Windpower in Kenya

report of a mission carried out for the
Belgian Agency for Development and Co-operation (BADC)

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1 Executive Summary

The Belgian Minister for Development and Co-operation charged BADC with a pre-feasibility analysis of windpower in remote towns in Kenya. In 1988 and in 1994, Belgium had granted a 200 kW, respectively a 150 kW and a 200 kW windturbine to the Kenyan electricity system. The former one is operating in an isolated, small rural system (Marsabit); the latter ones are integrated into the Kenyan interconnected system. Both projects are performing good to excellent, and their performance can further be improved with minor interventions.
Given these successful projects, the question is open whether they can be extended, and on what (financing) terms. An identification mission was carried out during November 13 - 24. Next to both existing projects, two candidate remote sites (Lamu and Garissa) were visited.
For the economic appraisal of windpower projects in isolated, small power systems, a computer model has been developed. Unfortunately, the basic data for feeding the model are largely missing, i.e. detailed statistics about the prevailing windspeeds at the sites favourable for windturbines and detailed electric load profiles characteristic for daily and seasonal load fluctuations. Both statistics are necessary to evaluate the balance of windpower supply and electricity demand, a balance determining completely the economics of investments in windturbines. Because collection of all the necessary statistics is a lasting task, requiring designated measurement equipment for the windspeeds observations, the model has been run with second-best data assembled during the mission and completed by fax afterwards.

The economic appraisal shows that windturbines are meaningful in a few places in Kenya, but certainly not in all places that have been proposed. The pay-backs of even the best projects run at 7 to 8 years, making foreign private capital an unlikely supporter of this type of projects. Moreover, the information basis is still lacking for the design of a convincing business plan of the projects, making private investors even more reluctant.

Given these circumstances, we advice BADC to focus on the most promising site, being Lamu-Mokowe, to help in the preparation of the project and to be ready to take up the granted financing of at minimum all the foreign components in the project and preferably also the local contracting work necessary to bring the project in operation in due time. We also advocate the upgrading of the Marsabit and Ngong Hills projects, requiring but few resources.

For the proposed intervention and for realising the Lamu-Mokowe project a budget of ca. 50 million BF for the years 1996-1997 should be reserved.
Next to its positive economic balance, investing in windpower shows significant positive externalities by providing a renewable, non-polluting, independent energy source. The high likelyhood of success and the visibility of the projects are a wellcome return for the joint Belgian and Kenyan efforts.

2 Economic evaluation of energy projects

In this chapter we give an introduction to the basics of the economic evaluation of energy projects. Readers that are familiar to the methods of economic appraisal can easily skip this chapter.

2.1 The five major determinants of profitability

The economic appraisal of most energy projects, whether in supply extension or in demand reduction, is generally based on the value of five major variables, i.e.:

1. Initial investment
2. The applied profitability criterium
3. Operation costs
4. Technical performance of the project (i.e. energy produced or energy saved)
5. The price of the next-by alternative solution

The first four variables in the list togehter determine the unit cost of the supplied or the saved energy by the project. This cost has to be compared with unit costs or prices of alternative solutions, referred to as the fifth variable in the above list. We discuss the five variables briefly.

1. Initial Investment.
The capital investment in a project is of course one of the major determinants of the economics of the project. In most applications, it is useful to express the initial investment as a specific cost, e.g. in \$ per kW or in \$ per m^2 rotor area for a windpower generator. As such the initial investment is well understood by all decision-makers.

2. The applied profitability criterium.
In the literature it is argued that Net Present Value (NPV) is the most performing criterium to judge investment proposals, mainly because it takes into account the time value of money and because it considers all the important cash flows of the project over a relevant time span or time horizon. Applying this criterium requires the projection of all cash flows of a project over the entire time horizon considered, and it is precisely this effort that is assessed as being too costly by most decision-makers. From this attitude follows the ineradicable popularity of the Pay-Back (PB) criterium: the initial investment is divided by the expected annual nett return of the project, and the outcome is compared with some prior stated maximum value of acceptable PB. One also can start from the latter and by division of the initial investment by the announced maximum PB-value, one learns the minimum annual nett return that a project has to yield in order to meet the imposed profitability requirements of the decision-maker.
Another short-cut and popular method of imposing profitability requirements on investment projects is the annuity factor δ, i.e.:

$$\delta\,(i,n) = \frac{i(1+i)^n}{(1+i)^n - 1}$$

with: i = time value rate (discount rate) in percentage points
n = time horizon of the project

By applying the annuity factor one charges the investment money with its time value (i %) and takes into account the time horizon of the project (n years). When applying the annuity factor to the initial investment one converts the initial total investment into yearly costs. The constant yearly $-amounts indicate the minimum annual nett return the project must yield in order to meet the profitability requirements of the investor.

Although pay-back and annuity factor methods are short-cut and not as comprehensive as a full-scale nett present value calculation, they are very popular and used by a majority of decision-makers, especially in the crucial phases of project appraisals when a variety of alternative proposals are screened against one another. We will include both pay-back and annuity factor criteria into our analysis here.

3. Operation costs

In this category we classify a multitude of small cost components related to the operation of a project, e.g. maintenance, inspection, control, insurances, etc... From project to project operation costs can vary widely, and in many cases rules of thumb are applied for their assessment. Mostly a fixed percentage of the initial total investment is handled as an approximation of the yearly operation costs of a project, especially for projects of a static nature that do not require a lot of personnel, nor a large throughput of resources. Typical examples of this type of energy projects are windpower generators, along with others such as solar panels, electric power transmission lines, etc... and in practice operation costs of this type of realisations are set at a fixed percentage (such as e.g. 1.5%, 2%, ..., 5%, ...) of the initial investment, or as some fixed yearly amount assessed with a rule of thumb based on engineering experience.

4. Technical performance.

Every energy project has as a purpose to generate, convert, transfer or to save energy resources. A windturbine should produce power, a thermal solar panel should deliver heat to its owner, a photovoltaic panel should deliver electricity to its owner, a power transmission line should transmit power from a source node to some load center, and so on.

The technical performance of a system is of course a major determinant of the economic performance. Technical performance may be limited by irregularity or shortages in supply (e.g. the intermittent and variable supply of winds limits the technical output of windturbines). Also limited demand on an energy system may limit its performance (e.g. the number of kWh usefully generated by a windturbine depends on the demand by the load center feeded by the windturbine). Also a combination of supply and of demand factors can put a ceiling on the technical performance of particular energy projects, while technical limits (e.g. losses due to conversion) will further lower the nett energy performance.

The nett energy performance of energy projects is the basis for recovering the investment and the operation costs of the projects. The higher the performance the better the total costs can be spread, and this will result in a lower specific or unit cost of the supplied or conserved energy.

5. The price of the next-by alternative solution.

In most cases project appraisal boils down to comparing several alternatives. Generally a decision-maker has a choice between whether realizing the proposed project or continuing business-as-usual or buying the required energy resources from some other supplier (a central energy company, or an energy importer, etc...). The price that is charged for the opportunity energy is the final yardstick for the profitability of the own project: when e.g. electricity purchased from the grid is cheaper than electricity saved by the proposed conservation project or than electricity generated by photovoltaic cells of a renewable energy project, the profitability of the latter projects is not guaranteed.

