under 'Soil improvement') In a survey on Lamu all ten interviewees where negative towards using hygenized manure derived from human urine and feces (19). Though experience from central province is that this attitude may change if good examples show benefit and safety of method. A way of avoiding fertilization of food crops with human waste is to use it for bio energy crops. The residues from bioenergy production can then later be used for food crop fertilization, closing the nutrient loop by adding another step in the chain.

### 7.2.2. Woody biomass and charcoal

Wood by direct combustion or converted into charcoal is the largest source of primary energy type in Kenya and on Lamu Island. There are huge capacity of improvement for this sector regarding energy efficiency, emissions and other environmental impacts. An obstacle is that charcoal is underpriced in current production systems. The real cost of raw material, wood, is often not reflected when since it is harvested illegally from unsustainably managed forests. This undervaluation result in wasteful and inefficient production and consumption, and creates a formidable disincentive for forest management and tree growing. Annual biomass yield of wood on semi-arid lands of Kenya is approximately 12 tons per acre. This will of course vary a lot but the number that have been assumed for non-irrigated land of Lamu District which can be considered to be semi-arid, (106).

In the traditional charring methods used all over Kenya most of the energy in the raw material is lost, kiln efficiency is about 10 to 20 percent. Part of the energy losses can however be compensated for during end use since charcoal stoves have higher efficiencies than the most basic wood stoves. (30 percent for charcoal stoves compared to 10 to 15 percent for open fire or tripod) Though if improved wood stoves are used this compensation will not be big. Charcoal also have other advantages over firewood (obviously, otherwise it would not be used to such extent) such as higher energy (by mass) density, less smoke produced during combustion and less attention needed during use, compared to firewood, (107).

Better charring kilns would greatly improve the overall efficiency of Lamu Island. Carbonization of wood gives rise to a complex range of products; solid, liquid and gaseous. In traditional kilns only the solids, the charcoal, is recovered. They are however very cheap, minimal capital cost since a shovel, strong back and a bit of experience is all that is needed. Theoretically dozens of useful chemicals could be extracted from the liquid condensate if it were economically practical. Further these compounds have negative environmental effects when not collected but released feely in the atmosphere. Approximately from one kilograms of dry wood (19 MJ/kg) the following heat quantities are available in the final products:

- Charcoal: 9.5 MJ/kg
- Pyrolysis Gas: 1.5 MJ/kg
- Condensable gas including tar: 8 MJ/kg (108)

If an external source of heat would be used, normally energy within the wood itself provide process heat If an external source of heat would be used, normally energy within the wood itself provide process heat . There are also other alternative conversion methods of woody biomass that can be advantageous in an efficiency perspective:

- Combustion for cogeneration, fluidized bed or other method
- Thermal gasification for combined cycle generation or further processing into other suitable fuel
- Biological, chemical or thermal hydrolysis for further processing with biological methods

These technologies do however have high up-front costs and are primarily suitable for large scale production. They will probably not be in question any time soon for Lamu Island since a decision of this kind cannot be undertaken without stable conditions currently not present; the resource area, replanting and agroforestry schemes and infrastructure must be committed for a substantial future.

A more realistic alternative is low-cost retort kilns already available in Kenya today. One example among is a unit that will produce one ton of charcoal per week at 35% to 45% Instead of about 18% efficiency compared to the traditional systems; calculated from dry weight. Investment costs is about ksh 55,000 for the simple construction of a one ton per week capacity with locally available materials (109) Investment cost is thus about ksh 0.12 per kWh annual capacity. Ideally kilns would be located near the town so that excess heat from the process can be used to for example to boil beans which are a common and energy intensive activity. There are social structures that would be affected and has to be considered for this type of an implementation. The income base for today self-employed charcoal makers would be reduced since value adding requested them would be reduced and volume product demand also. These are commonly small scale or subsistence farmers that have charring as a side business for cash income. In practice job opportunity moved from rural to urban areas.

A better option that can still be made in relatively small scale is flash pyrolysis of woody biomass into bio-oil. Conversion ratio of 75 percent wet bio-oil translates to energy efficiency of 70%. By weight, plant output is about 75 percent dry (11 percent of this is water) bio-oil with 17 MJ per kg higher heating value, 16 percent char/ash mix and 13 percent gas with low heating values. The bio-oil can be combusted directly in diesel engines after some adjustments to the motor or be further refined into fuels equivalent of regular petrol and diesel, (110). The total capital investments have been estimated to be USD 389,000 for a 1000 kg input per hour plant; this was for pyrolysis of rice husks, for example a chipping stage has to be added for wood fuel, but will serve as a rough estimation, (111). An attached oil refining plant turns bio-oil into 71 percent (by energy content) biodiesel equivalent fuel and 6.7 percent petrol equivalent fuel; bio-petrol with similar properties as ordinary petrol. The refinery has 10 percent energy losses. Adding a refinery step is estimated to increase the investment cost by 100 percent. This is not yet a fully mature technology but is developing fast and will readily available commercially soon, (112).

### 7.2.3. Biodiesel

The today most common crop in Lamu is coconut palm, Cocos nucifera. Smallholder plantations usually yield between 0.5 to 1 tons of copra per hectare (30 to 50 fruits per palm) and this is also a probable case for Lamu too, (113). Most of the islands coconut harvest is sold to processing companies in Mombasa. Lamu Oil Press is a local industry producing coconut and sesame oil; 50-70 liters of oil are produced per day, roughly one-third sesame and the rest coconut. This means per year about 10 000 liters coconut oil and 5000 liters of sesame oil. The oils are sold at; coconut ksh 180 per liter, sesame ksh 280 per liter. Coconut oil is sold as skin or hair lotion, the quality is not good enough to be food grade, a bitter taste probably due to some occurrence of nuts gone bad in each batch. Since it sells at higher price than diesel it is unlikely and unfavorable to use it as a fuel, even more so if press process can be improved so that the oil can be used for food.

Jatropha Curcas is a large perennial shrub or small tree that produces seeds rich in oil and that can live to more than 50 years. Yield per hectare has been reported as between one and eight tons of seeds per years. Oil content is around 35 percent, (114). Other literature claim yields of around 2.5 tons of seed per hectare in semi-arid areas of Kenya, (106). The plant survives in arid land but in order to give the high yields promised relatively high inputs of water and fertilizer are needed. There has been a bit of hype around the plant which did lead to millions of hectares of plantations in Asia and Africa. Reports are however showing that production has not made expectations, (115) (116). 50 percent of seed weight is left as press cake and which can be used as soil improvement or biogas production. Since most nitrogen, potassium and phosphorus are left in the press cake, and not the oil, little additional fertilizer is needed if this is returned to the soil. Digestion of press cake will produce additional energy output from seeds also without wasting the nutrients. Biogas potential of dry press cake is about 0.7 m3 per kg, (117). It is practical use hedges of jatropha plants for fencing since leaves are not eaten my animals and it will replace wired fencing of other shrubs with little value. When grow in a single, as a fence, it is estimated to produce around 1 kg of seeds per meter.

A farmer cooperative based in Mpeketoni on the mainland of Lamu District promote famers to plant Jatropha, not as a main crop but rather a supplement, for example using the shrubs as a living fence. The cooperative have facilities in Mpeketoni for seed pressing and a meeting hall where education for farmers can be arranged. A 14.7 kW diesel (converted to run on Jatropha oil) engine is used for powering the oil press. 25 percent of produced oil is used as fuel for the process itself. The oil is primarily sold to an energy cooperative in Kipini where it fuels an engine powering a generator in their local mini-grid. Seeds are bought from farmers at ksh 15 per kg. 4 kg of seed give 1 liter of oil and 3.2 kg of press cake. Oil is sold at ksh 105 per liter. Seed quality is important, they have to have the correct ripeness in order to have high oil content. The press cake is planned to be used as soil improvement though for now it is only stored in Mpeketoni. This give a field-to-tank yield is here about 500 liters per hectare and year. As of today most of the press cake is not used but stored in Mpeketoni, (118). Their oil press is an old one from TinyTech Ltd of India. An invoice from TinyTech suggests investment cost of about USD 16,700 for a 60 liter per hour plant. This translates into ksh 0.5 per kWh if using 12 hours per day load on the equipment.

Neem tree (Azadirachta indica) may play an important role for sustainable development with the many practical uses of the plant; pest and nutrient management, human health, bioenergy and environmental conservation, (119). It is today common on Lamu Island, perhaps the most common tree of all. A mature tree produce 30 to 50 kg of fruit per year where seed content in fruit is 25 percent and oil content of seed also about 25 percent, (120). The oil yield per hectare is rather low for the Neem tree but since it already grows wild it could anyway prove to be a profitable activity harvesting and processing the seeds. In India use of the oil is common but there the value is higher for using it for soap manufacturing.

Calophyllum inophyllum is also a tree species that grow freely on the Kenyan coast. Oil yield is up to 12 liters per tree and year has been noted, indicating potential of 4000 kg per hectare, (121) (122).

Moringa oleifera is a tree with wide range of uses. In East Africa it is today probably most used as food; the leaves are protein and nutrient rich and are eaten fresh, boiled or as a dry powder mixed in water. It also produces oil rich seeds that can be used as fuel. A special characteristic of the seed, crushed or seed press cake, is that it functions as a flocculent for water purification, (123). The oil is suitable for production of biodiesel though possible yield per hectare seem to be lower than other alternatives. The oil is eatable why it will probably have a higher value for human consumption, (124).

Investment cost for seed peeling, crushing and pressing, as well as oil filtering is in the order of magnitude of ksh 1.6 million for 1500 liters biodiesel per day output, appendix B. The finished product will then function in most diesel engines if fuel filter is changed. Most vegetable oils have higher viscosity that can give problems when starting in cold ambient temperature and it will in general work better for older engines without direct injection. Vegetable oil can also be converted into biodiesel compatible with practically all diesel engines by a relatively cheap and easy chemical process.

The globally most common crop for biodiesel production is the Oil Palm, Elaeis Guineensis, with a yield of 5 to 7 tons of oil per hectare. This is however for tropical regions in south-east Asia with richer soils and more rainfall, (125). It is unlikely to naturally grow well in the climatic conditions of Lamu District.

### 7.2.4. Ethanol

Cassava (Manihot esculenta) is a starch rich plant common in sub-Saharan Africa with low input requirements, drought tolerance, can grow on marginal land and is usable for bioethanol production. Cassava-to-ethanol conversion process is a well-established technology. Cassava is most commonly harvested manually, at the earliest eight months after planting. Cassava roots contain approximately 30% starch (106). Common yield in Kenya is around 8 tons per hectare and year, however with increased fertilizer input and field management yields of up to 21 tons per hectare have been recorded, (126). Manufacturing ethanol from cassava has several process steps: Feedstock pre-treatment (washing and crushing)

- Pulp cooking
- Saccharification (transforming pulp into fermentable sugars)
- Neutralization (bringing the pH value into the range 5.0–7.0 to allow fermentation)
- Fermentation
- Distillation
- Dehydration

A cassava ethanol plant of approximately 3000 liters per day of alcohol at 96% will cost around ksh 40 million. This is for the full process from fresh cassava, washing and peeling, grating, cooking, fermentation, distillation, and bottling. In addition a steam boiler, generating set, effluent treatment plant, and electrical system are required. Efficiency will depend on the starch content, 30% starch content will produce approximately 280 liters of alcohol per ton raw cassava. The plant will also produce around 2 to 3 $m^3$ per hour of effluent suitable for animal feed or biogas production. The plant will need a good water supply and a continuous electrical supply of around 50 kW and steam of around 1500 kg per hour, (127). This would give a field-to-tank yield of 3000 liters per hectare though energy requirement for steam generation will be almost two-thirds of the ethanol output heating value. This give that measures like effluent heat exchangers and solar heating panels should be included to improve plant economy.

