Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH

Wind Energy Programme TERNA

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Site Selection Report Ethiopia

April 2005

Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH – Wind Energy Programme TERNA
Dag-Hammarskjöld-Weg 1-5
65 760 Eschborn
Tel. +49 (0) 6196/79-1760
Fax +49 (0) 6196/79-1745

P.O. Box 51 80
65 726 Eschborn
internet: http://www.gtz.de/wind
e-mail: jasper.abramowski@gtz.de

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Dipl.-Ing. Benjamin Jargstorf
Hinter dem Chor 8
23 966 Wismar
Tel. +49 (0)3841 - 404 20
Fax +49 (0)3841 - 404 22
e-mail: benjamin@factor-4.com

Factor 4 Energy Projects GmbH

Table of Contents

Annexes

List of Abbreviations

3D	three dimensional
a.g.l.	above ground level
AAU	Addis Ababa University
ADA	Austrian Development Agency
Ah	Ampere hours
BMZ	Bundesministerium für Wirtschaftliche Zusammenarbeit (German Federal Ministry for Economic Cooperation)
CD	compact disk
DNS	direct numerical simulation
EEPCo	Ethiopian Electric Power Company
GEF	Gobal Environment Facility
GIGO	Garbage in Garbage out
GmbH	Gesellschaft mit beschränkter Haftung (limited company)
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH
h.v.	high voltage
KAMM	Karlsruhe Atmospheric Meso-scale Modell
km	kilometer
kV	kilo Volt
LES	large Eddy Simulation
m/s	meters per second
MW	Mega Watt
Sida	Swedish International Development Cooperation
SWERA	Solar and Wind Energy Assessment
TERNA	**T**echnical **E**xpertise of **R**e**N**ewable Energy **A**pplications
UNEP	United Nations Environmental Programme
WAsP	Wind Atlas Analysis and Application Program
WWEC	World Wind Energy Conference

Acknowledgment

The selection of suitable wind sites in such a large area in such a short time would be impossible without the dedicated support of EEPCo's Coal and Wind Energy Team, headed by Ato Tarekegn Kelemu. I want to thank them and all the other EEPCo co-workers from the regional offices for their help during preparation and in the field, where they had to go to great lengths to keep our ambitious time frame. However, any errors and omissions in presenting the results of the site selection mission in this report are mine.

Benjamin Jargstorf

Summary of Findings

In October 2003, EEPCo – Ethiopian Electric Power Company – filed an application for co-operation within the wind energy programme TERNA – **T**echnical **E**xpertise of **R**e**N**ewable Energy **A**pplications. This programme is executed by Deutsche Gesellschaft für Technische Zusammenarbeit GTZ GmbH on behalf of the German Federal Ministry for Economic Cooperation (Bundesministerium für Wirtschaftliche Zusammenarbeit BMZ).

After a positive vote in the appraisal procedure of GTZ in July 2004, a planning workshop in September 2004 agreed about the further project implementation measures.

According to this planning, a four stage implementation strategy for the planning of a 50 MW grid-connected wind park was to be followed:

1st stage: identification and operation of up to 10 wind measuring sites at 10 m above ground. If sufficient wind speeds are found the 2nd stage will be initiated, otherwise the project will be terminated;

2nd stage: based on the evaluation of the up to 10 sites, up to three 40 m high wind measuring towers will be equipped, operated and evaluated. If suitable wind speeds are experienced, the 3rd stage will be initiated;

3rd stage: elaboration of a feasibility study for up to 2 wind park sites;

4th stage: GTZ will provide assistance in the application for financing and in the tendering of wind park equipment including evaluation of bids and recommendation for award, if requested by EEPCO.

All stages of project execution are accompanied by appropriate capacity building measures.[1]

For the first two stages, the project sponsor GTZ has secured co-financing from the Austrian Development Agency (ADA).

The current report concerns the site selection mission of stage 1, which was carried out from 29th of December 2004 to 20th of January 2005.

The major **findings** of this mission can be summed up:

1. Employing a “reduction approach” for site selection in which all areas not considered highly suitable as wind park location are excluded, the mission focussed on four primary search areas.
2. In each area, possible wind park sites in close distance to existing high voltage transmission grid of EEPCo were identified and equipped with wind measuring stations (10 m high).
3. As such, 9 stations with 10 m towers and two measuring stations with a measuring height of 30 m were installed and a measuring campaign initiated.
4. The two 30 m stations were installed at a site in the North of Ethiopia (Mekelle, Province of Tigray), where a preliminary wind data analysis from another wind data logger showed principally sufficient annual wind speeds in the range of 6.5 m/s in 10 m above ground. Here a station from the 2nd stage of project implementation was erected, in order to shorten project execution time, and upon direct request of EEPCo.
5. EEPCo will collect the wind speed and wind direction data of all 11 measuring stations for the period of the next 6 months. Then an intermediate evaluation of wind data will take place, followed by a decision, where the three 40 m wind measuring towers are to be installed.

This report will explain the rationale of the site selection approach in **Section 1**, give some background information of the measuring equipment used and a description of the planning procedures. **Section 2** deals in detail with each pre-selected site, while recommendations for the execution of the measuring campaign and the evaluation of wind data are then discussed in **Section 3**.

As this report is intended as part of the capacity building measures, it discusses in detail background information to the site selection process and includes further reference material in the **Annexes**.

1) see ToR in **Annex 1**

Zusammenfassung der Ergebnisse

Der nationale Stromerzeuger Äthiopiens EEPCo – Ethiopian Electric Power Company – hat im Oktober 2003 einen Antrag auf Zusammenarbeit im Rahmen des Windenergieprogramms TERNA gestellt (**T**echnical **E**xpertise of **R**e**N**ewable Energy **A**pplications). Dieses Programm wird von der Deutschen Gesellschaft für Technische Zusammenarbeit GTZ GmbH im Auftrag des Bundesministeriums für Wirtschaftliche Zusammenarbeit (BMZ) durchgeführt.