2.2 Interdependence of the five major determinants

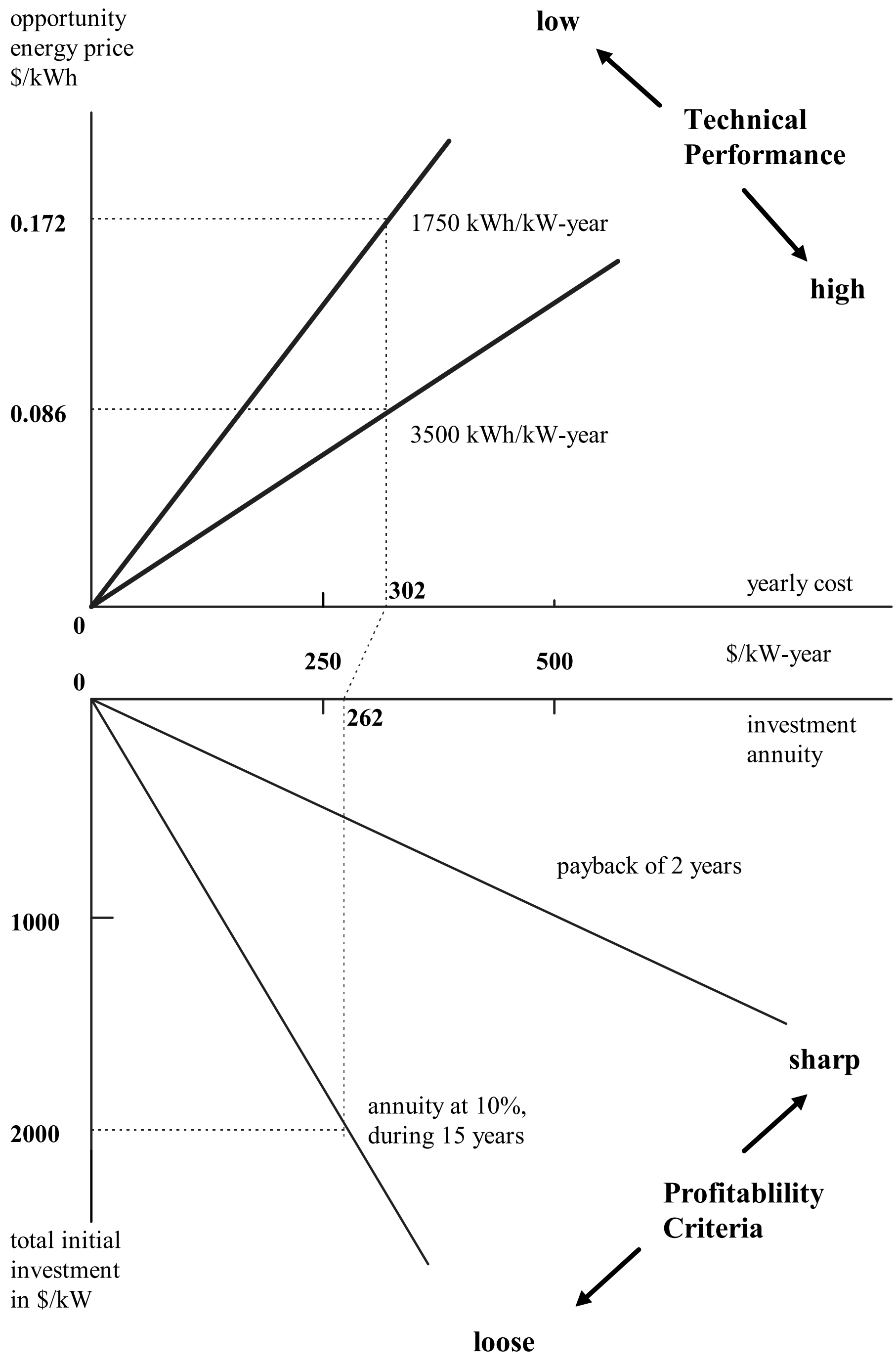
The five factors discussed above in 2.1 should be interrelated to find out about the economics of project proposals. The easiest way to understand the interrelationships between the five variables is to use the tool of a diagram that integrates the five determinants. Such a diagram is given in figure 1, with the above five variables shown counter-clockwise. For purposes of clarity an example of investing in windpower is used.

The bottom-part of the figure shows the transformation of total initial capital investment into an annuity. This transformation totally depends on the profitability criteria imposed by the decision-makers. Weak requirements (i.e. rays in the south-east quarter of the diagram that are sloping near to the south-pointing axis) convert investment sums into small annuities, while stringent requirements (i.e. rays in the south-east quarter of the diagram that are pointing rather eastwards) result in relatively high annuities. As an example it is shown how an investment in a windturbine at \$2000/kW is transposed with an annuity factor $\delta(i=10\%;n=15 \text{ years})=0.1315$ into a yearly sum of \$262/kW-year. The other rays shown in the south-east quarter of the diagram represent the profitability criteria of a 5 year and of a 2 year simple pay-back requirement on investment.

To the investment annuity one should add the yearly operation costs to keep the windturbines in good operational conditions. In the diagram of figure 1 this is simply done by a translation on the horizontal axis of the yearly costs. For purposes of clarity it is better to draw a second horizontal axis at a short distance above the first one to make the translation apparent. In the example we assume a budget for normal operational expenses at 2% of the initial investment outlays to be necessary. This amounts to 0.02x\$2000 = \$40 per kW-year. Added to the investment annuity, this increases the yearly cost that must be covered to \$302 per kW installed windpower capacity.

In the upper part of the diagram of figure 1 it is shown how the yearly electricity generation per kW installed capacity can repay the yearly cost per kW of the investment. When the power generation per kW is high (corresponding to rays of modest slope in the north-east quarter of the diagram), the costs can be spread over many kWh and the resulting specific cost of wind electricity is low, e.g. \$302/kW-year spread over 3500 kWh/kW-year (i.e. a capacity factor of 40%) gives a cost of \$0.086 per kWh). At lower capacity factors due to lower or to more irregular wind speeds and/or lower technical performance of the windturbines (represented by steep rays in the north-east quadrant of the diagram), the specific cost of windpower increases drastically.

Figure 1: Interdependence of the major determinants of the economics of energy projects



Continuing the example shown in figure 1, when the technical performance of the windproject would end in a capacity factor of 20%, i.e. supplying a total of 1750 kWh/kW-year, the unit cost of windpower amounts to $0.172 per kWh, or in other words a two times lesser technical performance is reflected in a two times higher specific cost of the system.

Whether the final specific cost of the output of an energy project is economic yes or no depends on the price of the other opportunities open to the decision-maker. When e.g. grid power is available and cheap, windpower will not be competitive in most cases, but when grid power is very costly to bring by, even windpower systems of limited efficiency will be competitive, i.e. its specific cost pointed on the upward vertical axis will be below the opportunity cost of other alternatives or below the prices charged in the market place.

With the very straightforward diagram of figure 1, it is easy to analyse all feasible conditions of the profitability of energy investment projects, because in the diagram the five major determinants of that profitability are linked to one another. The analysis with the diagram can be started from any one of the five determinants on: one can start with the initial investment as we have done in the example above, or one can start at the ray of the expected technical performance of the project and then look for the maximum affordable initial investment, given particular values for the other factors determining also the profitability of the project i.e. the opportunity cost of other energy supplies, the operation costs of the system and the imposed profitability criterium.

3 Determinants of windpower economics

The interrelationships discussed in chapter 2 are modelled in a spreadsheet program. This program has been prepared for this mission, and it allows the appraisal of any proposition of windpower investment in a remote town of Kenya (not connected to the grid).

Some of the inputs for running the model are the same or nearly the same for all sites, and we discuss them here. In particular the investment and operation costs of windpower generators, their technical performance and the opportunity costs of electricity supply by diesels, are treated now.

3.1 Investment and operation costs of windpower generators

The basis of our estimation given hereafter is a detailed cost assessment submitted by the company "Turbowinds", taking over the know-how of the Windmaster. The assessment has been worked out for the installation of two twin units of each 300kW at a particular site. We have evaluated the proposal against information gathered at other sources, in particular a price comparison worked out by the German periodic Wind Energie Aktuell for 168 windturbines, and against information on costs and prices collected during our mission in Kenya. We present the results in table 1. Although the proposition is worked out for a project of 2x300 kW units, we have found little evidence of major economies of scale. Therefore, the information remains valid when a single unit would be installed, or when more than two units would be placed on the same location. The investment cost per kW will shift only slightly.

The specific investment and installation costs of the Windmaster are at the high range of the present market prices in Europe. This is mainly due to the high 'balance-of-system' costs that were put forward by the company, and that are out of order with the normal ranges applied in Europe (being between 10 to 20 % of the investment cost of the generator itself; here this upscale amounts to 57%, i.e. the difference between 41.892 MBF and 26.622 MBF). Although one has to consider that balance-of-system costs may be higher in Kenya than they are in Europe, the difference should be reduced. We already did it to 37% (35.762 MBF versus 26.072 MBF), by reducing the 'study' and 'travel' allowances to the windgenerator supplier. Further reduction can be realised by assigning more responsibility for the generator installation to local contractors.

The numbers mentioned at item 9. in table 1 also show that the costs of maintenance for the windturbines are fairly low (700 000 BF for two years, or 1 295 000 K$, or 647 500 K$ per year, being lower than 1% of the initial investment cost). This figure is not at odds with observed practices as well in Europe as in Kenya where the three Windmasters are functioning now for several years. KPLC has responded that Ngong Hills units require monthly about 10 000 K$, and the Marsabit unit about 7 500 K$ for simple maintenance, greasing and transport costs. Although the KPLC figures do not entail major spare parts, overhaul, insurance, etc... they show that maintenance and operation are exceptionally low. This was confirmed repititively by all the people we interrogated about this issue (from floor operators in Marsabit and Nairobi, over engineering staff up to top management).