The most efficient crop for bioethanol production is sugarcane that yields 4000 liters of ethanol per hectare and year. This is without any additional energy input because the bagasse produced exceeds the amount needed to distill the final product. However, sugarcane does not grow well in poor sand soil and need significantly more rain or irrigation water than what is available on Lamu, (128). If irrigated with AD treated waste water it would however probably grow well. The leading country in ethanol production is Brazil where investment cost is calculated to be USD 0.5 per liter of ethanol per year, (129). The double cost will be assumed for Lamu because of smaller scale, transport and less local know-how; ksh 85 per annual production capacity in liters.

### 7.2.5. Waste Water Recycling

The waste water is today one of the most urgent problems on Lamu Island. But, this practice it is actually an opportunity: There is no waste, only the resources in the wrong place. The waste water actually contains all that is needed to increase agricultural output from the island; water, plant nutrients and soil carbon. , Table 6, (130).

**Table 6 Macro and macro nutrient, oxygen demand and biogas potential of waste waters and organic waste**

| | | Urine | Feces | Grey water | Organic waste | Total |
|---|---|---|---|---|---|---|
| Mass | [kg/pers.yr] | 511 | 43,8 | 33324,5 | 100 | 33979 |
| Nitrogen | [kg/pers.yr] | 3,285 | 0,657 | 0,438 | 0,85 | 5,2 |
| Phosphorus | [kg/pers.yr] | 0,292 | 0,1825 | 0,146 | 0,095 | 0,72 |
| Potassium | [kg/pers.yr] | 0,9855 | 0,3285 | 0,292 | 0,11 | 1,7 |
| Calcium | [kg/pers.yr] | 0,073 | 0,19345 | n/a | n/a | 0,27 |
| Magnesium | [kg/pers.yr] | 0,073 | 0,0657 | n/a | n/a | 0,14 |
| BOD | [kgO2/pers.yr] | 2,0075 | 8,03 | 9,855 | n/a | 20 |
| COD | [kgO2/pers.yr] | 4,015 | 18,25 | 18,98 | 29,5 | 71 |
| Cu | [g/pers.yr] | 1,46 | 146 | 1058,5 | 274,5 | 1480 |
| Cr | [g/pers.yr] | 1,3505 | 2,6645 | 133,225 | 68,5 | 206 |
| Ni | [g/pers.yr] | 0,949 | 9,855 | 164,25 | 41,15 | 216 |
| Zn | [g/pers.yr] | 5,986 | 1423,5 | 1332,25 | 350 | 3112 |
| Pb | [g/pers.yr] | 0,26645 | 2,6645 | 133,225 | 137,5 | 274 |
| Cd | [g/pers.yr] | 0,09125 | 1,3505 | 5,475 | 1,35 | 8,3 |
| Hg | [g/pers.yr] | 0,1095 | 1,2045 | 0,5475 | 0,125 | 2,0 |
| CH4 potential | [kWh/pers.yr] | 10 | 47 | 49 | 76 | 182 |

Developing a detail plan for a suitable waste water handling for urban areas of Lamu Island is out of scope of this paper but some introduction to a functional solution will be given, that can later be developed.

The main issue is Lamu Town, where majority of population live. A conventional sewage system cannot be built for reasons mentioned in a previous chapter, briefly: The open grey water drainage is not a good solution since it sometime overflow because of either blockages of donkey dung or other waste, or insufficient capacity during rainy season. The black water contaminates ground water because is infiltrated into the soil.

The suggested solution is a small bore sewage system for liquids only, (131). Each house need to have a septic in the bottom floor, partly buried below ground level. Preferably it will be as an anaerobic digester, inlet in the bottom, biogas collection funnel inside and liquids outlet on top; basically an Upflow Anaerobic Sludge Blanket, UASB, Figure 13. (132) Liquids will pass rather fast through the tank while solids are retained in the bottom and given time to digest. Biogas is easy to transport in plastic pipes for storage in preferably in an EPDM rubber bag for each house. If adequately dimensioned the tank should not have to be emptied manually from sediment in many years, solids will have sufficient time to digest.

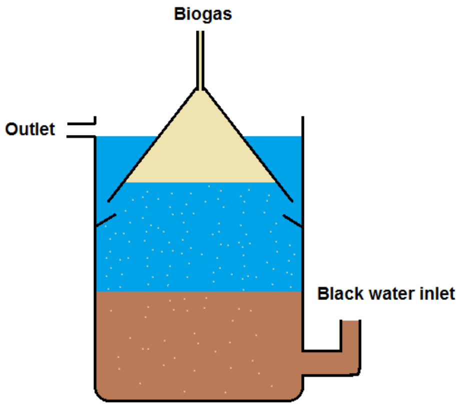



**Figure 13 UASB septic tank**

The liquid effluent can be transported, together with grey water, by gravity in small diameter pipe to one or several collection tanks in the town. These pipes can be fitted into current grey water drainage system. The collection points will have to be located in lower lying areas of the town and from them nutrient liquid is pumped to infiltration beds planted with Jatropha or other high yielding biofuel crops. The waste water should not be used for food cultivation because it would be difficult because of cultural reasons and in this system retention times are short so that there is little time for pathogen reduction.

Some important dimensioning parameters of such a system are:

- UASB-septic: Should be large enough for a hydraulic retention time (HRT) of about 4 to 12 hours, (133). If flushing toilets is used and grey water is mixed into the same tank the water use can be up to 100 liters per person and day giving a minimum volume of 50 liters per person. Further, direct waste water is a strong substrate, about 0.1 kg COD per person and day, and organic loading rate (OLR) should stay between 4 and 12 kg per $m^3$ and day. This also give that 50 liter tank volume per person is sufficient. A common building in Lamu Town is rather large and can house 20 people. This means that a common UASB-septic tank should be one cubic meter. However, emptying a septic tank full of sediment is not a nice job why tank volume can be increased with a factor two or three to be on the safe side.
- Collection tanks: These will be fitted with electric pumps so an important consideration is how long they should be able to receive waste water before overflowing if there is a power shortage. The population of Lamu Town is around 12,000 people. The average water consumption is much below 100 liters per day since most houses do still not have flushing toilets. A reasonable total collection tank size would be 600 $m^3$, assuming 50 liter average water use and one day of water storage capacity.
- Infiltration bed: In order to have a long term sustainable infiltration bed nutrient uptake of plants must be the same as nutrient inflow from waste water. Macro nutrient content in waste water from one person are nitrogen 4.4 kg, phosphorus 0.61 kg and potassium 1.6 kg, all values per year. For different crop alternatives under high yield condition, plant nutrient removal with harvest will be as Table 7, (134) (135) (136). This give that required cultivated area for uptake of plant nutrients in Lamu Town waste water is about 400 hectares.

**Table 7 Plant nutrient removal with harvest for selected bioenergy crops**

| | Nitrogen | Phosphorus | Potassium |
|---|---|---|---|
| Jatropha (kg/ha yr) | 120 | 60 | 55 |
| Sugar cane (kg/ha yr) | 140 | 15 | 45 |
| Palm Oil (kg/ha yr) | 190 | 21 | 40 |

Since water and nutrient availability would be well provided for in the infiltration beds yields would also be high. 400 hectares of high yield Jatropha cultivation can yield 600,000 liters of biodiesel, oil palm 1,600,000 liters of biogas and sugar cane 1,600,000 liters of ethanol. The biogas potential of waste water treated in UASB-septics would, calculated with a low efficiency, be around 0.85 GWh or equivalent of 58,000 kg of LPG. To close the nutrient loop press cake and ethanol production residues must be used for food cultivation. This recycled plant nutrients can now be used for this since they have definitely been cleaned from pathogens.

This suggested system is a huge project and quite unique in its form. To engage directly into such an enterprise would be neither good nor possible; too high capital investments, large insecurities and unexpected difficulties that will arise. One issue is the amount of piping needed to create such an infiltration bed, in the order of magnitude of 1000 km pipe. However, it would be possible to start in a smaller scale, with one or just a few houses, to test and develop the system.

Investment cost of AD will depend on technology used, desired efficiency and level of automation, difficult to predict. Based on experience of construction of a small scale digester for waste water in Ngong, Kenya, digester yield per unit volume is 600 kWh per $m^3$ and construction cost around 10,000 per $m^3$ digester volume, (137).

Since the situation is grave and urgent, the ground water inside and around Lamu Town is becoming undrinkable, a plan for immediate action is needed too. This would be prohibition of flushing toilets and preferable urine separating toilets only, regulation. This way there would be much less effluent from the septic tanks going into the soil and separated urine can fairly easy be transported by donkey to the interior part of the island for use as safe fertilizer. Urine is free from pathogens.

There are a lot of substances one do not want to have in the sewage-plant nutrient-food life cycle mainly heavy metals as cadmium. Therefor regulation of chemical use must go hand in hand with such a system. This would imply substantial community information campaigns as well as structured monitoring of chemicals brought to the island.

## 7.3. Soil improvement

Soil carbon content have a large effect on water evaporation meaning that soil containing decomposing organic material can hold moisture better than for example sand. It also has a positive effect of binding nutrients and making them more available to plants. On Lamu today it is seen as untidy when leafs and small branches lie on the ground. Since the easiest way of getting rid of it is burning this is what often happens. Slash and burn agriculture is a common method in the region. By burning the wild vegetation one easily clears an area for agriculture and the nutrients in the ash becomes available to cultivation. However, since biomass that could have built up soil carbon is lost duting burning the ‘ash nutrients’ are quickly washed away so that area need large amounts of chemical fertilizer or be abandoned quickly. Since Lamu Island have almost entirely sandy soils with very low carbon content any actions that increase it are very valuable, investments for a better future.

## 7.4. Wind Power

Wind data from a 40 meter high wind measurement mast in Mokowe have shown average wind speeds of about 6 m/s, (138). This is somewhat higher than indicated in a survey by Kenya Meteroligical Department, 4 m/s, (38) and lower than data based on oceanic surface movements measured by satellite for the SWERA project; 6 m/s at 10 meters elevation and 8 m/s at 50 meters elevation, (139). Wind turbines come in a very wide range of sizes; from a few hundred watts up to several MW. In general there is positive development of both environmental impact and cost efficiency as scale is increased, (140). However, turbines cannot be larger than demand and regulating capacity, there are issues of available infrastructure to consider and also an issue of how large plants can be brought to a site without major construction of infrastructure. Furthermore, credit availability is an essential factor for larger projects. Especially in developing countries an investment can be clearly profitable on paper but investors are not to be found. This is due to a variety of reasons from international politics and banking culture and of course also the risks involved. Interest rates in developing countries are high, in Kenya lower that 15 percent is hard to get event for top rated lenders. Higher interest rate directly implies higher discounting rate, income in the future is valued considerably lower than income today. A condition that does not favor investments in technologies such as wind and solar power characterized by high up front cost and low running costs.

**Table 8 Wind power investment cost in Europe**

| | Share [%] | Investment [kUSD/MW] |
|---|---|---|
| Turbine (ex. works) | 76 | 1333 |
| Foundation | 7 | 115 |
| Electric installation | 1,5 | 26 |
| Grid-connection | 9 | 157 |
| Control systems | 0,3 | 6 |
| Consultancy | 1,2 | 22 |
| Land | 1,2 | 22 |
| Financial costs | 4 | 69 |
| Road construction | 0,9 | 16 |
| Total | 100 | 1762 |

In Table 8 approximate investment cost for large scale wind turbines in Europe are shown. The data set was from 2006 and has therefor been modified in order to compensate for inflation, (141). If taking in account the high financial cost of Kenya, transport to Lamu and need for additional infrastructure compared to average site in Europe, the cost is estimated to USD 2,5 million or ksh 213 million per MW.