Nach dem positiven Ausgang des Projektprüfungsverfahrens im Juli 2004 wurden in einem Planungsworkshop im September 2004 die weitere Projektimplementierung abgestimmt.

Danach wird ein vierstufiges Planungsverfahren für die Implementierung eines netzgekoppelten 50 MW Windparks verfolgt:

Stufe 1: Standortidentifizierung und Betrieb von bis zu 10 Windmessstationen mit Messungen in 10 m über Grund. Werden erfolgversprechende Windverhältnisse gemessen, wird da Projekt mit Stufe 2 weitergeführt, wenn nicht, eingestellt.

Stufe 2: nach der Datenauswertung der 10 Standorte werden drei Standorte ausgewählt, an denen Windmessungen in 40 m Höhe durchgeführt werden. Je nach Ergebnis dieser Messungen, wird das Projekt in Stufe 3 weitergeführt oder eingestellt.

Stufe 3: Machbarkeitsstudien für bis zu zwei verschiedene Windparkstandorte werden ausgearbeitet.

Stufe 4: nach entsprechender Anfrage von EEPCo kann die GTZ Unterstützung bei der Kontaktaufnahme zur Projektfinanzierung, bei der Ausschreibung der Windparkausrüstung und bei der Auswertung von Angeboten gewähren.

Alle Projektphasen sind von umfassenden Aus- und Fortbildungsmaßnahmen begleitet, die ein wesentliches Merkmal des TERNA Projektes sind. [2]

Für die ersten beiden Projektphase hat die GTZ eine Ko-Finanzierung durch die Österreichische Entwicklungszusammenarbeit (Austrian Development Agency – ADA) vereinbart.

Dieser Bericht beschriebt die Standortevaluierungsmission nach Stufe 1, die in der Zeit vom 29. Dezember 2004 bis 30. Januar 2005 stattfand.

Die wesentlichen Ergebnisse dieser Mission können wie folgt zusammengefasst werden:

1. Als Methode für die Standortsuche wurde ein "Ausschlussverfahren" angewandt, wonach alle für den Windparkbetrieb ungünstigen Regionen Äthiopiens ausgeschlossen wurden. Dabei konzentrierte sich die Mission auf vier Suchräume.
2. Für jeden Suchraum wurden geeignete Windparkstandorte in unmittelbarer Nähe des Hochspannungsnetzes von EEPCo ausgewählt und mit Windmessstation ausgerüstet.
3. Dabei wurden 9 Stationen auf 10 m Messhöhe und 2 Stationen auf 30 m Messhöhe in Betrieb genommen und die Messkampagne gestartet.
4. Die beiden 30 m Messstationen wurden im Norden Äthiopiens (Mekelle, Tigray Provinz) errichtet, weil dort frühere Windmessungen auf eine Jahreswindgeschwindigkeit von etwa 6.5 m/s in 10 m über Grund erwarten lassen. Effektiv wurde hier bereits eine Messstation aus der 2. Projektstufe installiert, um auf Wunsch EEPCo's Zeit zu sparen.
5. EEPCo wird für die nächsten 6 Monate regelmäßig die Daten dieser 11 Stationen auslesen. Danach findet eine umfassende Winddatenanalyse statt, als Basis für die Entscheidung, welche drei Standorte mit 40 m Stationen ausgestattet werden.

Dieser Bericht entwickelt zunächst die Strategie zur Standortauswahl und stellt die Grundlagen zu Messausrüstung und zu Planungsverfahren in **Abschnitt 1** dar. In **Abschnitt 2** werden die ausgewählten Standorte im Einzelnen diskutiert, während **Abschnitt 3** Empfehlungen für die Durchführung der Messkampagne und die Auswertung der Winddaten gibt.

Dieser Bericht ist als Teil der Ausbildungsmaßnahme vorgesehen. Deshalb beschäftigt er sich im Einzelnen mit Hintergrundinformation zur Standortauswertung und ist mit einem umfangreichen **Anhang** ausgestattet.

2) vergleiche die Leistungsbeschreibung für den Gutachter in **Annex 1**

1. Basics of Site Selection

1.1 Wind Data for Ethiopia

1.1.1 Meteorological Data

The base for wind data and especially the value of meteorological and agro-meteorological data has already been discussed in some detail during the appraisal mission.[3] There is no need to repeat this discussion here.

1.1.2 Other Wind Data

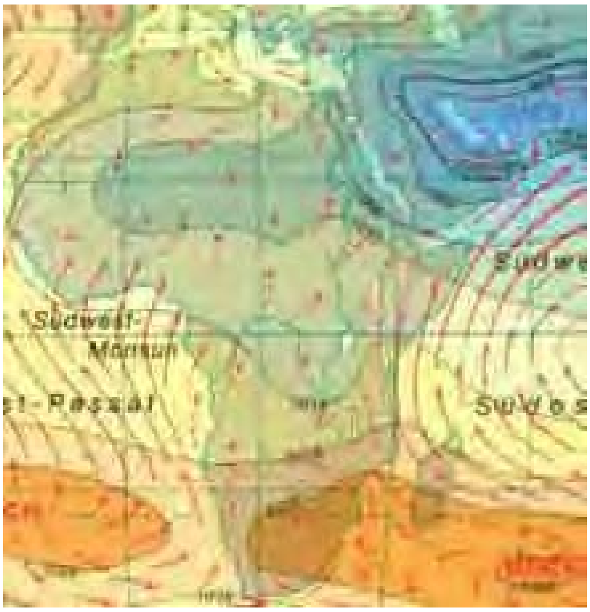
For the purpose of a country-wide search for large wind park sites, the wind pattern in a larger scale might be useful. According to established weather pattern, one can find atlases with wind maps, as shown in **Figure 1-1**. While such maps indicate that the wind flow pattern over Ethiopia are influenced – as the whole of East Africa – by the monsoon winds over the Western Indian Ocean, further analysis is normally not possible. A general wind direction analysis, in particular, for certain areas of the country, is not possible from such weather charts.