Table 1: Investment costs (Belgian Franks) in windpower plants (600 kW as 2 units of 300 kW)

Item	*Turbowinds*	*Adjusted*	*Comments*
1. Preparation works	1 450 000	790 000	
2. Development in Europe	1 800 000	600 000	
3. Foundations	5 300 000	4 200 000	
4. Delivery			
windmills	20 060 000	20 060 000	
towers	2 800 000	2 800 000	
transformers	1 100 000	1 100 000	
auxiliary (cabling, switchgear,..)	1 052 500	902 500	
windmast and datacom	1 610 000	1 210 000	
subtotal 4.	26 622 500	26 072 500	
5. Installation and commissioning	5 020 000	2 750 000	
6. Local project management	1 000 000	650 000	
subtotal of 1. to 6.	**41 192 500**	**35 062 500**	**Belgian franks**
7. Diesel generator (500kW)	-	8 500 000	
8. Transport costs	-	800 000	8 containers shipped
9. Spare parts for two years	700 000	1 500 000	adjusted cost includes diesel parts
Total in BF of 1. to 9.	41 892 500	45 862 500	
Total in K$ (1 BF = 1.85 K$)	77 501 125	84 845 625	Kenyan shillings
Total 1. to 6. + transport in K$	77 686 125	66 345 625	Kenyan shillings
Specific cost in K$/kW	**129 477**	**110 576**	**Kenyan shillings**
Specific cost in BF/kW	**70 000**	**60 000**	**Belgian franks**

In Europe it is observed that O&M costs are undergoing significant declines in the last years. For European windfarms, Molly (1989) gives a range of 0.8 to 2.7% for best and worst case maintenance costs from field experience with currently existing plants. According to Danish manufacturers, average maintenance costs for a windfarm of currently commercial, well-tested medium-sized machines can be calculated as 1.75 percent of capital costs (Cavallo et al. 1993).[1]

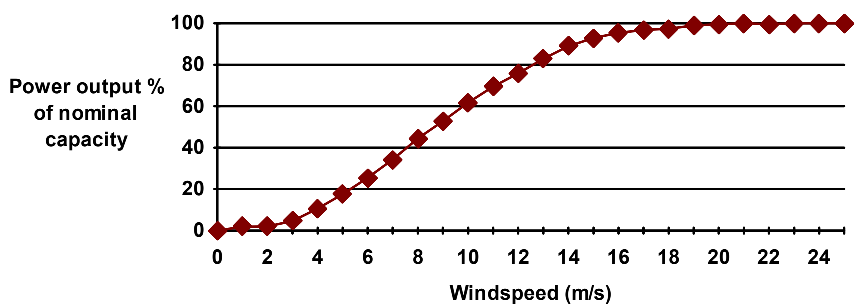
[1] Krause F., Koomey J., Olivier D. "Renewable Power. The Cost and Potential of Low-Carbon Resource Options in Western Europe", Energy Policy in the Greenhouse, Volume Two, Part 3D, 1995.

Because labour in Kenya is low-priced and because the maintenance of windgenerators does not require expatriate specialists, we will take into account a **low level of O&M costs at 1.0% of the initial investment outlays** (being from their side at the high range of the cost spectrum).

3.2 Technical performance of windgenerators

The technical performance of a windpower generator is concisely represented by its power-windspeed curve, giving the power output in e.g. kW as a function of the windspeed in m/s. Mostly the analysis is based on some theoretical power-windspeed curve. Here we have preferred to work with the curve derived from the observed performance of the two Windmaster generators at Ngong Hills. We scaled the curves of the 200 kW and of the 150 kW units at a 100% ordinate and took the arithmetic average of both observations. The result is shown in figure 2.

Figure 2: Power-output (% of nominal capacity) as a function of Windspeed (m/s)



The Windmaster generators show a good power-output, starting at rather low windspeeds. At gusthy wind conditions the windturbines are shut down because of safety reasons.

It becomes clear from figure 2 that windpower becomes only available at wind speeds above at least 5 m/s, and that full capacity is but reached at speeds above at least 15 m/s. It is also clear that outputs vary enormously with the speed of the wind, and that average speeds can mask important fluctuations. Whereas in the literature, there are standard density functions proposed for the distribution of wind supply, we will not make use of these for two reasons. First, the standard density functions are not documented nor verified for the wind regimes in Kenya. Second and more important, a density function makes abstraction of the timing of the wind supply. Because the value of the kWh generated is however very dependent on the real time of its availability, we want to take into account daily and seasonal fluctuations of the wind regimes in the various remote places in Kenya.

3.3 Cost of diesel power generation in Kenya

When evaluating investment projects in windpower in isolated areas, one has to consider the necessity of a full back-up in generation capacities that come along the windturbine capacity. Therefore, the installation of windpower units does not save on other capacity that could be canceled or retired because of the windpower supplies. There is some argument in the lowering of the loads on the other plants when windpower is supplied, but others will point to the very shifting load regimes imposed on the plants because of the variability in windpower output. We assume both effects may compensate for each other.

In Kenya remote power systems are driven by diesel units. We assume that the supply is forthcoming from up-to-date diesels[2] with an overall electricity generation efficiency of 43%. When the diesels are run in parallel to windturbines, we estimate their conversion efficiency to go down to 40% due to the much higher variability of loads and to the larger share of part-load running.

The savings that can be realised by windturbines boil down to the diesel fuel that may be saved when windpower is substituted for diesel power. To translate fuel savings into money savings one has to apply the price of the fuel at the various remote sites. In the tables we mention the information we collected during our mission in Kenya.

Table 2: Prices of Diesel Fuels in Kenya

Fuel type	Location	K$/liter (provided)	K$/liter (noted)
Light DO	Mandera, Lodwar, Marsabit, Moyale, Wajir (from Nairobi)	14.525	13.838
Light DO	Lamu, Garissa (from Mombassa)	-	13.327
HFO	Garissa (medium speed since August ‘94) ? Marsabit (from May ‘96 on)	12.220	10.730

The prices provided by KPLC on paper were somewhat higher than the ones I had noted in the KPLC-office myself for October 95. Maybe the provided prices were an average over some period, or the November 95 prices. Because they do not provide the difference Mombassa-Nairobi, I will use the ‘noted’ ones.

[2] In project appraisal studies, one has to apply the principle that for future investment state-of-the-art technology will be applied overall. This means not only the proposed (favoured) technology should be assumed to be state-of-the-art, but also all competing or complementary technologies.

Table 3: Cost of diesel fuel transport to Remote Diesel Plant

Site	from	Distance (km)	Cost/litre
Mandera	Nairobi	1200	8.400
Lodwar	Nairobi	722	5.054
Marsabit	Nairobi	622	4.354
Moyale	Nairobi	922	6.454
Wajir	Nairobi	721	5.047
Lamu	Mombassa	356	2.492
Garissa	Mombassa	480	3.360

Table 4: Total cost CIF of diesel fuel (K$/litre)

Site	Fueltype	Price/litre
Mandera	LDO	22.338
Lodwar	LDO	18.892
Marsabit	LDO	18.192
"	HFO	15.084
Moyale	LDO	20.292
Wajir	LDO	18.885
Lamu	LDO	15.819
Garissa	LDO	16.687
"	HFO	14.090

For the further analysis, it is assumed that the windgenerators do not substitute any other generation capacity in the remote areas, but that they lower the required reserve margin of the system, when the latter is estimated on the basis of the dispatchable units. This means that a higher system reliability will be attained when a diesel station in a remote area is complemented with a windpower generator than when such a unit is not available.
Given our working assumption that windturbines do not save other dispatchable capacity, it results that the only savings realised by windpower are the (diesel) fuel savings in the remote stations.

4 Appraisal of windpower projects in Kenya

4.1 Windspeed data

The quality of the outputs of our analysis depends on the quality of the data inputs. One major problem we face is the non-availability of measured windspeed-data at the various sites we want to investigate. We have done a real effort in getting the most complete data we could obtain, and in controlling their quality.
During our first meeting (November 14th) with KPLC's generation manager, mister Swaleh IMU, we brought the question forward. The main conclusion of this discussion was that there are no reliable statistics available about wind speeds. The few measurements that are made are not representative, and are not executed on the sites and on the height relevant for windpower turbines. This is a major problem, for this mission and for the decisions to be taken. It was proposed that:

⇨ I had to assess windspeeds anyhow; one simply cannot evaluate windpower projects without estimates on wind speeds. Therefore all available information resources should be collected, analysed and verified, in order to arrive at a best guess of wind speeds.

⇨ The appraisal model should then be developed, and be run with our estimates. From the results, it can already be obvious whether a further analysis is warranted, yes or no. But the model also could be run in reverse, by searching for windspeed levels where the economics of remote windgenerators break-even with other generation opportunities

⇨ At the various sites that would be selected for windturbine construction, a measurement campaign during at least one month (preferably a longer period such as a year) could be organised prior to a final decision on project acceptance. KPLC generation manager IMU said they were ready to run such a campaign, when someone (read: BADC) would provide the windspeed measurement equipment. The results of the measurement would allow for a decisive check on the assessments about wind speeds undertaken during the present mission.

Because of the crucial importance of data about wind speeds, we followed another course by contacting mr. Christopher OLUDHE[3] at the Department of Meteorology of the University of Nairobi (November 17th and 22nd). At the department historical data series about wind speeds at various sites in Kenya are stored. The data are forthcoming from the various meteorological stations spread over the country. About wind speeds, the finest time resolution of the data are three-hourly values. However the observations are noted visually and not with the purpose of evaluating the power content of the winds (but primarily to study evaporation). The anemo-meters at the meteo-stations are installed at a height of two meters, and there is no consideration whether the site is freely accessible by winds. Therefore it becomes nearly impossible to derive conclusions about available windpower in the locations based upon the meteo-observations. Nonetheless it is the only systematic source of information given that the observations are realised along the same procedures in all stations and that

[3] I learned to know mr. Oludhe because his name was mentioned in other reports about wind energy in Kenya. He is personally very interested in problems of windpower generation in remote areas. I would like to recommend him as an independent supervisor of a systematic windspeed measurement campaign in a number of locations in Kenya that could be considered as suitable for the installation of windpower turbines. His know-how could be worthwile in setting up the right procedures and in processing the obtained measurements.

there are series built-up over the long term. Therefore we will use the data not in an absolute sense but in a relative sense. Mr. Oludhe has processed for us the three-hourly windspeed observations of every day of some years in the past into three-hourly averages per month, and this for all the remote areas we wanted to study in this report. As such we get for every site 8 characteristic windspeed values for every month, or 96 values per year. We will use these values as a representative density function of the windspeeds over the year for the given site. For obtaining estimates of the relevant windspeeds for power generation we will multiply the density functions with a scaling factor larger than one (because windspeed will always be higher at greater height at a well-choosen site where the installation of the turbine is planned).