In order to make fairly accurate projection of what capacity factor (how large share of rated output will be the real mean output of the turbine) can be expected from a turbine detailed wind data is required. Mean annual wind speed is not enough, higher time resolution is needed. Two locations with identical mean average wind speed can have as much as a factor two difference in electricity output using the same turbine. If the wind characteristics have not been measured one can use a Weibull curve in its place and guess a shape parameter. The 8760 hours of a year is then distributed according to this. The characteristics are acquired from turbine manufacturer; each wind speed will generate a certain power output. The expected annual output is then calculated by multiplying time at each wind speed according to distribution with turbine data. Using the Weibull shape factor 2 was used for calculating power output of turbines on Lamu, Figure 14 and . Average wind speed is 6 m/s for the V29 turbine and 7 m/s for the higher V47 turbine. There are also online tools for calculating wind turbine output, or capacity factor if you like, but the one tested seemed to be working currently, (142).

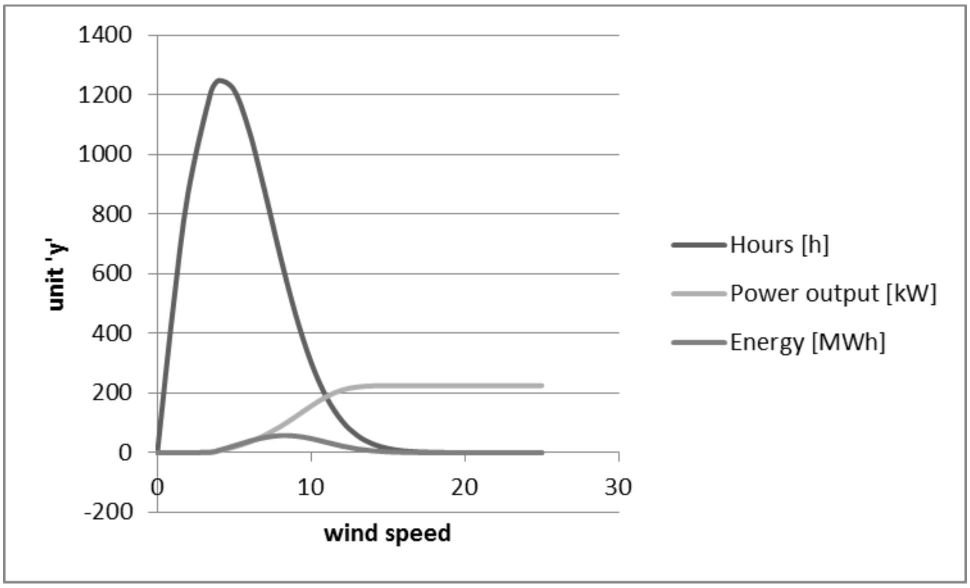



**Figure 14 Hours, power output and energy, distributed over wind speeds on Lamu for Vestas V29 (wind speed on x-axis)**

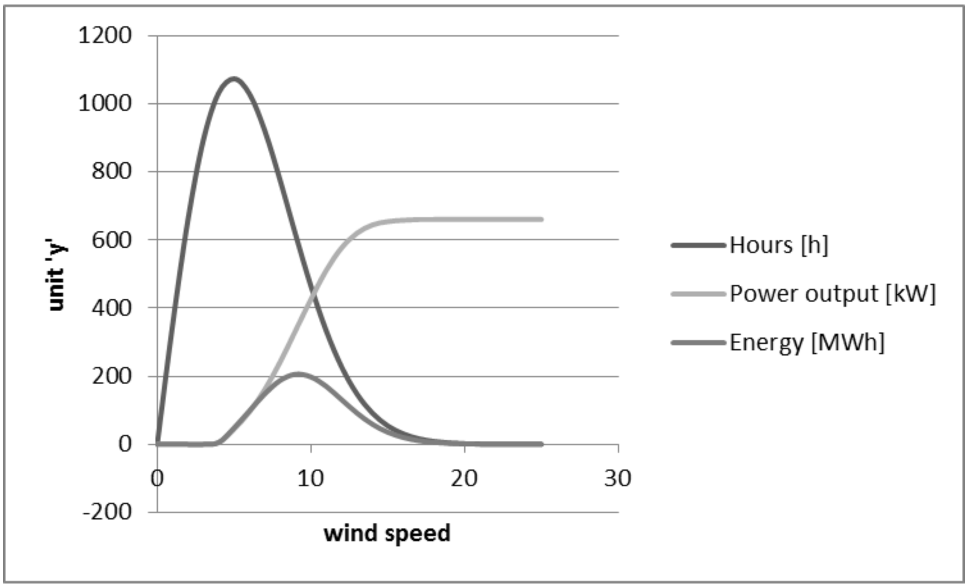



**Figure 15 Hours, power output and energy, distributed over wind speeds on Lamu for Vestas V47 (wind speed on x-axis)**

Most interesting wind power project in Kenya right now is the 300 MW Lake Turkana Wind Farm that will be the largest in Africa when finished. The contracted company Vestas from Denmark is to supply

365 pieces of model V52 wind turbines, each with a capacity of 850 kW, at a total cost of ksh 65 billion or ksh 210 million per MW, (143). Further a 428 kilometer transmission line linking the part to the national grid will be done by Isolux Corsan from Spain at a cost of ksh 15 billion. This gives a capacity cost of USD 3.13 million per MW, even without the transmission line which could be considered to be an extraordinary condition the cost is USD 2.55 million per MW. It is of course hard to tell if any irregularities have occurred during the procurement of Turkana Wind Farm. Assuming all is done by the book means a number reflecting increased cost of infrastructure investments and financial cost for a wind investment in Kenya compared with Europe. The latest news before this paper goes into print is that the project has been because power distributor KPLC will receive heavy losses if the power plant is ready before the transmission and whether KPLC can be relied on to buy the power generated by the wind farm as agreed, even if demand would at moments sometimes be lower than production, (144). The wind park has qualified as a CDM project with rights to sell 736,615 metric tons $CO_2$ equivalent per annum, (145).

Hotel Majlis on Manda Island, just a few kilometers from Lamu Town across the channel, have installed wind turbines and PV solar panels in order to reduce Diesel fuel consumption since they do not have a connection to the Lamu grid and needed to reduce their fuel costs. Before investments in renewables 200 liters of diesel per day was used that have been reduced to 70 liter per day. The installed capacity 29 kW of PV modules plus two times 5 kW vertical and 3 times 2 kW horizontal wind turbines from manufacturer Techwell of China. The amount of battery storage capacity was not inquired. The replaced 130 liters diesel would have given about 1.5 GJ or 400 kWh electricity at an efficiency of 0.3 which is then assumed to be the output of the PV-wind system. This give an overall load factor for the whole wind-solar system is 37 percent of the rated output which seem a unrealistically high. By any means, the hotel invested in renewable energy because it has an annualized cost lower than the replaced diesel generator capacity, maybe as much as 146 MWh at ksh 6 million per year. (Adding ksh 300,000 per year for oil and maintenance to the fuel cost) The electricity price of the PV-wind system is thus lower than ksh 41 per kWh but most probably higher that the grid electricity at about ksh 18 per kWh, (146).

A company by the name Cordisons International claim to have exclusive permissions from the Kenyan Ministry of Energy to invest in commercial, selling to the national grid, wind power in Lamu District. Further they state the plan is to build a total of 300 MW of capacity but the time scale or way of getting there is unclear, (45).

Second hand wind turbines is an interesting cost-efficient alternative with a now well-developed marked. Reason for removing windmills is often that the location is so good that is has become profitable to build a new bigger one to replace is as available turbine size has increased.  For example a refurbished Vestas V29 225/29 from 1990 that will easily last more years can be bought at ksh 12.3 million (plus shipping) which could be a good alternative, (147). This investment would generate ksh 4.7 million ksh per year if electricity can be sold at ksh 12 per kWh as stated by feed-in-tariff program of Kenya, (148). Shipping and construction of foundation is a substantial part of the investment. It is here assumed to cost as much as the turbine.

Wind power can also be used directly for mechanical work; water pumping is a common such application. Twalib Adam Omar has developed his own wind powered water pump which he manufactures in a workshop in Mpeketoni. The standard model gives 10m lift and 300 liters per hour flow rate at the Lamu average wind strength at 13 m height and with 3 meter rotor diameter. This give an annual energy output of around 3000 kWh. The investment cost is ksh 200,000. There are currently two Twalib wind pumps installed on Lamu Island, (149).

## 7.5. Solar energy

Solar irradiation on Lamu Island is about 2200 kWh per $m^2$ and year, equal to 250 W per $m^2$. To illustrate how much this is one can say that the islands full electricity need would be covered by 2.3 hectares of PV panels of 15 percent efficiency, an area of just about 150x150 meters or two football fields. (If grid regulating capacity was robust enough to handle the intermittency)

In Denmark PV is considered to recently have reached grid parity; become profitable for home owners to invest in PV modules on the rooftop. This is with a solar irradiation around 1000 kWh per $m^2$ and year, (150) only half that of Lamu. There are however a few important special conditions in the Danish energy sector that make this possible, (151):

- A traditionally high tax on electricity resulting in a high costumer price to buy electricity from the grid; currently around USD 0.4 per kWh.
- Net charge of electricity; meter run backwards when production is higher than consumption. In practice this is a form of tax reduction.
- Low taxation on PV equipment and installation

On the global market price per W peak capacity of PV modules is rapidly decreasing and was as of March 2012 at USD 2.2. (152) This is for the modules themselves, for full panels the price is higher since material for holding the modules in place and some wiring has to be added. Furthermore there is equipment like inverters, transformer and additional wiring that has to be added to the cost of a grid connected PV system. For off-grid systems also storage capacity usually in the form of lead batteries has to be added. The market is probably not fully competitive which mean that prices of PV systems are significantly higher than let's say Denmark though import tax on many types of renewable energy has recently been reduced. (153) A hardware distributor in Mombasa, SolarTech Ltd., sells whole PV systems at cost of roughly USD 20 per W. For an installation the PV panels themselves are about fifty percent of the investment. The labor is ten percent and the remaining forty are for accessories like batteries inverters and converters. Other companies in the same business are Chloride Exide and Davis & Shirtliff.

All modules are rated by manufacturers in terms of their peak power under standard test conditions: 1000W/m² of sunlight, 25 ºC ambient temperature and air mass of 1.5. In order to calculate energy generation from a PV system at a given location a number of factors need to be considered, apart from the solar irradiation; sun path over the sky, temperature, (PV output is reduced at high ambient temperature) panel inclination, shading and dust on surface. For calculating the expected potential of Lamu an online tool has been used; PV Watts, from the U.S. Department of Energy. Results show that one kW PV peak capacity will produce kWh 1406 per year in un-shaded, optimal inclination and with clean surface, (Appendix F). Given an average electricity price of ksh 18 and PV system price of USD 15 (a bit cheaper without battery storage) the simple pay-back time would be around 50 years. Since PV module life time is only about 20 years this is clearly not economically viable. This indicates that local PV market is not functional, possibly by cartel activities. For importing PV modules directly price, including inverters and transformers for grid feed-in, is estimated to be USD 3 or ksh 250 per W capacity.