While satellites monitor the air movement in a larger scale, these data are normally difficult to come by. Different services exist which make some of the wind speed data available (through the internet, for example), but the value of such data for a site selection in Ethiopia is questionable (see **Figure 1-2**).

Theoretically, it seems possible to get a relatively accurate picture of national and regional wind regimes in Africa through a long term evaluation of such data that are based on ground and satellite weather stations. But for this purpose one would need to carry out a very intensive wind vector analysis - preferably through an automated computer evaluation of such wind maps with regard to direction and magnitude – which in the end would only reflect the measuring inaccuracies of the entry data. (This is generally referred to as GIGO – Garbage in – Garbage out)[4]

<u>Figure 1-1:</u>
General Air Flow Pattern over Africa

typical for January



typical for July

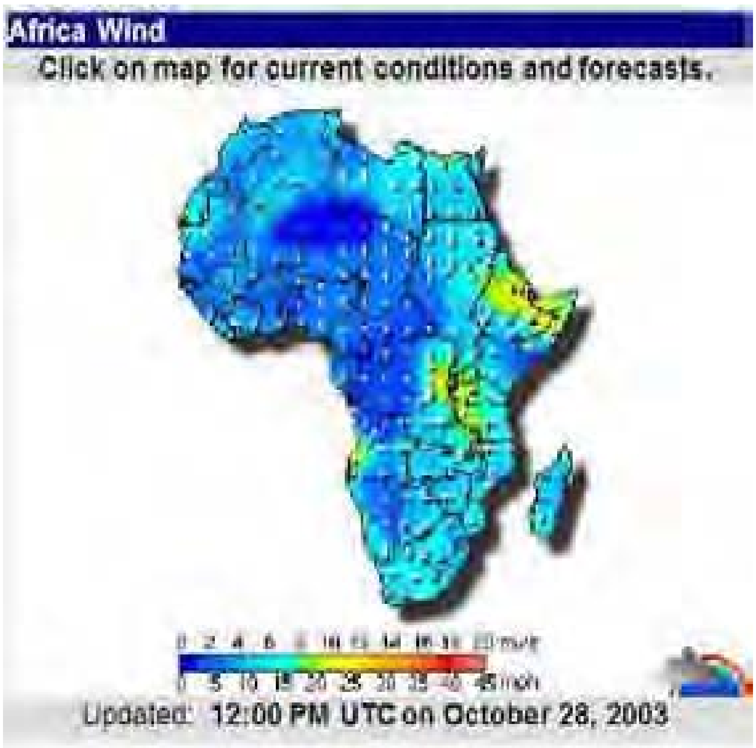
Source: Dierke Weltatlas, Braunschweig 2002, S. 219 (Cut-out), courtesy of Katja Bode, Deutsche Botschaftsschule Addis Abeba (German Embassy School)

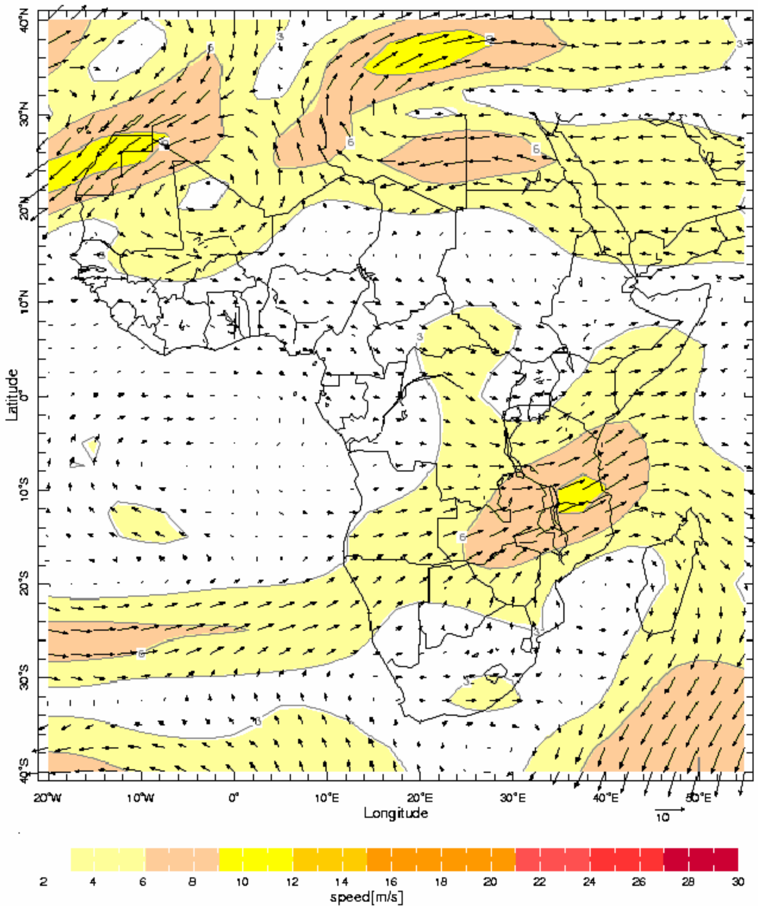
It is doubtful, whether such an analysis would yield usable data for a site selection approach in Ethiopia, as such a modelling of flow patterns does not take into account the topography and cannot consider adequately regional wind speed phenomena.

3) Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH (B. Jargstorf), "Wind Energy Programme TERNA, Information for Project Appraisal – Ethiopia, May 2004, Section 6 throughout, p. 43ff

4) InWEnt eGmbH Capacity Building International / Factor 4 Energy Projects GmbH (B. Jargstorf), "Wind Regimes of Africa - Comparative Evaluation of Wind Data from Selected Countries, May 2004, p. 8

Figure 1-2:
Examples of African Wind Maps





Source: http://www.windfinder.com

1.2 Wind Atlas Models

1.2.1 Linear Flow Models (WAsP)

For the decision where to place wind turbines, data about wind speed distribution has to be evaluated.