4.2 Evaluation of the existing projects

The main purpose of our mission was to investigate the economics and the financial profitability of new windpower projects in remote areas. Along this main objective, it was stated that a brief evaluation of the existing Windmaster project could take place. By a luck of circumstances I could visit both projects.

Marsabit

During our meeting on November 14th, mister S. IMU announced he would fly to Marsabit the day after. He accepted me to join him on that mission, so I could visit the Marsabit site, and the there installed windpower generator on November 15th.
KPLC is realizing a new diesel power station at Marsabit. The civil works have just started and are financed by the Ministry of Energy. The building provides room for the installation of 4x750kW units, and also encompasses offices, a repair shopand sanitary provisons for personnel. Skanska Kenya is the contractor (familiar to KPLC from former hydro projects). Two 750kW diesel (Stork-Wärtsila) are waiting at Nairobi to be transferred to Marsabit. These units were bought by Kenya on a loan credit from the Dutch government. Commissioning of the plant is sheduled for May 1996.
The Windmaster was not operating during our visit due to a broken pitch valve. The diesel unit related to the plant was operating. The local operators were very positive about the performance of the Windmaster and were in request for more units. The site allows the installation of at least two more units. The landscape shows there are strong East-winds, and also during our stay there were 'Light to Moderate' wind conditions, although rather irregularly.
At our visit to the Windmaster, we could note its total output and operation time since commissioning: 2 444 114 kWh during 54 464 running hours. This means an average output of 44.876 kW for a 200kW unit, or a capacity factor of 22.44 based on operation time.
If we consider that the unit is commissioned in November 1988, now running for 7 years (8760x7=61 320 hours), the capacity factor drops to 19.93, with an average annual production of nearly 350 000 kWh and an availability rate of almost 89%.
Although this performance is below the announced one by the supplier in a document

of 1989[4], we should notice that it stays at a high level for a WG, and certainly in such a remote place in Africa[5].
The unit shows a high availability, but it is also obvious from the capacity factor either that wind conditions in Marsabit are not ideal, or that prevailing low loads in the town have limited the turbine to supply the power it could generate. Because of lack of data we will not be able to find out the relative weight of the two factors. Therefore we continued to request detailed load and generation data.
Some other evidence was added during our mission by mr. M. SALIM being the local contractor of Windmaster in Kenya, about the integration of windpower and diesel power in island electricity generation, when the windgenerator capacity exceeds the prevailing loads in the area, what may be the case at Marsabit during low-load periods.
In Marsabit the system is designed so that 40% of the load has to be supplied by the diesel, installed next to the windturbine. This high figure is due to the characteristics of the complementing diesel unit, being a rather outdated Caterpillar not allowing modern load management (fast capacity gradients up and down). Also the connection with the main diesel plant downtown is not up-to-date (this will change in May 96, when a new control board will permit smooth parallel functioning).
Another problem of the windpower generator in Marsabit is the transformer of 200 kVA, that limits the power output of the turbine to about 180 kW active power. It may be one of the cheapest projects to replace the present transformer by one of the suitable size (e.g. 250 kVA). The existing transformer can perhaps be re-used elsewhere in the Marsabit system. If the constraint of the transformer was the binding one on the output of the unit, one could argue that eventually the capacity factor could have been about 10% higher than the actual one, i.e. 22.14 instead of 19.93.
In a newly designed configuration, the share of the diesel supply depends on the operation flexibility of the diesels themselves. A modern diesel works with short reaction times and steep ramps, and it can come down to part-loads of 20% without major loss in conversion efficiency and operation flexibility.

The load in Marsebit is forthcoming from domestic and service uses only. There is no industrial activity. The buildings in the town are widespread.

Conclusion.
Wind conditions in Marsabit seem to be fair to good.
The observed capacity factor is in line with factors observed in Europe, and we expect an improved performance can be realised when loads are growing, when the new diesel station can be substituted for the older back-up diesel and when the transformer can be replaced by one of the right size.
Although the site and built-up experience is in favour of extending the windpower capacity in Marsabit, loads are not available yet, and spare capacity is supplied by the 2x750kW medium-speed new diesels from May 96 on. Therefore, extension of the Marsabit windpower generation capacity should not have a high priority.

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[4] Van Melckebeke W. "An Autonomous Wind Diesel System in Kenya", unpublished (1989)
[5] During our visit we observed that the Windmaster was out of order, and that repair works were delayed by a few days (!), because the most elementary equipment was lacking.

Ngong Hills

I visited the Ngong Hills site on November 16th, accompanied by two KPLC staff members.

The wind and site conditions at Ngong Hills are extremely favourable to the installation of windpower generators. The hills have a textbook-shape and position for wind power generation. There are two units installed and they both were operating during our visit. Only the logging computer was out of order, so we could not observe the actual windspeeds.

We noted the main statistics at the control board of both units (commissioned October 20th, 1993, or since 2 years and 26 days at the moment of our visit, i.e. 18 144 hours). The main statistics on the performance of the units are given in the following overview.

Unit size (kW)	Output (kWh)	Operation hours	Capacity factor	Availability %	Capacity factor on availability
150	1 090 112	13 218	40.05	72.85	54.98
200	1 179 888	12 983	32.51	71.56	45.44

From the table we learn that the availability of the units is mediocre, and one should investigate the reasons for this, because the units are grid connected and so they can supply their entire output to the grid (functioning as an unlimited storage compared to the capacity of the windturbines).

The capacity factors however are exceptionally high, proving the exceptional wind conditions at the Ngong Hills site. When we assume a 100% availability and compute the capacity factors in this case the results are astonishing.

I feel confident that any European windturbine-manufacturer that would visit Ngong Hills would fall in love with the place and would do all what he could to have running one of his windgenerators at that site.

A systematic investigation of the causes of the low availability of the windgenerators installed at Ngong Hills is recommended to come up with firm remedial solutions.

Some monthly availability rates for the period Oct.93 (start-up) to April '94 (broke down of the computer system storing, processing and providing the numbers), were printed by J. MURIITHI (KPLC Nairobi), and shown to be good:

	Oct.93	Nov.93	Dec.93	Jan.94	Feb.94	Mar.94	Apr.94
n°1	99.8	84.1	83.9	98.9	98.4	99.9	96.7
n°2	98.2	89.4	76.1	80.8	79.2	72.3	93.4

The above rates only prove that the availability must have come down afterwards, and that a good computer-monitoring system is of crucial importance to improve on the quality control of the system. The latter point was confirmed once more when we received hand-written statistics about monthly operating hours of the units that exceeded the physical maximum of 744 per month!

As additional arguments, a long outage due to a failure in the hydraulic system was mentioned (the pump was not in supply in Kenya), and the fact that there was no monitoring on site.

I also interrogated M. SALIM, the Windmaster local contractor in Kenya about the low availability record of the units, but he was very amazed and not informed about the issue. He did not know of major breakdowns or technical problems, so that was not the source of the problem. He came up with two explanations:
1) because of ghusty winds at Ngong Hills, the units cancel themselves. When the storms last for a longer time but with intervals of calm wind, the units try to restart but are cancelled again in the midst of this operation. This results in real or in fake but signaled cable-twists, shutting down the units.
2) the main cause he suggested (after some time of thinking about the problem) may be the power outages and power rationing practices in that part of the grid connecting the windturbines. Because the windgenerators do not run without external voltage supply, the outage of this supply will automatically lead to the shut-down of the windturbines.

Because this point is so relevant, I brought it up again in a discussion in Lamu, where next to M. SALIM, mister M. MDEGWA toke part. The latter was in charge of the windmasters at Ngong Hills for nearly two years (before he was nominated at Lamu, he was in office at Nairobi South). He was firm in stating that the only real reason could be the cable twists that were not remedied in good time, because no qualified personnel is in duty at the Ngong Hills site, and because the remote control system is out of order due to a broken computer.

Conclusion.
The Ngong Hills site owns exceptional wind supply conditions, and there is ample room to install a complete windpark of several tens of Megawatts.
Notwithstanding mediocre to low availability factors, the capacity factors of the units remain very high, proving the exceptionality of the wind conditions.
In order to raise the availability of the units, one should re-install the datalink between the KPLC-generation headquarters at Nairobi and the windpower generators at Ngong Hills, in order to watch availability from nearby and remedy any problem immediately instead of leaving the units out-of-order untill the next sheduled control visit.