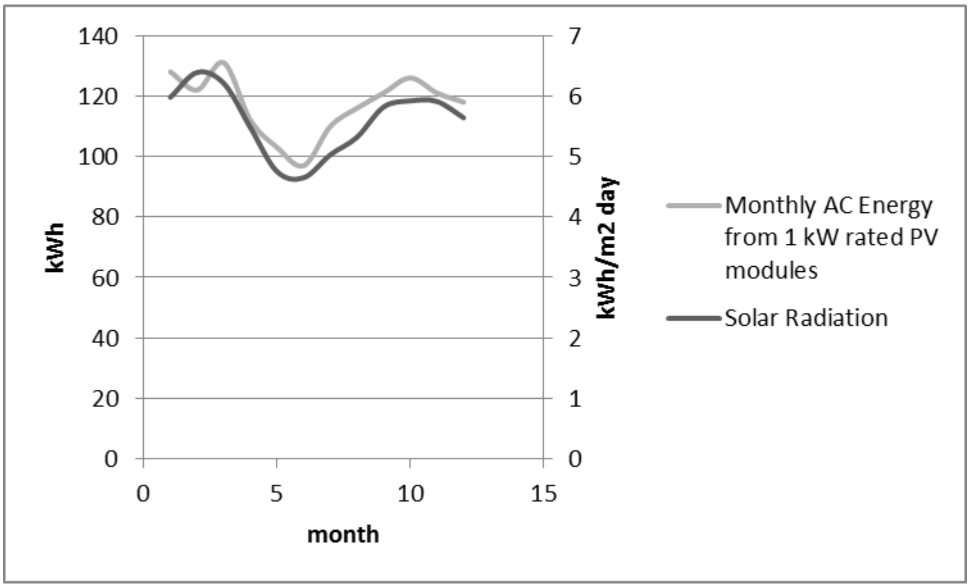



**Figure 16 Solar irradiation and monthly generation from 1 kW PV on Lamu optimal site conditions**

If Kenya would have similar energy policies and a developed market for grid connected PV systems as Denmark, PV would clearly be a at grid parity. However, already today the conditions (half the electricity price but double solar irradiation compared to Denmark) should be good enough if one bypass local PV retailers and import directly at a competitive price. If exceeding the own consumption profitability drop since there is no scheme for net charge or sales to the grid for common electricity subscribers. If going through the long process of becoming an IPP one can sell to the grid, it can be profitable to produce electricity with PV on Lamu though the feed-in-tariff policy document a bit confusingly states that a price not exceeding USD 0.2 per kWh shall be paid by the grid operator, (148). So profitability will depend on the tariff the IPP will be able to get from KPLC in the negotiations.

Solar water heating is a cheap and simple technology already in use for some of the hotels today. Since the climate is warm and the ocean always close, few people actually use much hot water for washing. Solar water heaters are therefore not included in the scenarios. For those homes and hotels which have not yet installed in is of course an economically and environmentally wise investment.

## 7.6. Tidal energy

Tidal energy is a promising technology since the energy density of moving water is so much higher than moving air. The channel between Lamu Island and the mainland experience a rather strong semi-diurnal tide meaning that mostly four times per day there is a current with 6 knots peak strength. Tidal power is intermittent as wind power put has an advantage of being very predictable, (154). First generation devices have reached large scale prototype stage for rigs in the British channel looking similar to 'marinized' wind turbines. Projected tidal electricity cost is £ 81.25 per MWh in UK (155). Projections for the capital costs for early 250 kW small batch constructions is just less than £ 3.5 million per MW and in later 500 kW larger batch productions £2 million per MW, (156). Tidal energy is a promising energy for Lamu in the future thanks to the strong tidal currents but since the technology is still rather immature it will not be considered in the scenarios of this paper.

## 7.7. Plastics recycling

Plastic littering is the largest environmental problem in the eyes of the people of Lamu and a local ban of thin plastic bags was in fact established by the County Council in 2011. There are however no enforcing of the rule whatsoever so they are still being used in every shop and market stand, (157). The Los Angeles County Board of Supervisors has adopted an ordinance banning single use plastic carryout bags at stores in the County unincorporated areas, while requiring they charge 10¢ for each paper bag provided to a customer. The 10-cent charge on paper bags is not subject to State sales tax, (158). Used fresh water bottles are the other large source of litter. This is a problem related to tourism since it is mostly tourists who buy their drinking water. The county council received two bottle compressing some years ago of which one is being used in Shella Town while the other one is placed at the Councils office in Lamu town without being used.

On Zanzibar, Tanzania, an ambitious enterprise of starting up local plastics recycling is under development. The waste resource base is according to investigation near the limit of economic sustainability. This is for an island of 2460 $km^2$, one million inhabitants and 200 000 tourist visits per year. PET will be made into flakes, PE and PP pellets, and sold on the international market. This is for a processing facility that invests in standard recycling machinery of the shelf, (159). Zanzibar has a factor 40 larger population and surface area compared to Lamu, meaning that the available amount of waste is not enough for an investment in modern recycling equipment. There is however low-tech options that can be adopted, simply melting PE or PP in an oil drum to mold construction bars or roof tiles is being done in a few locations in Nairobi. PET bottles cannot be molded this way but are also the polymer with the highest recycling value, around ksh 25 per kg, in Mombasa. Since Lamu is a net importer of good from the mainland there should be opportunities to arrange cheap transport of PET for recycling.

If no other solution can be made one might as well make use of the combustion energy, for example for cooking beans in large quantities, an energy intensive activity for the restaurants and households. It would also be favorable if incineration would take place in improved chambers to reach a more complete combustion. Even if it is not realistic that a sophisticated flue gas cleaning equipment will be fitted, better combustion will at least reduce amount of polluting hydrocarbons and carbon monoxide emitted. Special concern must be taken for PVC plastics which produce very toxic dioxins during combustion and should therefore not be burned at all. PVC is a common material for water, sewage and gas pipes.

# 8. Results

Simple projections of what the energy situation on Lamu Island will be like in 2015 for three different scenarios; business-as-usual, light green with modest initiatives in sustainability and deep green with substantial initiatives in sustainability. For all three scenarios population is expected to grow by 8 percent and energy use by 15 percent, equally distributed over the energy carriers, during the time period. Fuel prices are assumed to increase by 6 percent, inflation adjusted. Renewable energy technology hardware is assumed to remain at constant price though trend is they are getting cheaper. The national electricity grid connection is finished and Lamu Power Station only used for back-up power during a total of 7 days per year.

The two “green” future scenarios each include new energy sources and technologies for energy conversion that was chosen by the author. In energy systems modeling one can also make simulations where scenarios are created based on profitability under chosen restriction on for example a polluting emission, which is thus not the case for this study. The light green scenario been created with the objective of including the changes that would be cheap and ‘easy’ to implement. The deep green scenario was created with the objective of maximized but realistic transition to a sustainable energy sector with diverse, available and cost efficient technologies. The construction of the scenarios was made by connecting corresponding energy sources, carriers and end use activities with each other into complete energy supply chains.

During the creation scenarios estimations had to be made in order to describe complete supply chains. Current and future demand of liquid fuels and electricity is not exact since the data from field study was not complete. Yields of biomass from plants and conversion efficiencies are cannot be given exactly but are qualified estimations based on statements from commercial companies and scientific literature. The economic data for each scenario are not complete or accurate and only serve to show the order of magnitude of the investment required for new generating or processing capacity included in each scenario. Despite all estimations scenarios are not unrealistic possibilities for the future energy system depending on choices to be made and policies to be decided upon by the people on Lamu.

## 8.1. Business-as-usual scenario

If no investments in sustainable local energy are made and demand grow as previously mentioned projection the future energy system of on Lamu will look according to Figure 17. Land use for energy production in this scenario is only that of firewood production; around 410 hectares on Lamu and 1700 hectares on the mainland, total about 2100 hectares, for making the charcoal imported from the mainland. (If forestry was conducted in a sustainable manner, which usually is not the case) All energy except a small amount of firewood (or woody biomass) originates from Lamu Island.

| | | Fuel oil [* = L] | Kerosene [* = L] | Diesel [* = L] | Petrol [* = L] | LPG [* = kg] | Charcoal [* = kg] | Firewood [* = kg] | Electricity [* = kWh] |
|---|---|---|---|---|---|---|---|---|---|
| Annual consumption | [*] | 50600 | 233760 | 773760 | 742980 | 101664 | 2430000 | 2508000 | 9120000 |
| Price | [ksh/*] | 109 | 117 | 127 | 138 | 261 | 42 | 5 | 19 |
| Energy dispersity | [*/GWh] | 87800 | 97400 | 99200 | 101500 | 70600 | 112500 | 190000 | 1000000 |
| Energy price | [ksh/kWh] | 10 | 11 | 13 | 14 | 18 | 5 | 1 | 19 |
| Annual energy use | [GWh] | 0,6 | 2,4 | 7,8 | 7,3 | 1,4 | 22 | 26 | 9,1 |
| Island import balance | [Mksh] | -5,7 | -26 | -101 | -102 | -25 | -95 | 0 | -173 |