In Europe and North America, where wind energy utilization has spread during the past 20 years, site selection for wind parks or individual turbines has become the job of specialists, who use sophisticated wind data evaluation tools.

These computerized tools employ a scale of models and approaches, using direct numerical simulation (DNS), large Eddy simulation (LES), mesoscale models, linear flow models or a combination of some of these. By far the most popular program for evaluation of wind sites and for a prediction of wind turbine output is the Wind Atlas Analysis and Application Program (WAsP), which was originally developed for the first edition of the European Wind Atlas in 1987.[5]

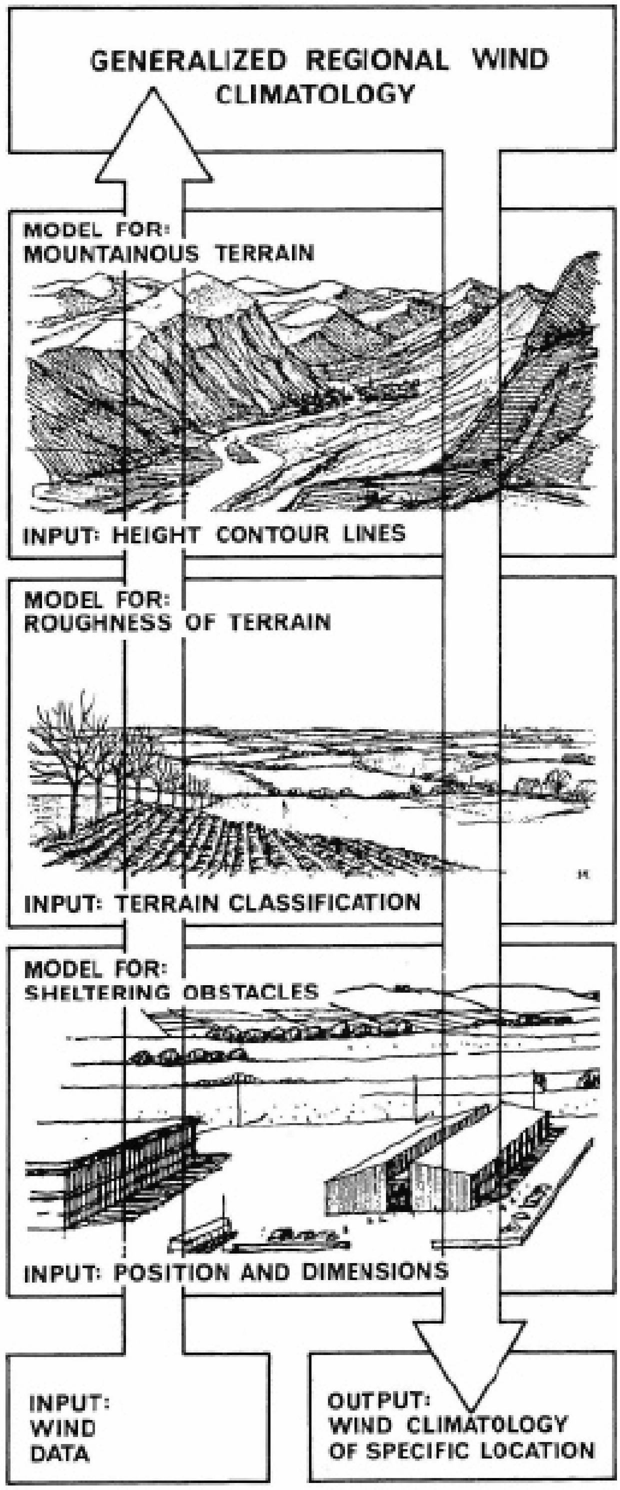
In the meantime, WAsP has appeared in its 8th version (January 2003). The basic approach has not changed from its first version, only the user interface has been refined. All in all, the basic approach of WAsP – a linear flow model – works fine in flat, uniform terrain and requires, as a prerequisite, the wind data from quite a large number of reliable meteorological stations as an input. As a rule, one has to establish the on-site data, such as the topography, the roughness of the terrain and the obstacles as input for a WAsP calculation (see **Figure 1-3**)

By now, the limits of WAsP are well known: basically, one can say WAsP works well under typical European and North American weather conditions, i.e. in climes with neutral atmospheric conditions (i.e. strong winds), no thermal flows (i.e. no land-sea breezes and similar effects) and in gentle topogra-

5) for more Information, see **Annex 2**

phy (i.e. with slopes not steeper as approx. 20 to 30°). In particular, WAsP is unable to calculate wind flow separation which generally occurs in complex terrain.

Figure 1-3:
WAsP – Basic Procedure



Source: The European Wind Atlas

For the major part of Ethiopia, therefore, it will be difficult to employ WAsP with good results. The sheer complexity of Ethiopia's topography, as well as the thermal flows between different landscape types within the country (mountains, desert areas, rift valley etc.) make plausible results from a linear flow model highly unrealistic.

Apart from that, linear flow models like WAsP depend (as do all models) on a validation through measured data. Thus, only after the model has been validated through a large number of points, where predicted data has been compared with measured data or actually generated energy, the model gains some practical value. This is considered, in the case of Ethiopia, to take some time.

1.2.2 Meso-scale Models

While a detailed discussion of all of the aforementioned models within the scope of this report is not possible, we shall deal in detail with meso-scale models, as such an approach is just used to develop a wind speed map for Ethiopia. This is currently done within the Solar and Wind Energy Resource Assessment (SWERA), a programme sponsored jointly by the United Nations Environmental Programme (UNEP) and The Global Environment Facility (GEF).[6]

Meso-scale models generally use a grid size of between 2.5 x 2.5 km and 250 x 250 km. All models using smaller (= more accurate) grid sizes are called 'micro-scale' models. The principle of meso-scale models is to calculate the wind vectors in three dimensions (3D) for the complete reference area. For that purpose, these models have to solve non-linear transport equations for mass (air), momentum and energy. Practically all models for wind energy flow maps employ different forms of Navier Stokes equations.[7]

These equations are a set of nonlinear partial differential equations that describe the flow of fluids such as liquids and gases. They are successfully applied to model weather or the movement of air in the atmosphere, ocean currents, water flow in a pipe, as well as many other fluid flow phenomena.