4.3 Model for evaluating new windpower projects in remote areas

In order to quantify as much as possible the economics of new windpower projects in remote areas in Kenya, I developed a small Excel-spreadsheet / Visual Basic model. In this section we present the model briefly, with the help of a sample of input and output sheets of the model, added to this report as annexe A.

The main inputs for the model are data about windspeeds and about electricity loads in a particular remote site. These data are supplied in two tables of 96 values, being 8 three-hourly average values, representing a typical day for each of the 12 months of the year.
The windspeeds (in m/s) were computed from a large database by mr. C. OLUDHE (see § 4.1 of this report), and provided directly in the required format for the various sites.
Information about electric loads was not available in the same way. I had to require the hourly (half-hourly) loads at the various stations for a single typical day, and the

total electricity consumptions for the months of the last complete year. With this information I assessed the corresponding three-hourly average loads for the twelve months of the year. Because the loads in most remote areas are forthcoming from households (lighting, food preservation, some small appliances) and from small enterprises (flour milling, refrigeration), the loads are characterized by regular daily and seasonal patterns. That is why we think the extrapolation we applied delivers valid results.
An example of the input data of one of the case studies is given as "Lamudata" in annexe A. Next to the tables, we added bar-charts of the data, showing more directly the daily and seasonal profiles observed. The but exemplary data show clearly that windspeeds are highly variable during the day and over the year. The electric loads are less variable over the year and show the typical evening peak loads of small power systems in African rural areas.

The model consists of 6 steps.
In step 1 the windspeed data can be scaled (up or down) by a multiplier (larger or smaller than 1). This scaling is necessary because our basic windspeed data are forthcoming from observations at a height of two meter, generally installed in a site surrounded by trees or buildings. In the analysis we performed, we have always kept the distribution of the windspeeds intact, but have scaled up the windspeeds with multipliers equal to 1.5, 2.0, 2.5 or 3.0.

In step 2 the electric load structure is supplied to the model. In this step, we have not changed the original data, because the possibility of introducing a load growth rate is provided in step 6 of the model.

In step 3 the characteristics of the windpower generator units are given (see §3.1), being based on the typical 300 kW windturbine. One has to provide the following data:

- aggregated nominal capacity in kW of the windturbines (in principle being a multiple of 300 kW, athough one can consider any scale of the windpower system when one accepts homotheticity in the characteristics of the units),
- specific investment cost of the units in K$/kW capacity installed (in our analysis kept at 110 576 K$/kW, i.e. about 60 000 BF/kW),
- the % of the total investment required for O&M (in our analysis kept at 1.0 %),
- the availability rate of the windpower generators (in our analysis fixed at 0.90)

The model then estimates the power output of the windturbine capacity installed, given the (scaled) windspeeds at the site, using the poweroutput-windspeed curve as shown in figure 2 (see §3.2), and assuming there are no constraints on the generation by the windturbines because of low electric loads in the area, and taking into account the assumed availability rate of the windturbines.

In step 4 we match the supply of wind-generated kWh with the demand for power in the particular remote town, taking also into account that diesels have to be operational all the time for delivering the complementary loads. Because diesels cannot meet the load intstantaneously when they are not running, we have imposed the constraint that a minimum diesel output has to be taken up by the system at all times. This minimum is hold at 50 kW in our analysis, but can be changed by the model-user.

With the above constraint, the program estimates for every three-hourly value of windspeed and dito value of electric load, the power supplied by windenergy and the power supplied by diesel-units.

In step 5 the model assesses the fuel (GJ) saved by the windturbines. Here it is first computed how much diesel fuel would be burned when all loads would be met by diesels (at the high efficiency of 43%). Then the fuel consumption by the diesels when part of the loads are met by windpower, is estimated. In the latter case, we assume that the whole or part of the diesel-fuel has been converted at a lower efficiency (40%) because of more load gradients and because of more low-load conditions imposed on the diesel units. The model limits the lower-efficiency conversion to, at maximum, the amount of diesel-kWh replaced by windpower (this is when the share of windpower falls behind the complementary share of diesel generation, i.e. behind 50% of the total loads).
The GJ-savings are transformed into K$-savings by multiplying the fuel quantities with the relevant fuel-price in the particular towns. Fuel prices are quite different in the various remote places of Kenya because of the differences in transport costs (see §3.3).
All the computations thus far are referring to some particular base year (1995). The program estimates the benefit/cost ratio and the pay-back of the windturbine investments under the assumption that the conditions of the year 1995 are frozen for the future. This already provides first-hand statistics about the economics of the projects.

In step 6 the program adds a cash flow analysis of the project, up to some future time horizon (here kept constant at the year 2010, because 15 year is a guaranteed lifetime of the windturbines). We apply a real discount rate of 5%, and provide the possibility of incorporating a load growth rate (in the analysis we have assumed load growth rates of 2.5% and 7.5% per annum).
The program performs for every year from 1996 to 2010 the calculations described in step 1 to 5 above. The main results are once again the annual fuel and money savings realised by the supply of windpower. Discounting and adding the financial returns to the present, gives us the 'present value of the savings', and this permits the calculation of the benefit/cost ratio and of the 'discounted' pay-back of the project.
The various yardsticks allow one to judge the economics of the project in a reliable way, because the main determinants of profitability have been taken into account.

When time would be there, I could develop the model further (e.g. by including a search procedure for the optimum timing of the investments in windturbines), but for the moment the model sufficiently meets the needs of prefeasibility studies.

5 Case studies of windpower in remote areas in Kenya

During our mission in Kenya, we could visit two remote towns. On November 19th-21st we visited the Lamu-area, and on November 22nd we were in Garissa. During the visits I was accompanied by mr. P. VERLEYSEN (BADC section head at Nairobi). Lamu is clearly the most promising of the two sites we have visited. Therefore, I carried out a rather detailed analysis of the Lamu case. Learning from the results of the Lamu analysis, we can limit the number of program runs for the other remote towns. Obviously, we cannot verify whether our analysis for the towns that we did not visit is really reliable because we had to work exclusively with data transferred to us by fax. The reader will also see that we cannot add any description of that towns because we lack the information.

5.1 Lamu

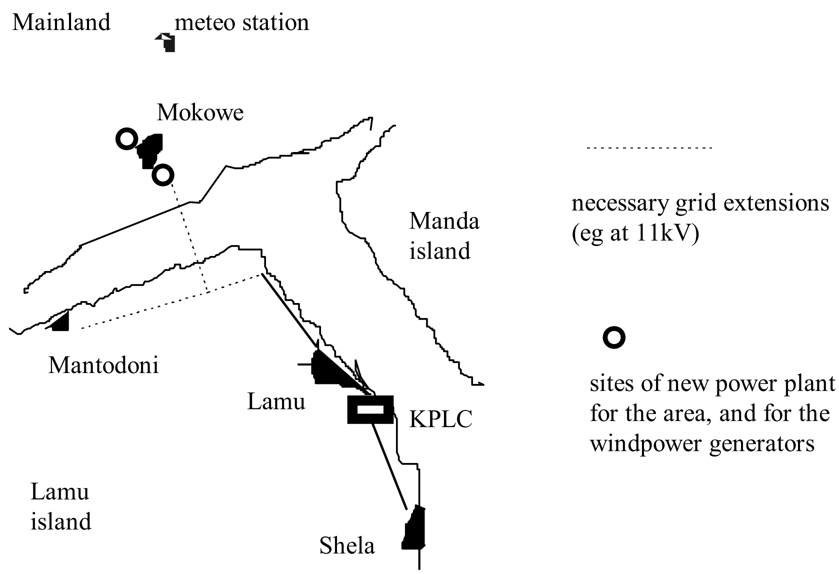
The area of Lamu we consider here, consists of the island of Lamu and the town of Mokowe on the mainland. We do not analyse the problem of the Manda island in face of Lamu, nor towns on the mainland further from the coast, such as Hindi, Pangani, etc.... The population centres are then:

Name	on Lamu-island	inhabitants	power now
Lamu town	yes	8000	yes
Shela	yes	3000	yes
Matondoni	yes	1000	no
Mokowe	no	4000	no

A basic degree of electrification (mainly lighting and food preservation) amounts to a required (peak) capacity of about 100kW/1000 people. Therefore the total service area considered would require a capacity of about 1.5 MW. When electricity supply at Mokowe could attract new activities, one could plan for a capacity of 2.0 to 2.5 MW in the year 2000.
To understand the situation we give a map of the area in figure 3.

The present KPLC diesel plant is located South in Lamu town. It is composed of four Cummins 289 kW- light fuel/high speed diesels. During our visit three were functioning, and one was in overhaul.
The oil supply to the station is particularly cumbersome: oil arrives by truck in Mokowe were it is transfered in 200-liter drums, shipped to the KPLC jetty, and then poured into larger storage tanks (2x9ton + 1x27ton). It is not to be avoided that some spillage occurs, resulting in soil contamination at the site, and in oil waste that is tipped (somewhere) on the island. The oil may contaminate the scarce groundwater resources of the island.