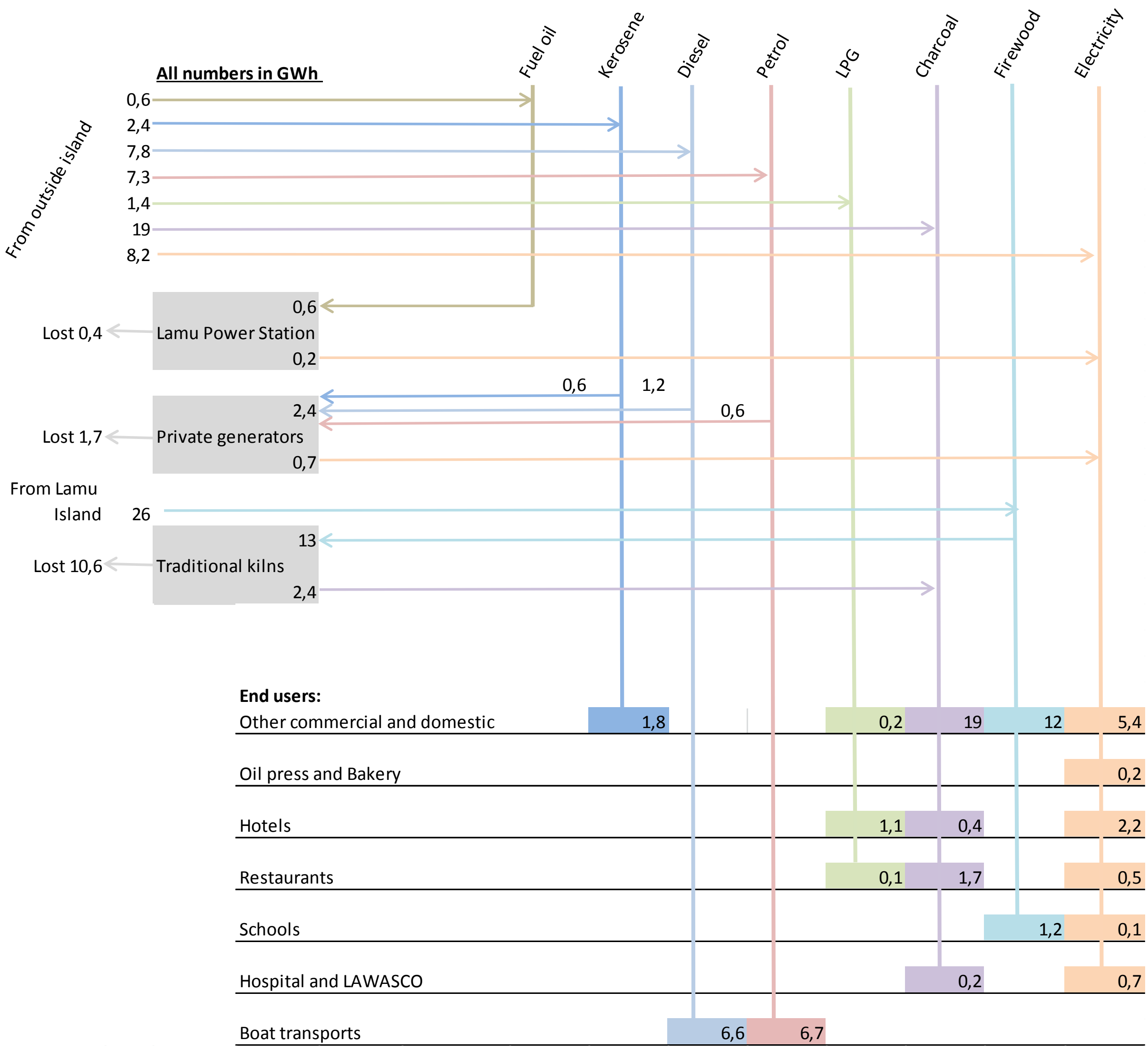



**Figure 17 Business-as-usual energy system scenario**

## 8.2. Light green scenario

- Reduced water use through prohibition of flushing toilets unless waste water AD treated and reused for bioenergy crops. Applied at schools, public institutions and a few hotels.
- Jatropha used for fencing and small plantation irrigated with waste water from schools, urine collected from dry-toilets and grey water drainage system
- Jatropha oil used directly in modified Lamu Power Station and private generators
- Jatropha press cake used in AD for biogas.
- One improved kiln for charcoal, production of 50 tons charcoal per year capacity on Lamu Island.
- One used 225 kW wind turbine by local initiative IPP for grid feed-in.
- Total of 70 kW of private PV installations by hotels and home owners to partly cover internal electricity use.

| | | Biodiesel [* = L] | Kerosene [* = L] | Diesel [* = L] | Petrol [* = L] | Biogas [* = m3] | Charcoal [* = kg] | Firewood [* = kg] | Electricity [* = kWh] |
|---|---|---|---|---|---|---|---|---|---|
| Annual consumption | [*] | 54000 | 233760 | 773760 | 742980 | 210000 | 2430000 | 2508000 | 9120000 |
| Price | [ksh/*] | 111 | 117 | 127 | 138 | n/a | 42 | 5 | 19 |
| Energy dispersity | [*/GWh] | 90000 | 97400 | 99200 | 101500 | 149000 | 112500 | 190000 | 1000000 |
| Energy price | [ksh/kWh] | 10 | 11 | 13 | 14 | n/a | 5 | 1 | 19 |
| Annual energy use | [GWh] | 0,6 | 2,4 | 7,8 | 7,3 | 1,4 | 22 | 26 | 9,1 |
| Island import balance | [Mksh] | 0 | -26 | -101 | -102 | 0 | -95 | -13 | -164 |

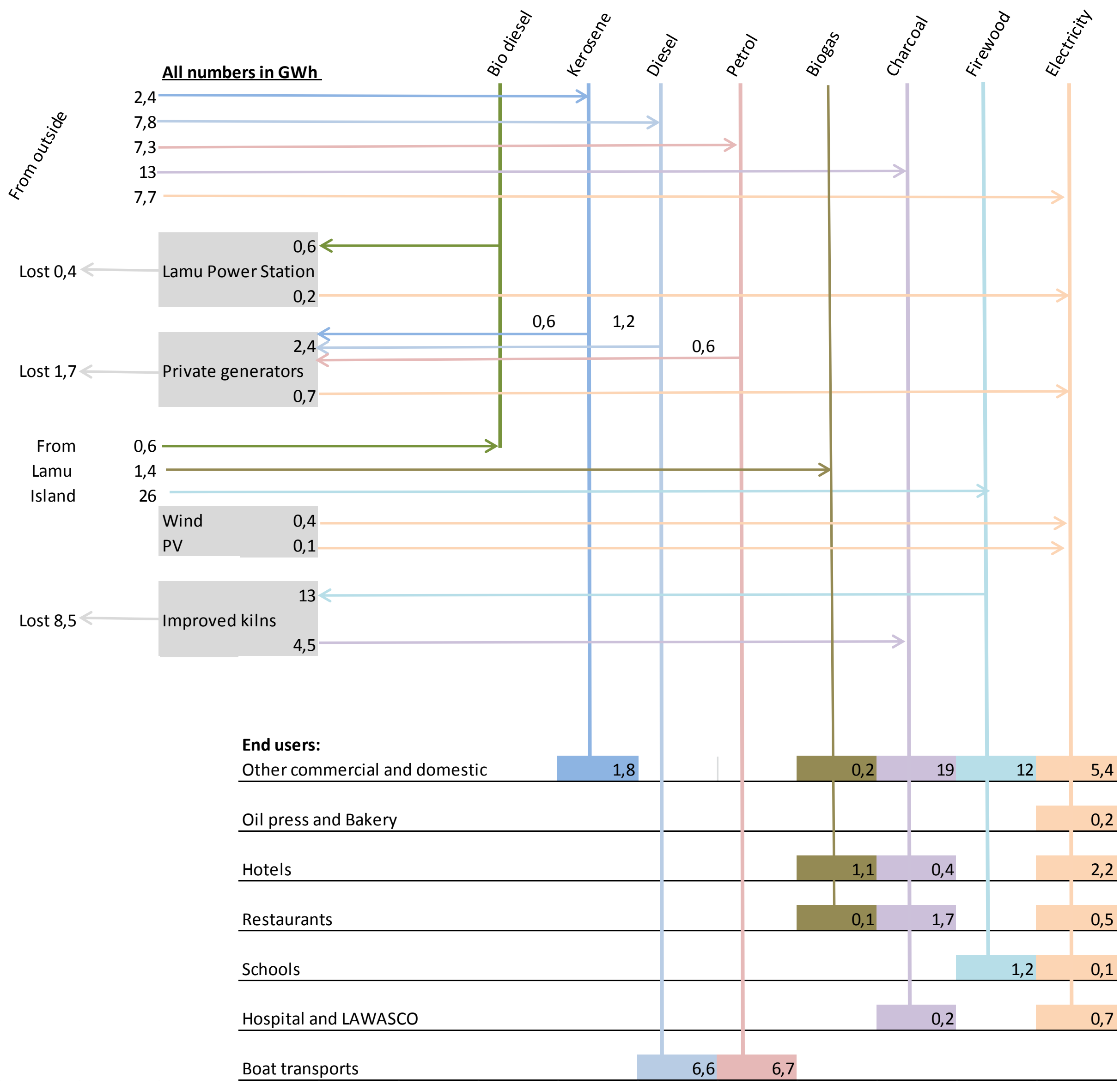



**Figure 18 Light green energy system scenario**

Biogas: AD of waste water from 5000 (2500 PE) school children, 400 person equivalents (PE) of other public institutions and 100 PE from hotels yielding 50 kWh biogas per PE and year. AD of jatropha press cake, 270 tons per year, with 0.6 $m^3$ biogas per kg yield give 162,000 $m^3$ biogas per year. (biogas; 6.7 kWh per $m^3$) Total biogas production: 1.4 GWh. Estimated investment cost: Ksh 23.8 million.

Biodiesel: 23 hectares of jatropha plantation irrigated with waste water from schools, urine collected from dry-toilets and grey water drainage system at 1500 liters per hectare yield plus 20 km of jatropha for compound fencing at 1 liter per meter per year yield. Total biodiesel production: 54,000 liters or 0.6 GWh. Estimated investments cost for processing equipment: Ksh 300,000.

Charcoal: The improved kiln has a wood to charcoal conversion factor of 0.35 as opposed to the traditional kilns with a factor of 0.18; an efficiency improvement yielding 2.1 GWh charcoal per year. Investment cost: Ksh 545,000.

Wind: According to calculations behind Figure 14 the annual output of the 225 kW Vestas V29 turbine would be 0.37 GWh of electricity. Estimated investment cost: Ksh 25 million.

Solar: 70 kW PV capacity would generate 0.1 GWh of electricity per year according to the PV Watts calculation software. Estimated investment cost: Ksh 18 million.

The total for-energy land use is 1150 hectares on the mainland for charcoal manufacturing, 410 hectares on Lamu Island for woody biomass and 23 hectares of biodiesel, in all around 1600 hectares.

## 8.3. Deep green scenario

- All households in urban areas of Lamu and Shella are connected to the small bore sewage system with UASB-septic tanks for nearly all houses
- Plantations of jatropha and sugar cane in waste water infiltration bed.
- Jatropha press cake used for AD.
- Plantation of cassava on arid areas for use as ethanol feed stock.
- Bagasse covering energy need of sugar cane and cassava ethanol production
- Six new 225 kW wind turbines by local co-operative IPP for grid feed-in.
- Total of 250 kW PV capacity by local co-operative IPP and hotels and home owners to partly cover internal electricity use.
- Mitigation of cooking fuel from charcoal to biogas
- Flash pyrolysis plant for conversion of wood into charcoal and bio-oil, on mainland since it reduce raw material transport but still included within scenario system boundary
- Refining plants for biodiesel, pyrolysis bio-oil and ethanol
- Extended and improved local electricity grid; no need for private generators.

| | | Biodiesel [* = L] | Biopetrol [* = L] | Ethanol [* = L] | Biogas [* = m3] | Firewood [* = kg] | Electricity [* = kWh] |
|---|---|---|---|---|---|---|---|
| Annual consumption | [*] | 2790000 | 684000 | 1100000 | 210000 | 1007000 | 9120000 |
| Price | [ksh/*] | 111 | n/a | n/a | n/a | 5 | 19 |
| Energy dispersity | [*/GWh] | 90000 | 99200 | 170000 | 149000 | 190000 | 1000000 |
| Energy price | [ksh/kWh | 10 | n/a | n/a | n/a | 1 | 19 |
| Annual energy use | [GWh] | 31 | 7 | 6,5 | 7,4 | 53 | 9,1 |
| Island import balance | [Mksh] | 0 | 0 | 0 | 0 | -53 | 0 |