With these equations – which assume that the control medium (in this case air) is a continuum – the statistical dynamical approach of large-size clima-

6) for information on SWERA, GEF and UNEP see www.swera.unep.net/swera/, www.unep.org/ & www.gefweb.org/

7) for more information, see, for example, www.navier-stokes.net/ or http://en.wikipedia.org/wiki/Navier-Stokes_equations/

tology (up to several thousand square kilometres) is relatively simple.

For the numerical simulations of the SWERA project, the developers of the European Wind Atlas and WAsP – Risoe National Laboratory, Denmark – used the Karlsruhe Atmospheric Meso-scale Modell (KAMM)[8] on a 10 km grid size. That means the results do not account for local influence on scales below the grid size. Additionally – as is the case with all models – they depend on the quality of the input data. Apart from the topographic data (height above sea level, surface roughness, vegetation cover) these are mainly the so-called geostrophic winds, i.e. winds in more than 1,000 m above ground, so high, that they are not influenced by the surface at all.

The preliminary SWERA results for Ethiopia had been made available for this site selection procedure in form of a wind potential map. This map indicates, for the major part of Ethiopia, annual average wind speeds between 1 and 3 m/s in 50 m a.g.l. – for the meteorological standard height of 10 m this would transform to average wind speeds below 2 m/s.

Only in the Eastern part of Ethiopia (Ogaden) a larger area with about 4.5 to 5.0 m/s is predicted. This area, however, is – for the purpose of this study – of low interest, since EEPCo is not operating (or will operate, in the near future) an electric transmission grid there.[9]

According to this preliminary map, there are two other larger regions with annual average wind speeds in the range of 5 m/s at a height of 50 m a.g.l: the region around Mekelle in Tigray and Yabelo in Sidamo.[10] The rest of the country does not show very much distinction in this model when it comes to annual average wind speeds.

A comparison of the model results with a topographic map of Ethiopia shows a strong correlation between topography and annual average wind speed: i.e. the lower the altitude, the lower the wind speeds (see **Figure 1-4**). The only marked exception the map shows, is in the region approx. 80 km East of Addis Ababa: here, near the town of Nazareth, the widening of the rift valley, obviously, contributes to a tunnelling effect which results in higher than average wind speeds.[11]

8) for a description of this model and a comparison with WAsP, see H.P. Frank and L. Landberg, "Modelling the Wind Climate of Ireland", in: Boundary-Layer Meteorology, Vol. 85 (1997), p. 359-378

9) that does not mean that wind energy cannot play an important role for the development of Eastern Ethiopia (water lifting, electricity supply in isolated networks etc.) – it just does not make sense to make a follow-up of this region within the scope of project of large multi-MW grid-connected wind parks.

10) Yabelo sticks out sharply – according to this map, it looks like a singular windy area in Southern Ethiopia. No measurement station was installed here within TERNA, since this area (200 km South of Arba Minch) is too far away from the electric grid (see **Section 2.2.4**)

11) this is confirmed by the first measurement results (see **Section 3**, station Nazareth: 7.9 m/s)

Figure 1-4:
Topographic Map of Ethiopia

Source: Arno Peters (ed.), "Peters Atlas", Zweitausendeins 2001, p.42 – 43

1.3 Other Approaches

1.3.1 Overview

In a broader perspective, approaches to site selection can be categorized as follows:

1. **scientific approaches**, such as three dimensional flow models (see **Section 1.1**)
2. **empirical approaches**, using mainly engineering judgement (looking for secondary signs of wind etc.)
3. **pragmatic approaches**, a combination of engineering judgement with measurement at selected sites.[12]

Figure 1-5:
Vegetative Indicators of Strong Winds
South of Gonder – Aba Antinos Mountains

The scientific approach has the inherent disadvantage that – for a large country with a complex terrain like Ethiopia – the calculation is extremely complex and requires quite some computing power. In addition, large areas have to be calculated where there is no chance whatsoever that a wind power application is installed (top of mountains far away from the electric grid, deep valleys etc.).

As we have seen in the preceding section, there is also the risk that this modelling might not yield usable practical results.

In contrast to that, the empirical approach does not use any science at all: In practice, one would look for secondary signs of higher wind speeds, for example with the vegetation. In **Figure 1-5** one can see that, obviously, the tree regularly experiences strong winds, always from the same direction. It would be safe to install wind turbines here – but we would have (without prior measurements) no idea, how much such a turbine would produce. We only know that the production at this location would be above average.

For our task – a nation-wide site selection for large wind parks – empirical approaches can be ruled out. Even if successful in identifying promising wind park sites, we would have to start measurements in order to have base data for an economic analysis. Only for smaller projects – single turbines or small battery chargers for example – such an approach might be used.

1.3.2 Pragmatic or Reduction Approach

Combining engineering judgement in combination with measurements can be referred to as the "pragmatic approach". This approach can also be called **Reduction Approach**, since it reduces, through the successive application of different selection criteria, the area which is actually evaluated for wind measuring.