Figure 3: Schematic map of the Lamu-Mokowe area



A masterplan for the future power supply, should decide on the following:

- the construction of a new power plant on the mainland at Mokowe, with a capacity of about 2 to 2.5 MW. Windgenerators could be added to this plant, lowering the installed diesel capacity to the bare peak loads.
- the KPLC plant at Lamu should be kept operational as standby and peak-load supplier (also being a stabilizing factor in the starwise extended grid)
- the construction of a transmission line from the mainland to Lamu-island. This line could cross the ca. 300-400 meter sea channel by air, or on the shallow seabed. The latter solution has the advantage of lower (visual) pollution of an area worth of preservation
- transmission grid to Matodoni over about 10 km
- distribution grids at Mokowe and Matodoni

This masterplan exceeds the terms-of-reference of the present mission, but a broader approach is necessary to make the Lamu-area suitable for the development of wind power.
Construction of windgenerators on the island itself is not warranted because the necessary equipment to erect a windmill cannot be brought on it at an affordable price, and because the scenic beauty of the sanddunes would be affected. Given the context of the masterplan, decision making on providing windgenerators has to be co-ordinated with the other decisions.

We visited first the KPLC dieselplant, being received there by Mr. Morris Waweru MDEGWA, technician in charge. Then we visited the District Commissioner, Mr. Keah MADAGOW. He expressed his interest in our mission, and commited his full contribution.
We visited Matodoni village, where the chief showed us around, and emphasized that electricity would boost the shipbuilding activity in the village, and the possibility of

fish preservation. KPLC confirmed that there are about 120 applicants for a connection to a power grid in Mantodoni.
We shipped then to Mokowe on the mainland. There we investigated the various sites where the windmills could be installed. The plot of land assigned to KPLC for the construction of a future power plant is far from the village centre and situated further inland than the meteo station to the West of Mokowe (see plan). Therefore we insisted on other sites. We indicated two suitable ones (see map). The one north of the centre is landinwards on a low hill (a few meters), with good winds (trees with no outgrowns in the dominant windstream). The only problem that may arise is that the (now) open space in front of the site would be developed with buildings, causing turbulence in the main wind flows. The site south of the village faces also an open area towards the sea, and the probability of development is much lower because the land is more sandy, and towards the coast the land is owned by the Forestry Department. The latter site seems the most promising one. It is anyhow necessary to do an intensive investigation of the various micro-sites that prove to be suitable for windpower.
We stopped at the meteo site to observe the way the wind is measured. We can testify that the anemo-meter is placed at a height of two meter, shielded by trees. The place is also several kilometers inland. Therefore the windspeed observations at the meteo site in Lamu can be no more than a rough indication of wind variability and not of absolute values of the windspeed at greater, unshielded height near the coastline.
At Lamu there are for certain opportunities for wind power. One only has to look for the optimum site and for the embedment of the wind power in the overall electricity supply of the area.

Within our terms-of-reference we have analysed the economics of windturbines in Lamu (rather Mokowe), with the model we described in chapter 4. In order to get a more reliable view on the economics of the projects we carried out 16 program runs. The results are shown in table 5.
The first three columns of table 5 are used to show the input options of the runs. First, we consider two investment decisions: once a single 300 kW windturbine, and then two 300 kW units making up 600 kW. We evaluate the performance of the two investments for four different regimes of windenergy availability (summarized in the multipliers 1.5, 2.0, 2.5, and 3.0 of the basic windspeed table; see §4.1). In addition we have applied two load growth assumptions, one of 2.5% per year and one of 7.5% per year.
Combining the above options requires 2x4x2=16 different runs with the model (see the 16 rows of table 5). A few summary statistics of the model outputs are shown in table 5. First we give an idea of the impact of the investment in windturbines on the total supply of electricity to the area by mentioning the share of windpower in the years 1996, respectively 2010 (beginning and end of the period analysed). Next, the capacity factors of the installed windturbines are shown also for the first and last year of the period analysed.
The last three columns of table 5 contain the statistics of economic performance: the benefit/cost ratio of the investment, the 'discounted' pay-back period and the discounted annual savings in fuel expenses made possible by the windturbines.

Table 5: Economic evaluation of installing windpower generation units at Lamu.

Input options			Results from the model runs						
Wind-power kW	Wind-speed multi-plier	Load growth %/yr	Share in 1996	of wind in 2010	Capacity in 1996	factor in 2010	**Benefit /cost ratio**	**Pay-back years**	Present value savings 10^3K$
300	1.5	2.5	23.0	16.3	.32	.32	**0.9**	**11.7**	32877
300	***2.0***	***2.5***	***34.7***	***24.6***	***.48***	***.48***	***1.4***	***7.4***	***49703***
300	2.5	2.5	43.8	31.0	.61	.61	**1.8**	**5.8**	62679
300	3.0	2.5	49.6	35.2	.69	.69	**2.0**	**5.1**	71102
300	1.5	7.5	21.9	8.0	.32	.32	**0.9**	**11.7**	32877
300	***2.0***	***7.5***	***33.1***	***12.0***	***.48***	***.48***	***1.4***	***7.4***	***49703***
300	2.5	7.5	41.7	15.2	.61	.61	**1.8**	**5.8**	62680
300	3.0	7.5	47.4	17.2	.69	.69	**2.0**	**5.1**	71109
600	1.5	2.5	44.8	32.5	.31	.32	**0.9**	**11.8**	65267
600	***2.0***	***2.5***	***60.5***	***48.7***	***.42***	***.48***	***1.3***	***7.9***	***94075***
600	2.5	2.5	68.4	59.1	.47	.58	**1.6**	**6.6**	111936
600	3.0	2.5	72.6	65.0	.50	.64	**1.7**	**6.0**	121317
600	1.5	7.5	43.2	15.9	.31	.32	**0.9**	**11.7**	65624
600	***2.0***	***7.5***	***59.2***	***24.1***	***.43***	***.48***	***1.4***	***7.6***	***97570***
600	2.5	7.5	67.6	30.3	.49	.61	**1.7**	**6.1**	120626
600	3.0	7.5	71.8	34.4	.52	.69	**1.9**	**5.4**	134841

The main conclusions that can be drawn from the results shown in table 5 are:

- the availability of wind is the single major determinant of the economics of the investments in windturbines. This is of course a trivial conclusion, but its impact is tremendous.
  As long as windspeeds are multiplied by a factor of 1.5, the capacity factor of the windturbines is about 0.31-0.32, resulting in pay-back periods of the investments longer than 10 years! This result is striking because in Europe and the USA capacity factors of that order of magnitude are considered to be good. Part of the problem in our project proposals are the rather high investment cost we face (110 576 K$/kW), leading to an investment of 33.173 million K$ for a 300 kW unit and of the double (66.346 million K$) for a 600 kW plant.
  When the multiplier is set at 2.0, the capacity factor increases significantly and so

does the benefit/cost ratio, while the pay-backs are falling. In table 5 the corresponding runs are shown bold-italic because we consider these windspeed conditions as the most likely ones.
A further increase of the multipliers to 2.5 and 3.0 improves the results even more, but the underlying capacity factors are becoming extremely high, and one can doubt about the feasibility of attaining such high factors in practice. It anyhow assumes wind conditions of the same or even higher exceptional quality as the ones observed in Ngong Hills, and in addition it assumes a guaranteed availability of 90% of the windturbines.

- When we decide to install one windturbine of 300 kW, the system can absorb the full output of the windpower plant. In the year 1996, we nearly reach the 50% share of load matching when windspeeds would be high (multiplier=3.0). The share decreases when total load grows, to arrive even at a low 8.0% in case of low windspeeds (multiplier=1.5) and high load growth (7.5% per annum).
  When 600 kW is provided from the first year on, there is some overcapacity in windpower during the first years of the period (showing a share of more than 70% of the electricity consumed in the area), of course under the hypothesis that the windspeeds and capacity factors are extra-ordinarily high. When the latter hypothesis is not retained, the provision of two units of 300 kW does not burden the system with overcapacity in windpower. Nevertheless it may be wise to spread the investments over a longer period, e.g. installing one unit in 1996 and a second some years later.
- The future growth of the demand for electricity in the area has but a limited impact on the results. When a single 300 kW windturbine is installed, the load growth has no effect at all because the supply of windenergy can be taken up at all times. When the double capacity is installed, the load growth is necessary to fill the overcapacity. In this case one observes that the benefit/cost ratio's and the pay-backs improve when a load growth of 7.5% is assumed instead of 2.5% per annum.
- Considering the overall performance of the windturbines, it is obvious that it is very unlikely to reach a pay-back value lower than 5 years. Rather a value of 7 to 8 years seems the most likely one. This moderate economic outcome is partly due to the high investment price of the windturbines, and partly to the not-that-high price of the substituted diesel fuel at Lamu-Mokowe (15.819 K$ per litre; see table 4 in §3.3).

With the prefeasibility analysis we have tried to give an unbiased view of the economics of windpower at Lamu. Of course the model can be used to run any other project proposal one wants to consider under any other given exogenous circumstances.