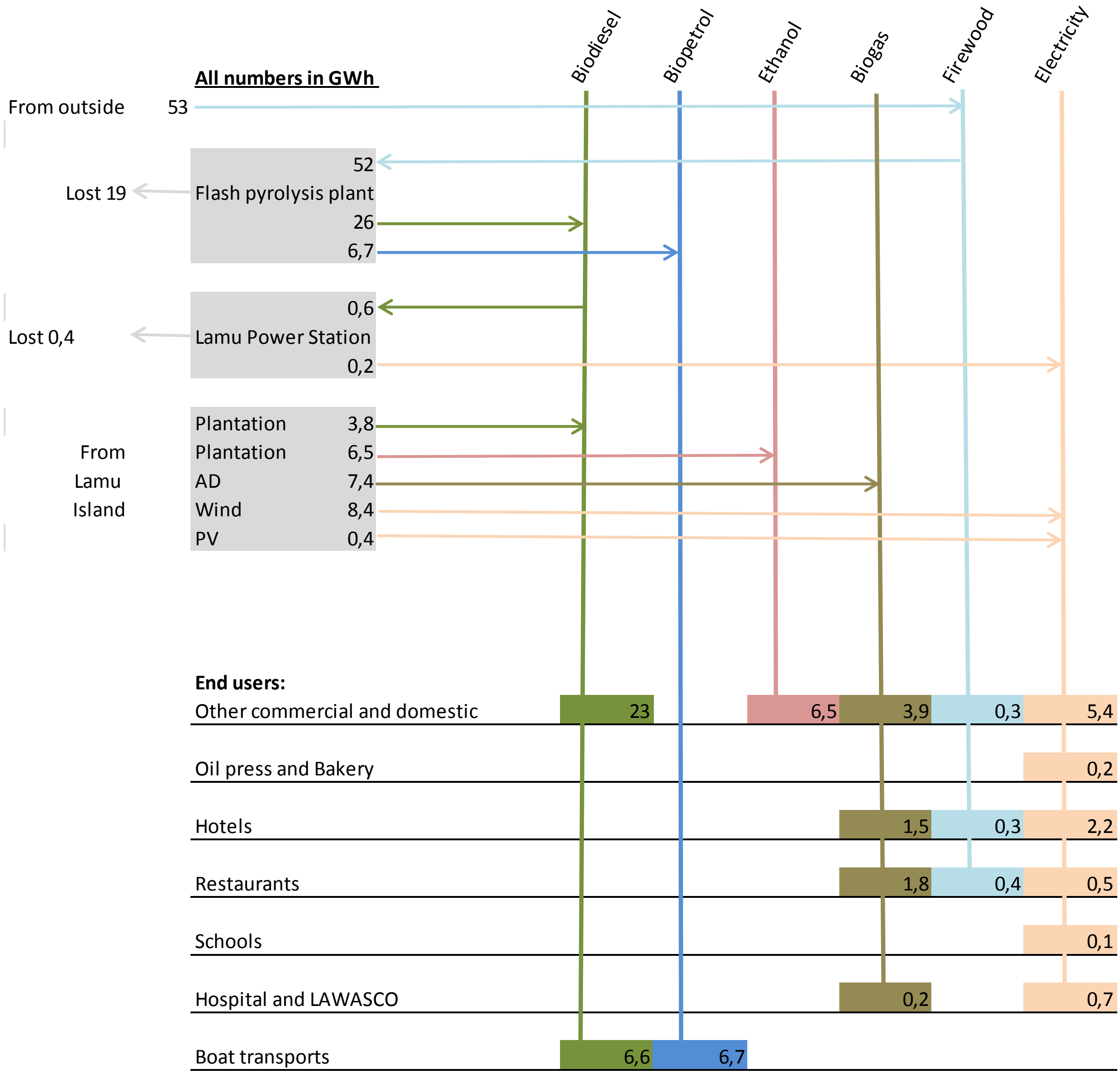



**Figure 19 Deep green energy system scenario**

Biogas: AD of waste water of 12000 PE at 50 kWh biogas per PE and 1700 tons of jatropha press cake per year give 7.4 GWh biogas. Estimated investment cost: Ksh 126 million.

Biodiesel: 200 hectares of jatropha plantation irrigated with AD treated waste water plus 40 km of jatropha fencing yielding 340,000 liters of biodiesel or 3,8 GWh per year. Estimated investments cost for processing equipment: Ksh 1.9 million.

Ethanol: 200 hectares of sugar cane plantation irrigated with AD treated waste water yield at 4000 liters per hectare. 100 hectares of rain fed cassava plantation yielding 3000 liters per acre. Total will thus be 1.1 million liters or 6.5 GWh of ethanol. Estimated investments cost for processing equipment: Ksh 93 million.

Bio-oil: Instead of traditional kilns a larger flash pyrolysis plant used. It would be located on the mainland since that is where most of the raw material is located. Size of plant would thus be to handle 10,070 tons biomass per year. 12 hours per day operation give 2,300 kg per hour. Input is 53 GWh per year so at 70 percent conversion ratio into bio-oil 36 GWh of this intermediate is produced. In the attached bio refinery bio-oil is turned into 26 GWh biodiesel and 6.7 GWh of bio-petrol. Total investment cost is in order of magnitude of ksh 160 million.

Wind: Figure 14 gives that the annual output of six 660 kW Vestas V47 turbine would be 8,4 GWh of electricity at assumed wind speeds. Estimated investment cost: Ksh 840 million.

Solar: 250 kW PV capacity would on Lamu generate 0.35 GWh of electricity per year according to the PV Watts calculation software. Estimated investment cost: Ksh 64 million.

Land use for energy purpose in the Deep Green scenario is 840 hectares for woody biomass on the mainland and on the island 200 hectares for biodiesel and 300 hectares for ethanol, thus total land use for energy of around 1340 hectares.

## 9. Discussion on results

It must be emphasized that the accuracy of data of neither analysis of current system nor future scenarios are precise. However, the purpose is not to provide material for an investment analysis of any included technology. It is not meaningful for to discuss profitability, annualized costs or pay-back periods for the technologies. The aim of this report is to show what possibilities there are for Lamu Island to become for self-sustainable in terms of energy. This is also why for example a certain amount of PV has been introduced in the 'green' scenarios even though it has significantly higher investment cost per unit energy produced than wind power.

Future energy need have been projected to grow equally for all sectors and energy carriers, by 20 percent; this is not a probable case, for example the schools will hopefully increase their energy use more as they get better facilities, more equipment and start serving school lunch.

Energy use of bio fuel processing or refining, for example biodiesel production and AD, has not been specified but they have simply been given an efficiency which takes this in consideration.

Land use on mainland for provision of the woody biomass used for making char coal is not reflected well in scenarios. Only in the deep green scenario it says how much woody biomass is used from the mainland; 52 GWh which corresponds to 870 hectares of land used for this purpose, which is a lot. However, in the Business-as-Usual and Light Green scenarios there is 19 or 13 GWh of charcoal brought to the Island which require 1800 and 1200 hectares of surface on the mainland respectively. For the moment a lot of timber for charcoal making comes from the area, 40,000 hectares, where the port is being built.

One way of significantly reducing the land use for bio-energy in all scenarios would be to increase use of electricity for cooking. An electric stove is however a very illogic investments for most people on Lamu; very expensive, will not reduce running cost of cooking and is not the preferred way of cooking

Wind power does seem to be clearly more economical than PV in the brief economical investgation. However, it could be a good to install some PV in order build experience, it seems cost of PV will continue to decrease in the future. PV is also regarded to be less intrusive on the visual environment which is an advantage.

It is obvious that biodiesel has lower investment costs than ethanol. However, yield of the jatropha plantations are still highly uncertain and they may have been over estimated. It is also interesting to see how ethanol perform because it as a replacement of petrol it could generate a high sales price.

Transition from imported fossil fuels to sustainable and efficient domestic fuels will also result in lower emissions of GHG emissions.

Positive development works like evolution, step by step, new technologies must come hand in hand with local capacity building in all type of capital; natural, financial, productive, infrastructural, human, institutional and social. The author would strongly discourage large scale tech-fixes dependent on external financial and human capital, for example purchase of a large bio-oil pyrolysis plant. Each of the suggested technologies in this thesis can be introduced in an evolutionary manner which would also bring down cost for consultancy, maintenance and provide jobs for local population. A few small scale, low-tech, anaerobic digesters can be introduced as pilot plants (this was made by the author during field study period, a soft membrane PFR that did produce biogas but a biogas stove could not be bought in time before departure). A few jatropha plants can be planted and used also as fencing to demonstrate and give experience on biodiesel production.

## 10. Conclusions

Water is the most urgent environmental issue on Lamu which will soon have large humanitarian, environmental and economic effects if not addressed properly. Reducing the outtake from the Shella aquifer and better waste water management in Lamu town is required. Water, food, waste and energy is however one interconnected system. Reducing water use and waste water treatment in an energy and cost efficient manner require combined solutions, such as reusing waste water for irrigation and fertilization. It will further assist in the important issue to get rid firewood and charcoal use in traditional stoves for three reasons; health impacts, low energy efficiency and the global warming effect of the sooth they emit.

It is not only a matter of good practice; the laws of Kenya continuously violated by the current situation. But who is responsible? Can the case be taken to court? Loss of fresh water resource is not easily reversible. Convicting someone for malpractice after it is already gone will not help much.

Communication between local governance and the community is not functional today. Important announcements are today made by employing a person walk around to shout out the information all over town. The challenges standing before Lamu will require involvement and participation of the whole community. Islam, its prayers and mosques, are most probably the largest source of social capital on Lamu Island. Involving the Imams to address these urgent issues in their services would be a great way of generating knowledge. Football is probably the second largest source of social capital on the island. There are a number of cinemas normally showing games from the European leagues and action movies in the evenings that could be used for informative and educative movie shows.

Financing the large investments of the green scenarios will not be easy for any individual stakeholder on Lamu, and it is probably not worth waiting for the central or regional government to do it. A suggestion is to form well-structured and co-operatives. For example as a co-operative IPP buy wind or PV generating capacity or for a group of farmers buy biodiesel processing equipment.

Implementation of technologies in green scenarios will require skilled and inspired people. This is why the local schools, mainly Lamu Polytechnic Collage and the secondary schools, will play an important role of educating people in appropriate technologies. Education is very much an instrument that influence the direction of social development, even purely technical schooling, since people tend to engage in activities they have knowledge about.

Appropriate technology is methods and solutions designed to be "appropriate" to the context of its use. The concept is closely related to sustainability and the ‘Small is Beautiful’ thinking, which places more power at the grassroots, in the hands of the users and local entrepreneurs. However, there are also examples when the most appropriate technologies are large-scale. Appropriate Technologies are always adapted to the local conditions, an appropriate solution for one context may not be appropriate for another. Further, an appropriate technology should be easy to maintain to be effective in practice. To be effective for many people and have a wide impact, an appropriate technology must be affordable. There is a global movement for the spreading of theory and experience of appropriate technology solutions, a lot of it based around the website: www.appropedia.org.

Today there is a heavy dependence on tourism for the local economy of Lamu Island. During 2011 and 2012 the island experienced how an insecure source of income tourism can be. After a few kidnapping incidents many countries advised against traveling to the region which significantly reduced the number of tourists. Many people normally living of the tourism industry did during this time not afford proper food and health care. With better local import-export balance, more internal food production and energy sources, Island will be more resilient in times of lower tourism.

For the Kenyan energy sector in general better energy policies could be wished for:

- Net charge of electricity for households would promote private investments in renewables.
- Feed-in-Tariff policy needs to be re-formulated since it does not clearly state the minimum price power producers will receive for their electricity and no guarantees that all output will be bought.

Water most urgent and large share of Swedish aid is for this sector. Lamu Island is not the poorest and most needing location. However, since private sector (hotels and tourism) and interests will assist the chance of success can be rather good. This will provide inspiration and experience to apply similar solutions in other locations in the future.