These selection criteria are generally

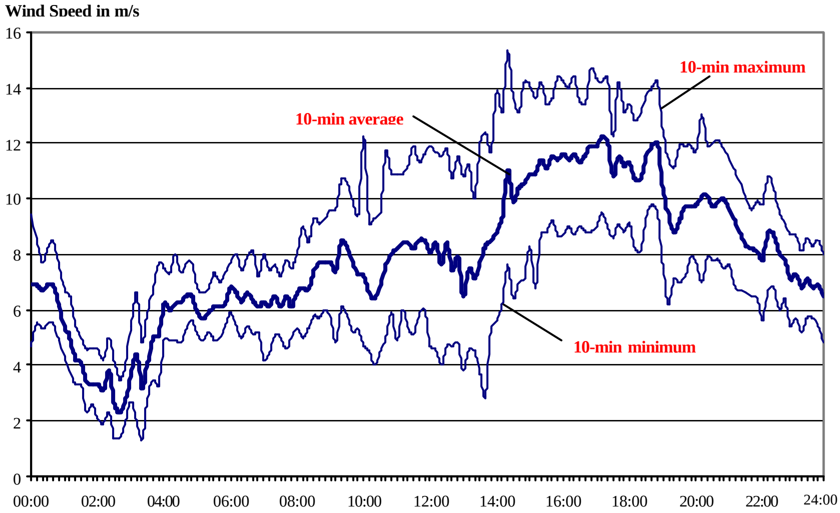
- close distance to the transmission lines;
- good road access; and
- environmental considerations (distance to human dwellings, nature reserves etc.)

The obvious advantage of such an approach is that measuring stations are only installed and operated at sites which can be regarded as potential wind park sites. We are not concerned with a lot of evenly distributed wind measuring stations, which would be required otherwise to get a nation-wide idea about available wind resources.

A disadvantage of this approach could surface when areas of high wind regime are missed out in the selection because they do not fit non-wind related criteria (for example: closeness to the road network).

12) InWEnt Capacity Building International, "Grid connected Wind Turbines", Post-Graduate Course, Part 1, Lecture 35 Planning Wind Power Projects (B. Jargstorf)

Figure 1-6:
Typical Diurnal Variation of Wind Speeds (Tigray)



Ashegoda (Mekelle), 16th of January, 2005

For the identification of suitable wind park sites we used the following main criteria:

- no conflicting land use planning, such as military, infrastructure, communal buildings etc.;
- expected high wind speed, low surface roughness (are there secondary signs of high wind speeds?);
- close distance to transmission lines;
- close distance to substations of the 66, 132 or 230 kV level
- easy to reach when transporting bulky, heavy and long structures;
- sufficient distance to next agglomeration of houses.[13]

It is not always easy to have a clear hierarchy for these criteria, but by far the most important one is the distance to the grid. Therefore, the first round of sites are all relatively close to the grid (< 1 km), and whenever possible in close distance to a substation.

Thus, the steps for the pragmatic site selection approach, under consideration of the above listed criteria, can be summed up as follows:

1. in quest for a suitable wind park site, do not look further than approx. 2 km from the existing h.v. overhead transmission lines: this already reduces the search area in Ethiopia (a country with a scarce electric grid network) considerably.
2. check for sites first, which are close to an existing (or a newly-planned) substation: a further considerable reduction of the search area
3. prefer sites which do have road close by and dispose of terrain which is not so difficult to access: considering the Ethiopian topography, this criteria was not always easy to meet
4. check for an appropriate size if the wind park site: as a rule, 3 km^2 was considered the minimum area. Depending on the local topography, this criterion was not always followed very strictly. Since we have adopted a two stage approach to the site selection, a more detailed survey of the surroundings of a promising site for the installation of the 40 m tower during stage 2 might be conducted to identify a new (larger) site close by.

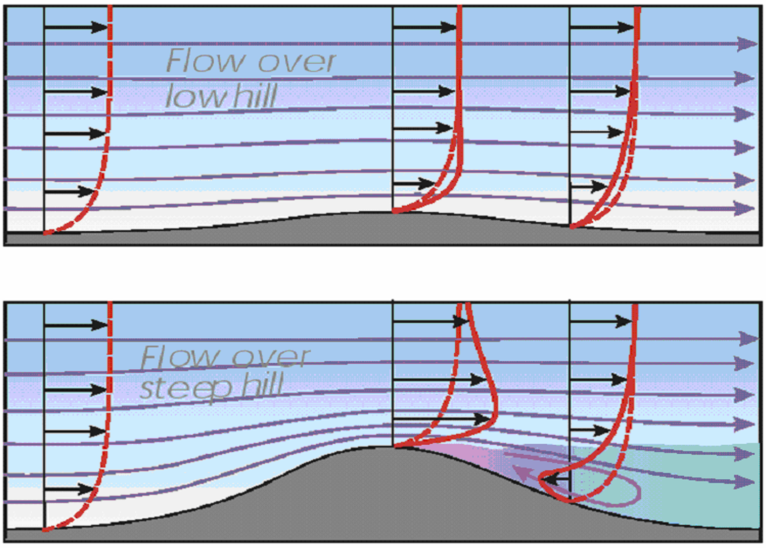
While these four steps were discussed, and potential sites compared with each other using these criteria, naturally, the expected wind speeds were always of primary concern.

However, due to the strong characteristics of diurnal pattern in Ethiopia, it was not always possible to identify possible windy sites. This was particularly true for a site exploration during the morning hours. Then, as a rule, wind speeds were more than half of the average wind speeds of the afternoon (see **Figure 1-6**).

As the wind regime was the most decisive factor for the pre-selection of sites, the local/regional amplification of wind speeds was always the primary motif for site selection.

13) Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH (B. Jargstorf), "Wind Energy Programme TERNA, Information for Project Appraisal – Ethiopia", May 2004, p. 60

Figure 1-7:
Wind Flow over Low and Steep Hill

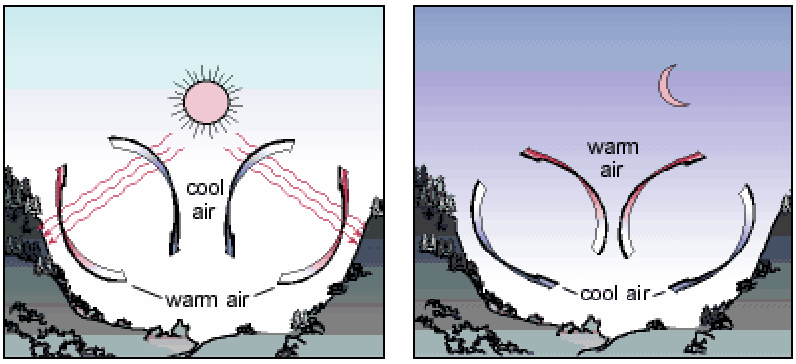


Source: Copin, P.A., Ayotte, K.A., Steggel, N., "Wind Resource Assessment in Australia – A Planners Guide", CSIRO Wind Energy Research Unit, 2003, page 56

Figure 1-8:
Narrow Spaced Wind Turbines on Mountain Ridges

Tarifa (Spain), Photo: B. Jargstorf

Figure 1-9:
Wind Effects in Mountainous Areas



during day **during night**

Source: Iowa Energy Center, http://www.energy.iastate.edu/renewable/wind/wem/wem-08_power.html

1.4 Local/Regional Wind Speed Amplification

1.4.1 Basics

The most obvious local wind speed amplification is through topography, i.e. if there is a hill in predominately flat terrain, the wind speeds on top of the hill are considerably higher than in the surroundings.

To achieve the maximum wind speed, however, the slopes of the hill may not be to steep – then the resulting turbulence reduces wind speeds and available energy output.

Figure 1-7 displays the change of the wind shear over hilly terrain. Wind shear is the variation of wind speed as a function of the height above ground. It is difficult to determine exactly when the increase of wind speed over a hill is offset by increased levels of turbulence. In any case, looking for a gentle slope keeps turbulence down.

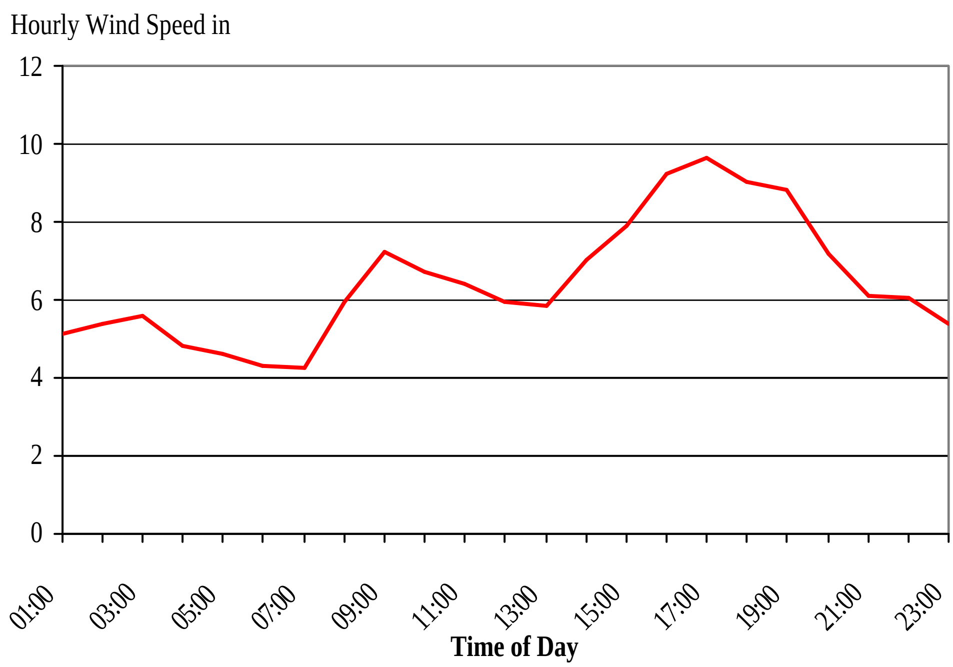
In practise, the situation is more complex since there is not just one wind direction – and the hill, too, is a three-dimensioned structure. As a rule, however, when looking for a suitable wind park site, look at hill tops and mountain ridges.

A mountain ridge which is rather long has an another advantage: since it can be interpreted as a barrier to the wind flow, it diverts the random wind direction always into a direction perpendicular to the ridge. Thus, the turbines on its top can be space more narrow than on non-mountainous terrain (**Figure 1-8**).

This narrower spacing has several advantages: shorter roads, shorter electrical connection, thus reduced electrical losses etc. Therefore, a carefully selected mountain site is normally desirable over a site in flat terrain.

In very rare instances we can find a local wind speed amplification in valleys: this is, when the valley acts like a tunnel and forces the wind

Figure 1-10:
Diurnal Variation as a Result of Updrafts in Mountains (hourly wind speed for February 2005 – Sululta)



through, while the mountains on both sides act like a funnel. In most cases, however, such a situation only allows a few wind turbines to be placed.

1.4.2 Mountain Winds

Wind is the result of solar radiation. The surface of the earth heats and cools unevenly, creating atmospheric pressure zones that make air flow from high- to low-pressure areas.

The situation of uneven heating up and cooling down is more complex in mountain areas, and gets even more complex, when we consider different vegetation covers and different reflection rates of soils.

For Ethiopia, we expect the basic effect of mountain winds according to **Figure 1-9** to be a common feature, which, in most instances, will be superimposed by other local and regional effects. Most likely the peculiar diurnal variation, measured in Suluta (North of Addis) is the result of a complicated updraft effects as a result of solar radiation (see **Figure 1-10**).

At the end of the measuring campaign, with data from the rainy season (no or little solar radiation) we will be in a position to say more.

Also other effects in a wider regional range can cause wind speed amplification, such as the high and low-pressure areas between large mountain massifs and neighbouring plateaus or desert areas. A well-known example is the world's first developed wind region: California. Here the fertile coastal areas form a strong (pressure) contrast to the Mojave desert on the other side of the Rocky Mountains, leading to strongly increased wind speeds in summer.

In Ethiopia we have a similar situation in the Mekelle area. There the different reflection rate for solar radiation between the mountainous area contrasts with the Danakil desert area. A strong wind with a strong predominant wind direction is the result (see for more detail in **Section 2.2.1**)

1.5 Wind Measuring Campaign

1.5.1 Data Logger

After 20 years of dynamic wind technology development, data loggers for wind resource assessment are today state of the art equipment.