5.2 Garissa

During our visit of Garissa, we worked on a very tight shedule. First we drove to the meteo station. The anemo-meter is placed at a height of two meters, and is mainly used as an information source for the investigation of evaporation in the country-side. Three-hourly wind speeds are not measured with some standardised equipment but by visual inspection of the cup-speed of the anemometer and of the agitation of leaves by the wind. Daily the revolutions of the anemometer are noted, so one gets aggregated/averaged wind-speeds per day (expressed as km/day). Also there are balloon measurements of speeds at 10 meter at regular intervals.

Next there was a visit to the deputy Province Commissioner, mr. J. MAKUMI, where we also met mr. Austin MUTIGA, the KPLC manager at Garissa. The total number of inhabitants of Garissa is not well known, mainly due to the migration by drought-refugees. A few years ago 30 to 40000 inhabitants were living in the town of Garissa. With the drought that number has augmented to about the double. The refugees are not able, nor willing, to leave the town when they do not get the hand on some cattle, the basis of their livelyhood in the country-side. Because they now live in tents and other preliminary constructions, they are not connected to the grid, and the question is whether they ever will be connected in the near future.
In Garissa are now 3000 meters installed. Power is supplied to about 50% of the population. Each month there are about 30 new applicants for a grid connection. Electricity is used for lighting, refrigeration and fans. Air conditioning is still limited. The largest consumer is the KBC (Kenyan Broadcasting Corporation) for a booster station at about 10 km distance from the center of Garissa.
The diesel station in Garissa is commissioned in August 1994. It is composed of medium-speed (750rpm) HFO diesels: 1 M.A.N. of 1064 kW and 2 Stork-Wärtsila units of 700 kW each. This total capacity of about 2.5 MW is sufficient for quite some time in the future. NGO-people in Garissa testified that power supply in Garissa is very reliable, and that other utilities (water supply, domestic garbage collection) require more urgent attention.
We could not identify particular micro-sites at Garissa that showed exceptional wind conditions. Garissa is located in a large fluvial plane, with a slow mounting-up eastwards of the town centre. We assess that over a distance of about 10 km the rise is about 50 meters, going over in another vast plane. The KBC station is located on this plateau, and there can also be installed the Windgenerators because a 11-kV powerline is already running that far. During our visit of the place wind conditions were very low, pointing to no particular better opportunities than at other sites. Although 10 kilometer is a short distance, we were accompanied by armed guards, and had to pass several control posts. The difficult accessibility of Garissa, and the harsh working conditions in the area, make the construction of new windturbines in the region less attractive, and presumably more costly than in other, safe regions.
The model was applied to the data available about Garissa, for the investment in one 300 kW windturbine. The results are shown in table 6.

Table 6: Economic evaluation of installing windpower generation at Garissa

Input options			Results from the model runs						
Wind-power kW	Wind-speed multi-plier	Load growth %/yr	Share in 1996	of wind in 2010	Capacity in 1996	factor in 2010	**Benefit /cost ratio**	**Pay-back years**	Present value savings 10^3K$
300	1.5	2.5	7.9	5.6	.19	.19	**0.5**	**24.6**	17433
300	***2.0***	***2.5***	***12.6***	***8.9***	***.30***	***.30***	***0.8***	***14.0***	***27975***
300	2.5	2.5	17.0	12.0	.41	.41	**1.1**	**10.1**	37628
300	3.0	2.5	20.6	14.6	.50	.50	**1.3**	**8.2**	45530

From table 6 one learns that the power system in Garissa is large enough to take up the electricity delivered by a windturbine of 300 kW, and also more units could be included. However, the economics of windpower in Garissa are bad, mainly because the wind conditions are not adapt and because the opportunity cost of diesel generation is not excessively high. Because in addition, Garissa has received a modern diesel station in 1994, windenergy in this town can attract but a low priority.

The following towns have been studied on the basis of data supplied by fax, without a visit on site. The main drawback of this method is that we cannot assess the value of the supplied information about windspeeds. For every place, we have done the same computer-runs as for Garissa. More runs at this moment would not add to our insight in the feasibility of windpower in the various towns.

5.3 Lodwar

The electric system in Lodwar is small. In the KPLC-bookyear 1994-1995 total consumption amounted to about 1650 Mwh, i.e. the average load over the year is less than 200 kW. Therefore, the system today is too small to incorporate a windturbine of 300 kW capacity. When the wind conditions would be favourable, a significant share of the potential windenergy would have to be wasted, because the system cannot take up the power deliverable.
In table 7 the results of the computer analysis are shown, and prove that the economics of windenergy are not particularly favourable today in Lodwar. However, the Lodwar-case can turn into a good project when economic and electric load growths develop in the coming years. Wind speeds could be measured during one of the coming years, to provide a reliable basis for project judgement in the future.

Table 7: Economic evaluation of installing windpower generation at Lodwar.

Input options			Results from the model runs						
Wind-power kW	Wind-speed multi-plier	Load growth %/yr	Share in 1996	of wind in 2010	Capacity in 1996	factor in 2010	**Benefit /cost ratio**	**Pay-back years**	Present value savings 10^3K$
300	1.5	2.5	40.5	33.6	.22	.25	**0.8**	**13.5**	29026
300	***2.0***	***2.5***	***49.7***	***47.4***	***.27***	***.36***	***1.1***	***10.0***	***37768***
300	2.5	2.5	55.7	54.8	.30	.41	**1.2**	**8.6**	43414
300	3.0	2.5	59.9	59.6	.32	.45	**1.4**	**7.8**	47499

5.4 Mandera

Also Mandera owns but a small electric system today, the size being 10 to 20% larger than the Lodwar-system. Again we face the same uncertainties about the windspeeds. The results of the computer-analysis are given in table 8. In the case of low windspeeds the economics of windturbines in Mandera are very bad. There is a noteworthy improvement at higher windspeeds, mainly because of the high opportunity cost of diesel generation in Mandera (see table 4, showing that Mandera faces a dieselfuel price of 22.338 K$/litre).

Mandera, being sited at 1200 km from Nairobi at the border with Somalia, is also difficult to reach, and this may increase the investment costs in the project.

Table 8: Economic evaluation of installing windpower generation at Mandera.

Input options			Results from the model runs						
Wind-power kW	Wind-speed multi-plier	Load growth %/yr	Share in 1996	of wind in 2010	Capacity in 1996	factor in 2010	**Benefit /cost ratio**	**Pay-back years**	Present value savings 10^3K$
300	1.5	2.5	27.9	20.0	.17	.17	**0.7**	**16.5**	24309
300	***2.0***	***2.5***	***44.5***	***33.8***	***.26***	***.28***	***1.1***	***9.4***	***40180***
300	2.5	2.5	54.7	46.5	.33	.39	**1.5**	**7.0**	52592
300	3.0	2.5	60.3	55.7	.36	.47	**1.7**	**6.0**	61164

5.5 Wajir

The electric system at Wajir is of the same order of magnitude as the one in Lodwar. The results of our analysis in table 9 show again poor economics because of too low windspeeds and too small loads that cannot take up at many occasions the energy deliverable by the windturbine.

Table 9: Economic evaluation of installing windpower generation at Wajir.

Input options			Results from the model runs						
Wind-power kW	Wind-speed multi-plier	Load growth %/yr	Share in 1996	of wind in 2010	Capacity in 1996	factor in 2010	**Benefit /cost ratio**	**Pay-back years**	Present value savings 10^3K$
300	1.5	2.5	21.7	15.4	.20	.20	**0.7**	**16.2**	24743
300	***2.0***	***2.5***	***34.7***	***25.1***	***.32***	***.33***	***1.1***	***9.4***	***39936***
300	2.5	2.5	45.9	34.1	.42	.44	**1.5**	**6.9**	53456
300	3.0	2.5	54.1	41.2	.50	.54	**1.8**	**5.7**	64216

5.6 Marsabit

The case of Marsabit already has been discussed in $4.2, given that since November 1988 a windpower generator is running in that place. In this section we have analysed the economics of windpower in Marsabit with the same model and with the same assumptions as the other five cases above.

Contrary to the other sites, the values of windspeed we received from the meteorological department at the University of Nairobi, are rather high (on average 8.4 m/s over the year, while this value was in Garissa 3.6 m/s, in Lodwar 4.4 m/s, in Mandera 3.5 m/s and in Wajir 3.8 m/s). By applying the same multipliers (1.5 to 3.0) as in all the other case studies, we come up with extremely high wind speeds involving storm-weather conditions during most of the year (e.g. the factor 3 makes the average wind speed equal to 25.2 m/s). This is not beneficial to the economics of windenergy because the turbine would be stalled during long periods of the year. The impact of this stalling is obvious from the results in table 10, where the economics become worse when the multiplier value is 2.5 or 3.0.

The reason of the higher windspeed values we received for Marsabit can simply be due to another siting of the meteo-station in that place, e.g. on a hill and/or not hindered by trees or constructions. In table 10 we have emphasized row 1 instead of row 2, because a 50% upscaling of the windspeeds looks a more plausible approach than a doubling.