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# Appendix A – Current and planned national electricity grid

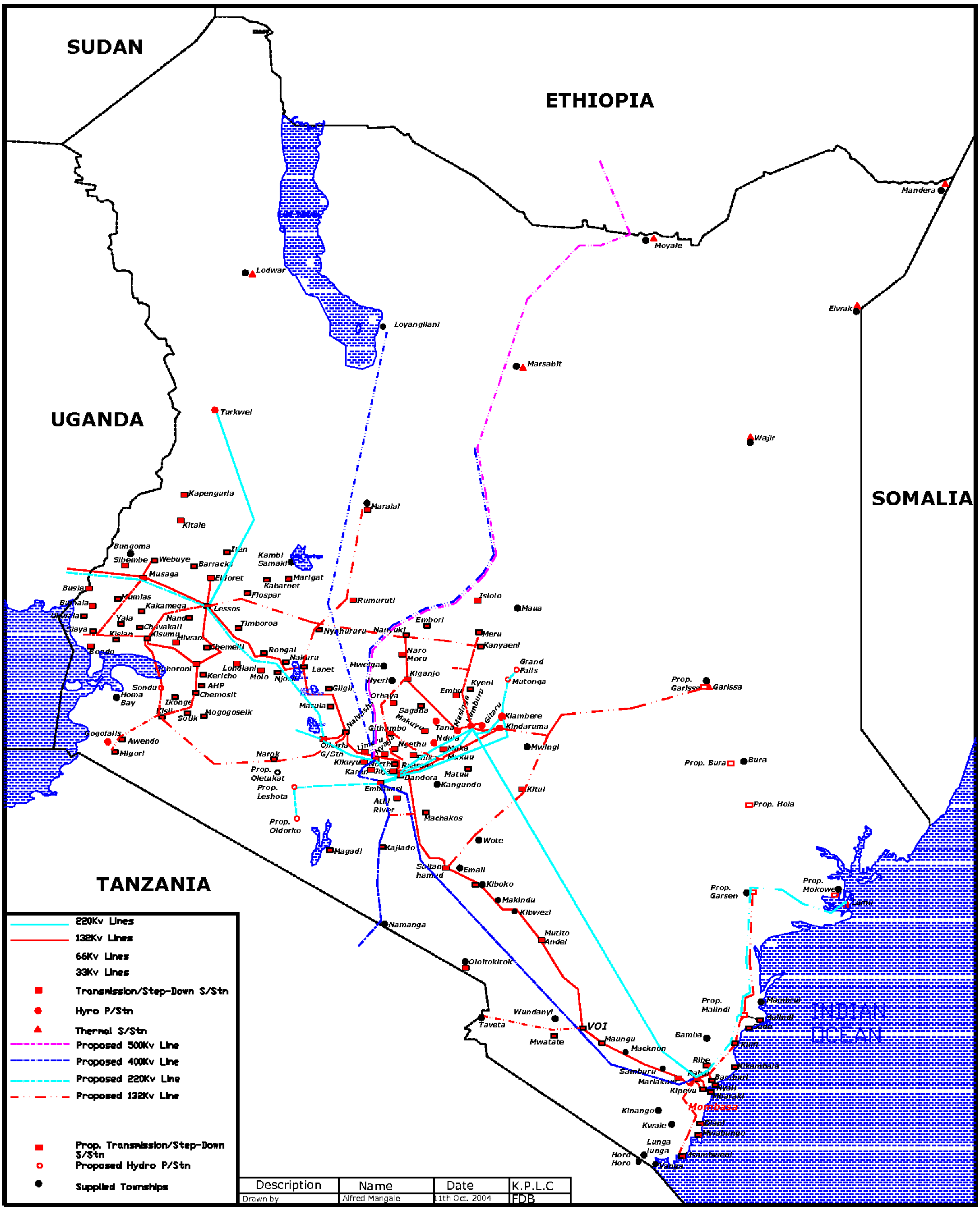



**Figure 20 Current and planned electricity grid of Kenya**

# Appendix B – Biodiesel processing

**Table 9 Investment cost breakdown of a biodiesel processing plant**

**PROFORMA INVOICE**

**TINYTECH OIL MILL CRUSHING CAPACITY 6 TONES JATROPHA IN 24 HOURS**

**Approximate output 25% pure filtered oil of crushing capacity**

(BIO DIESEL PLANT FOR CAPTIVE CONSUMPTION)

| Description | Rate | Qty 6 Tn | USD 6 Tn |
|---|---|---|---|
| Oil Expeller 22"x4" crushing capacity 125 kg./hr. complete | 2500 | 2 | $ 5000 |
| Round feeding / cooking kettle complete | 600 | 2 | $ 1200 |
| Electric motor 12.5 hp 960 rpm with starter | 800 | 2 | $ 1600 |
| Accessories (Pipelines, beltings, valves, fittings) | 350 | 2 | $ 700 |
| Filter press 16"x16"-16 plates complete with all accessories | 1500 | 1 | $ 1500 |
| Spare parts kit for 3 years for 2 expellers + 1 filter press | 1350 | 1 | $ 1350 |
| Digital weighing scale capacity 500 kg. with SS platform size 2 feet x 2 feet | 250 | 1 | $ 250 |
| Trans Esterification vessel of Mild steel capacity 1000 lit/batch with 1.5 HP electric motor | 1500 | 1 | $ 1500 |
| Jatropha Decorticator (250 to 300 kg per hour ) with 2 HP motor + starter. | 1200 | 1 | $ 1200 |
| Baby boiler complete with all required accessories | 1100 | 1 | $ 1100 |
| | **FOB INDIAN PORT** | | $ 15400 |
| | **Mombasa ( Kenya)-Kenya Sea Freight** | | $ 1300 |
| | **C&F Mombasa ( Kenya)** | | $ 16700 |

# Appendix C – Wind speeds

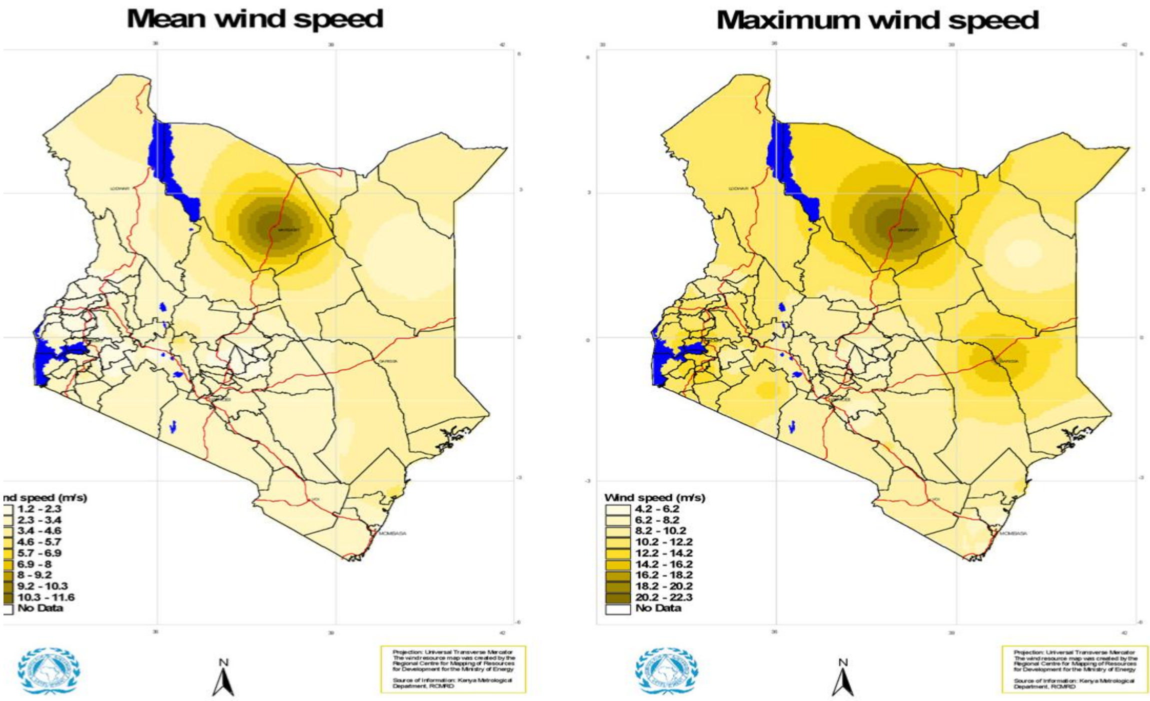



**Figure 21 Wind Atlas for Kenya 2004, Ministry of Energy. Rebublic of Kenya.**

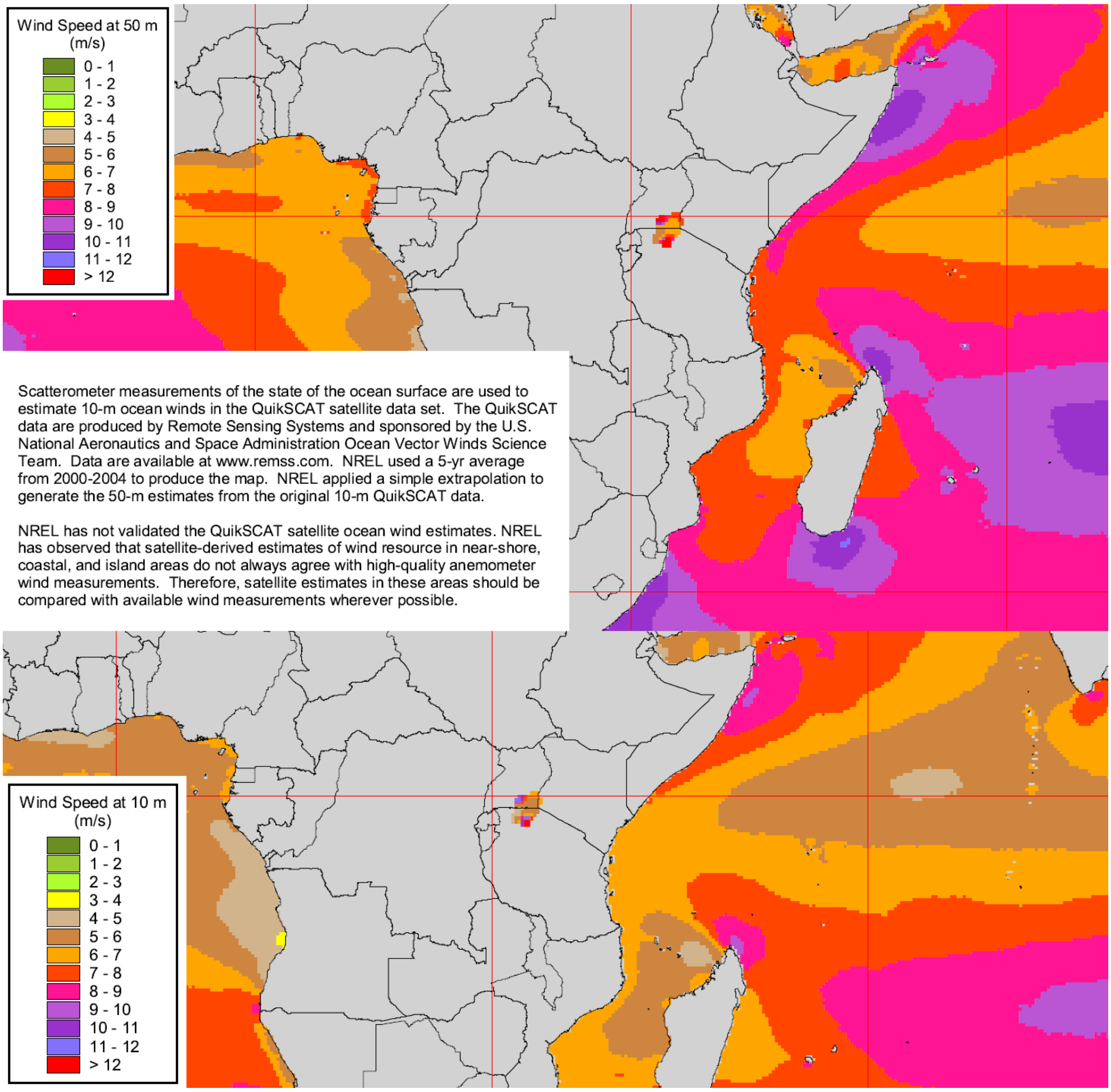
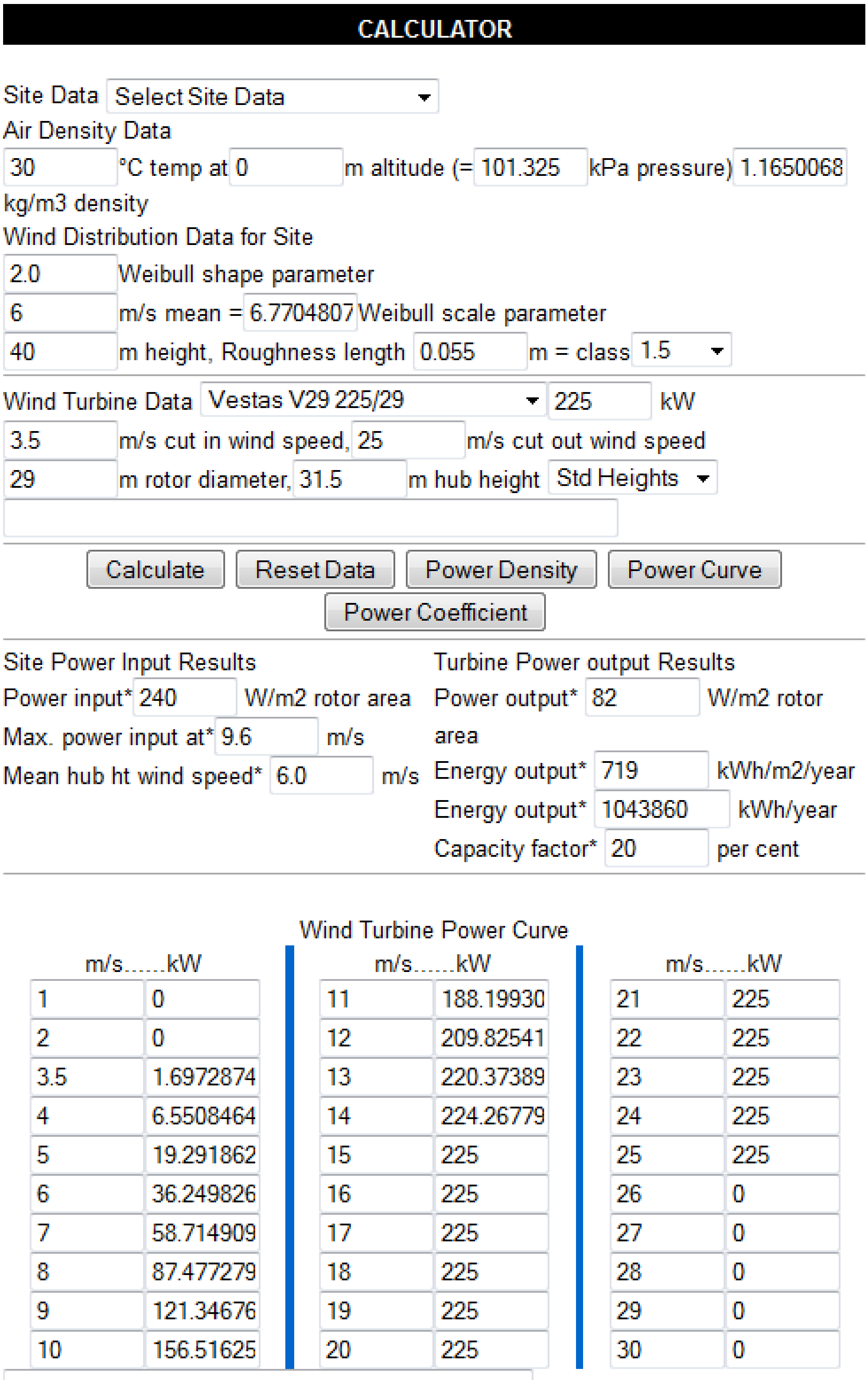



**Figure 22 Ocean surface vector wind data from the QuikSCAT mission**

# Appendix D – Wind calculator



CALCULATOR

Site Data: Select Site Data

Air Density Data

30 °C temp at 0 m altitude (= 101.325 kPa pressure) 1.1650068 kg/m3 density

Wind Distribution Data for Site

2.0 Weibull shape parameter

6 m/s mean = 6.7704807 Weibull scale parameter

40 m height, Roughness length 0.055 m = class 1.5

Wind Turbine Data: Vestas V29 225/29, 225 kW

3.5 m/s cut in wind speed, 25 m/s cut out wind speed

29 m rotor diameter, 31.5 m hub height, Std Heights

Calculate | Reset Data | Power Density | Power Curve | Power Coefficient

Site Power Input Results

Power input* 240 W/m2 rotor area

Max. power input at* 9.6 m/s

Mean hub ht wind speed* 6.0 m/s

Turbine Power output Results

Power output* 82 W/m2 rotor area

Energy output* 719 kWh/m2/year

Energy output* 1043860 kWh/year

Capacity factor* 20 per cent

Wind Turbine Power Curve

| m/s | kW | m/s | kW | m/s | kW |
|---|---|---|---|---|---|
| 1 | 0 | 11 | 188.19930 | 21 | 225 |
| 2 | 0 | 12 | 209.82541 | 22 | 225 |
| 3.5 | 1.6972874 | 13 | 220.37389 | 23 | 225 |
| 4 | 6.5508464 | 14 | 224.26779 | 24 | 225 |
| 5 | 19.291862 | 15 | 225 | 25 | 225 |
| 6 | 36.249826 | 16 | 225 | 26 | 0 |
| 7 | 58.714909 | 17 | 225 | 27 | 0 |
| 8 | 87.477279 | 18 | 225 | 28 | 0 |
| 9 | 121.34676 | 19 | 225 | 29 | 0 |
| 10 | 156.51625 | 20 | 225 | 30 | 0 |

**Figure 23 Image of the Power Calculator from the Danish Wind energy Association**

# Appendix E – Solar irradiation map

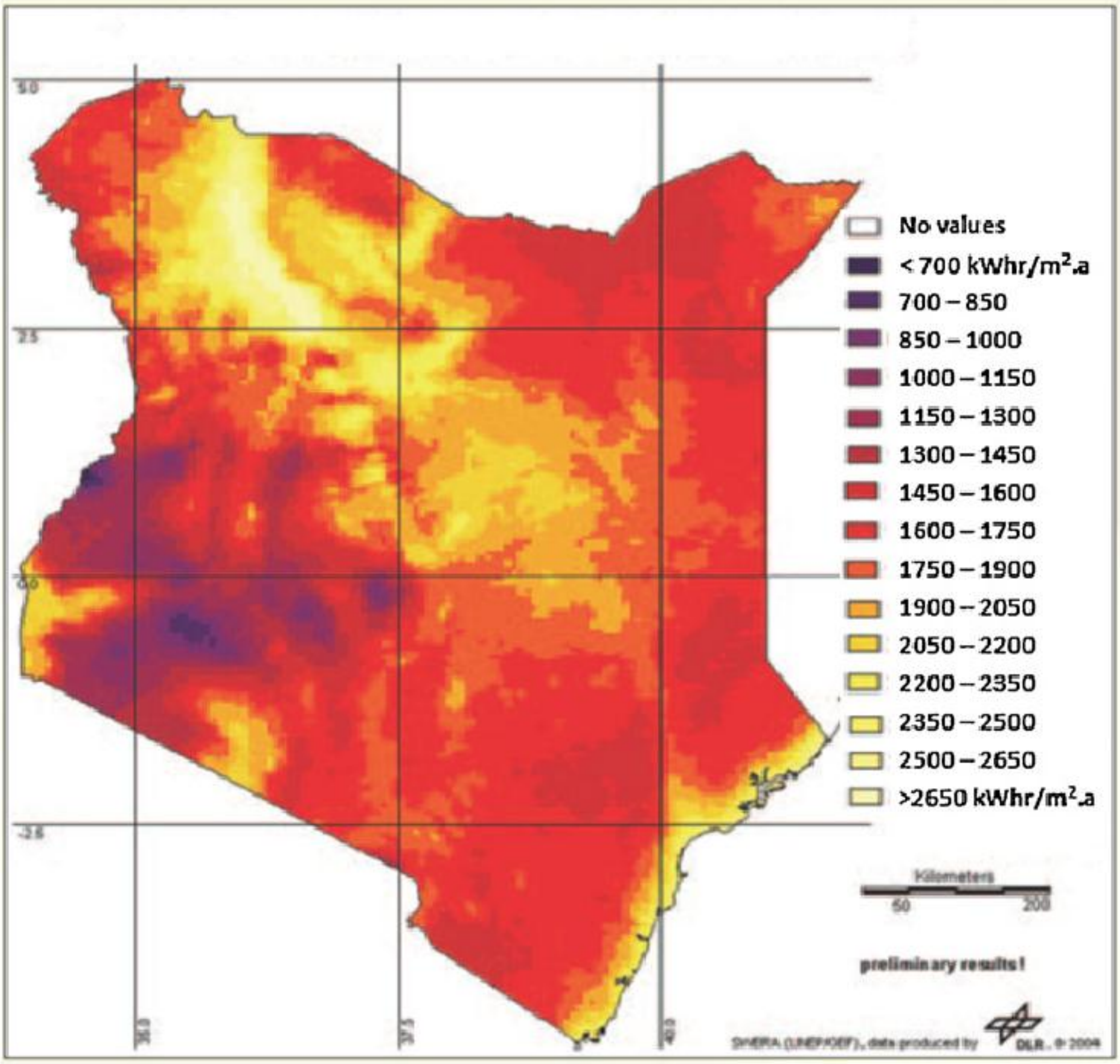



**Figure 24 High resolution solar radiation assessment for Kenya: SWERA report.**

# Appendix F - PV output

"PVWatts Site Specific Data calculator allows users to select a photovoltaic (PV) system location from a defined list of options. For locations within the United States and its territories, users select a location from a map of 239 options. For international locations, users select a location from a drop-down menu of options.

The PVWatts Site Specific Data calculator uses hourly typical meteorological year (TMY) weather data and a PV performance model to estimate annual energy production and cost savings for a crystalline silicon PV system. For locations in the United States and its territories, the PVWatts Version 1 calculator uses NREL TMY data. For other locations, it uses TMY data from the Solar and Wind Energy Resource Assessment Programme, the International Weather for Energy Calculations (Version 1.1), and the Canadian Weather for Energy Calculations. The Hourly Data calculator offers data only for defined locations. If your U.S. location is not included, you may choose a nearby, similar site or use PVWatts Grid Data Calculator (Version 2)."

**Table 10 Conditions for calculated PV capacity factor on Lamu Island**

| Station Identification | |
|---|---|
| City: | Lamu&Manda Island |
| Country/Province: | KEN |
| Latitude: | 2.27° S |
| Longitude: | 40.83° E |
| Elevation: | 6 m |
| Weather Data: | SWERA |
| PV System Specifications | |
| DC Rating: | 1.00 kW |
| DC to AC Derate Factor: | 0.77 |
| AC Rating: | 0.77 kW |
| Array Type: | Fixed Tilt |
| Array Tilt: | 2.3° |
| Array Azimuth: | 0.0° |
| Energy Specifications | |
| Energy Cost: | 18 shilling/kWh |

Table 11 Components of the derate factor

| Component Derate Factors | |
|---|---|
| Component | Derate Values |
| PV module nameplate DC rating | 0,95 |
| Inverter and Transformer | 0,92 |
| Mismatch | 0,98 |
| Diodes and connections | 0,995 |
| DC wiring | 0,98 |
| AC wiring | 0,99 |
| Soiling | 0,95 |
| System availability | 0,98 |
| Shading | 1 |
| Sun-tracking | 1 |
| Age | 1 |
| **Overall DC to AC derate factor** | **0,769** |

## Appendix G - PV price development


**Figure 25 Development of PV module prices from year 2006 to 2012**

http://www.solarwirtschaft.de/typo3temp/pics/5ac74bf10c.jpg