The economics of windpower in Marsabit prove to be fair to good, although here again one faces the problem of a too small electric system for taking up the deliverable power at any time. This may change in the nearby future because development plans for the Marsabit region become more and more firm. Economic development of the region will also be boosted by the commissioning in May 1996 of the new diesel power station (see §4.2), making the urgency of additional windturbines in the area much lower. Finally, one should not overlook the presence of the 200 kW-Windmaster, still operational for 10 to 20 years, and reducing the space left over for new additional windturbines.

Table 10: Economic evaluation of installing windpower generation at Marsabit

Input options			Results from the model runs						
Wind-power kW	Wind-speed multi-plier	Load growth %/yr	Share in 1996	of wind in 2010	Capacity in 1996	factor in 2010	**Benefit /cost ratio**	**Pay-back years**	Present value savings 10^3K$
300	***1.5***	***2.5***	***61.0***	***49.4***	***.52***	***.59***	***1.6***	***6.6***	***55565***
300	2.0	2.5	67.9	57.0	.58	.68	**1.8**	**5.7**	63999
300	2.5	2.5	56.1	47.3	.48	.57	**1.5**	**7.1**	51923
300	3.0	2.5	28.8	24.2	.24	.29	**0.8**	**15.0**	26343

Rounding-up the discussion of the computer analyses of the economics of windpower at the various remote sites in Kenya, we once again have to warn for the weak data basis underlying our outcomes. As long as reliable information about windspeeds, and in second order about electric load(diagram)s, is not available, we cannot guarantee firm conclusions.

6 Conclusions and Recommendations

6.1 Major findings

Before summarizing our recommendations to BADC, we want to repeat briefly the major findings of our mission and the major assumptions determining the economic analysis model:

- one cannot get a reliable judgement on the economics of windpower in a particular place, when no detailed and precise windspeed-data are available.
  Because winds are volatile and nowhere equal, one needs real measurements of wind speeds at the sites designated for windturbine erection.
  For the realisation of our analysis we made use of windspeed-data processed by the Meteorological Department of the University of Nairobi. The data are collected from meteo stations at the remote towns. We have hold the distribution of the windspeeddata constant, and we have scaled-up the observations.
- the experience thus far with windpower in Kenya (Marsabit and Ngong Hills) is positive. The turbines have been running well, and their performance is as good or even better than the reference units in Europe.
- investing in new windpower generation units in remote electric systems in Kenya is not straightforward because the limited scale of most systems limits the use of supplied windpower, wasting part of the capacity installed. One could think of windturbines of a capacity smaller than the present standard of 300 kW, but this possibility has not been investigated in this study. It can but be an alternative when the specific investment cost per kW does not increase significantly.
- the investment cost in new windturbines remains rather high and makes pay-back periods everywhere longer than 5 years, also when wind-supply conditions are excellent. In practice a pay-back of 7 to 8 years should be taken into account. This period is too long for attracting private investor's money, but is only half or one third of the windturbine's lifetime (a lifetime of 15 to 20 years is normal, while 25 years is becoming a standard for new equipment). Because the operation and maintenance costs of windturbines are very low, units can show benefit/cost ratio's of 2à3, making investments in this option more than worthwile.
- the economic evaluation considers the present conditions continuing for the next fifteen years (project horizon was set at 2010), i.e. no oil price changes are fore-seen, no nearby interconnection of the remote electric systems is assumed, only smooth load growth scenario's are studied (i.e. 2.5% and 7.5% per annum), etc...
  Changing the technico-economic environment of the remote electric systems can bring about very different conclusions on the economics of windpower, as well in a positive as in a negative sense.
- in our study, we did not consider the important positive externalities related to windpower as a renewable energy source, nor did we put a price on the negative side-effects of conventional energy use, in particular fossil fuel combustion and handling. We referred only to e.g. site and soil contamination by oil spillage and waste dumping at Lamu, that may threaten (in the medium or long-term) the scarce fresh water resources of the island.

Given the above list of considerations, our general conclusion is that windpower should be supported as a valid source of electric power supply in remote electric systems in Kenya when it is warranted economically, even when the financial terms are not attractive enough for private investment.

Under these circumstances public policy has to come in, and the point-of-view of the Minister of Energy of Kenya is important. During our mission we visited Mr. P.O. GENGA (deputy secretary) and mr. M. NGANGA (energy economist). We discussed two major issues: what remote places were of particular interest for siting windpower generators, and how the financing could be set up.

Mr. Genga informed me of a major development project in the coastal area of Kenya, i.e. at Garsen on the river Tana (the Lower Tana project), involving irrigation and construction. It could be worthwile to investigate the opportunity of windpower related to the project. However, there is also a feasibility study undertaken by Germany to extend the power grid at 132 kV from Kilifi over Garsen up to Hola and later to Garissa. The realisation of this project is sheduled for the period 2000-2002.
Considering the remote urban areas for power supply assisted by windpower, we agreed that the following order is warranted:

1. Lamu - Mokowe
2. Lodwar (Mr. Genga feels confident the wind conditions are very good out there)
3. Mandera
4. Wajir

We also could settle on a low priority (for the time being even leaving out) of projects at Garissa and at Moyale. The former because there are no major power supply problems to be attended in the near future and because in the longer term interconnection is on the agenda. The latter because the Ethiopean part of Moyale is developed well enough (road and power links to the center of the country are there), and because a trans-border connection is the most rational solution. In the future it could be investigated whether windpower supply into the grid (cfr. Ngong Hills) is not economic and then other places need attention, such as Ngong Hills extension, Garsen, and others.

About the financing aspects, mr. Genga agreed that joint contribution by the donor and by the Kenyan government is a good basis for co-operation. Foreign equipment should be granted by the donor (at some occasions also a soft loan could be considered), while local costs could be carried by the Ministry of Energy.

6.2 Recommendations

The further involvement of BADC in the supply of electricity in remote areas in Kenya is justified because it provides the necessary basis for economic and social development. An involvement by means of supplying windturbines is also justified because one supplies renewable, clean energy at a technological level that nowadays is mature and affordable by a country at the state-of-development of Kenya.
We recommend the following steps:

1. Follow-up of existing projects:

• Marsabit	• deliver a transformer of the right capacity (250 kVA) • wait until the electric system has grown to the MW-scale before installing additional windturbines
• Ngong Hills	• re-install immediately the communication links between the site and the KPLC's headquarters • improve the KPLC management system for immediate follow-up of the performance of the windturbines • look for Worldbank or commercial banks or investors support for installing additional windturbines at the (excellent) site

2. Windspeeds measurement campaign

• supervising team	• compose supervising team with representatives from Ministry of Energy, KPLC, BADC-Nairobi, Meteorological Department (Univ. Nairobi)
• technical team	• KPLC should be in charge of the technical execution (with the help of e.g. a contracting firm such as ACL)
• equipment	• BADC should provide the necessary equipment for the measurements (ca. 200 000BF/unit, excluding mast)
• execution	• start the measurements as soon as possible in Mokowe (Lamu) at the identified site • after three months of measuring, the results can be analysed, and compared with data at the Meteo Dep. of the Univ. of Nairobi. The new data can be fed to our model to evaluate the economics • after or concurrently with the campaign at Lamu, one should start measuring at Lodwar

3. Windpower Project development in general

• priorities	• we recommend to focus in the short term on just one project, i.e. Lamu-Mokowe because the economics of windpower are there most promising • in second order one should identify whether Lodwar owns suitable sites for windpower
• parties involved	• Ministry of Energy, KPLC, BADC, local contractors, foreign contractors
• financing terms	• the economics of windpower in remote areas are positive but not financially attractive enough to attract risk capital. As for other rural electrification projects, public support is justified

4. Specific project development in Lamu-Mokowe

		deadline + BADC budget
• masterplan	• KPLC and the Ministry of Energy should develop a (concise) masterplan for electricity supply in the area (see §5.1 of this report)	May 96
• measurement	• BADC should deliver the necessary equipment (ship 2 loggers + finance local mast) • BADC should take part in the supervising committee, and evaluate the measurement data	March 96 ca. 1 MBF Sept 96
• realisation (if justified)	• BADC should deliver the full equipment for a stand-alone electric supply system at Mokowe-Lamu (a 300kW-windturbine, a 500kW-diesel capacity, switchboard, control and auxiliary equipment)	Feb. 96 ca. 35-40 MBF

We estimate that the BADC contribution for the next two years (1996 and 1997) can be limited to 25 MBF per year or 50 MBF in total (including the upgrading of the existing projects, the development of the - first phase of - the Mokowe-Lamu project, the necessary studies and support activities).
For this amount a real development project can be realised, centered on renewable energy and as such promoting a sustainable future. In addition, the visibility of the BADC contribution will be high.

We recommend the BADC to engage in the project as we have designed it, i.e. carefully but without delay.

Annexe A: data and computer sample output

In the following pages, one will find data on windspeeds and electric loads for the various towns analysed in the report. Also one outprint of a computer run is added as it is discussed in the main text (see §4.3).
The information is assembled in the following order:

- **Lamudata**
- **sample output of computer run (Lamustudy)**
- **Garissadata**
- **Lodwardata**
- **Manderadata**
- **Wajirdata**
- **Marsabitdata**