GTZ opted for a data logger from Ammonit Gesellschaft für Meßtechnik GmbH which is prepared for up to three anemometers and two wind direction sensors (WICOM 32). Details of the logger and sensors can be found in **Annex 4** (technical specifications etc.)

For an easy installation of the logger and measuring equipment, the unit comes mounted in a water-tight protection box (see **Figure 1-11**). Normally, these loggers are powered by small photovoltaic (PV) cells. As it was feared that these PV modules would raise too much attention, small sealed lead-acid batteries were used instead (6.5 Ah).

For the installation of the measuring station, only mounting brackets for the sensors, for the protection box and plastic tubes for the protection of the sensor cables were needed.

1.5.2 Measuring Towers

Originally, for the stage 1 measurements, only 10 m towers were planned. However, since one site had already previously been measured at 10 m, additionally, one 40 m tower was included in the current phase.

Figure 1-11:
10 m Tower with Anemometer, Wind Vane and Lightning Arrestor (Sululta)

Source: EEPCo

On account of a co-operation agreement between the local Ethiopian SWERA project partner EREDPC and EEPCO, EEPCO was to receive the 40 m tower from EREDPC. Their measuring tower was installed on the outskirts of Addis Ababa where further measurements would not be needed.[14]

Upon closer inspection, it was found that the measuring tower of EREDPC was just 30 m high and could not easily prolonged (guy wires would have been too weak). Thus, it was decided to install the 30 m tower as it was (see **Figure 1-14**).

For the 10 m a.g.l. measuring stations, EEPCo used locally available 12 m wooden poles. This was the best and most economic solution, since the local line and cable men of EEPCo were familiar with the transportation and erection of these poles.

Figure 1-11 shows an erected tower with both anemometer and wind vane installed. Great care was put into installing an effective lightning arrestor, since during the rainy season most regions of Ethiopia experience high lightning incidents.

The box with data logger was installed ca. 3 m above ground to avoid unauthorized access. For data retrieval, EEPCo staff arrives at the site with a suitable ladder.

1.5.3 Preparation of Site Selection Mission

According to the proposals recommended in the project appraisal procedure and jointly agreed upon with EEPCo during the planning workshop, the preparatory work was divided as follows:[15]

GTZ: procure data logger, sensors, batteries etc. along with a portable computer for data retrieval and handling

EEPCo: prepare measuring poles (10 m), dismantle 30 m tower of EREDPC, make available topographic maps for pre-selected search areas.

Before the mission, four tentative search areas were defined according to information from different sources. Most of this information came from the participants of the planning workshop, among them members of the National Meteorological Service and the Addis Ababa University (AAU), Faculty of Engineering. These search areas will be discussed in more detail in **Section 2**.

1.5.4 Site Selection Mission

The site selection mission was carried out from 29th December 2004 to 28th January 2005. Unfortunately, problems with customs caused delays in retrieving the data logger equipment, which had arrived, as planned, in mid-December.

14) see **Annex 5** for information about the EREDPC tower

15) for details, see **Annex 6**

In addition, the EREDPC 30 m tower could not be dismantled before the arrival of the consultant. Thus, it had to be done jointly – a difficult venture, since the measuring tower was, by now, surrounded by trees (**Figure 1-13**). In the same way, the mounting brackets and other auxiliary parts for the installation of the meteorological mast were not prepared, work on it started only after the arrival of the consultant.[16]

Thus, the first field trip – to Mekelle, where at least one site had already been pre-selected (Harena /Messobo)[17] – could only be started with 10 days delay. In **Figure 1-12**, the list of measuring stations with the installation date is given.

Figure 1-12:
List of Measuring Stations

No	Name	Erected
	30 m tower	
1	Harena/Messebo 30 m	16.01.2005
2	Harena/Messebo 30 m (Telecom)	16.01.2005
	10 m tower	
3	Ashegoda	15.01.2005
4	Maymekden	14.01.2005
5	Gondar (Bilagig)	20.01.2005
6	Harar (Ghiorgis Meda)	29.01.2005
7	Nazret (Sire Ababune)	01.02.2005
8	Debre Berhan (Beryu Meda)	09.02.2005
9	Sululta (Gorodima)	11.02.2005
10	Bahir Dar Substation	17.02.2005
11	Nefas Meewcha	19.02.2005

note: #7 - # 11 erected by EEPCo staff

1.5.5 Training and Capacity Building

There were two types of training and capacity building measures planned: lectures with exercises (presentations) and on-the-job training.

A total of 7 modules were presented, according to the following list:

1. TERNA Ethiopia – Kick-off Meeting Site Selection Mission
2. Introduction to Wind Energy
3. Wind Power Project Planning and Operation
4. Photo Impressions of a Wind Park Installation
5. Introduction to Wind Measurement
6. Resource Assessment
7. TERNA Ethiopia – Results of Site Selection Mission[18]

Figure 1-13:
Dismantling of EREDPC 30 m Tower[19]

Were appropriate, exercises and discussions were held. Unfortunately, due to unfinished preparatory works, the staff of the EEPCO Coal and Wind Energy Project team could not always attend the lectures, as they were busy elsewhere (trying to get the logger equipment out of customs, preparing the mounting brackets and auxiliary materials for the installation of sensors and data loggers, etc).

On account of this situation, it is proposed that during the next mission a thorough repetition of the training subjects is offered – this time exclusively for the EEPCo project staff. However this time, they got an intensive on-the-job training, which obviously was successful: After the departure of the consultant EEPCo's project staff selected the sites of 4 and installed 5 of a total of 11 measuring stations unaided (**Figure 1-12**)

16) see **Annex 8**

17) see Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH (B. Jargstorf), "Wind Energy Programme TERNA, Information for Project Appraisal – Ethiopia, May 2004, p. 51ff

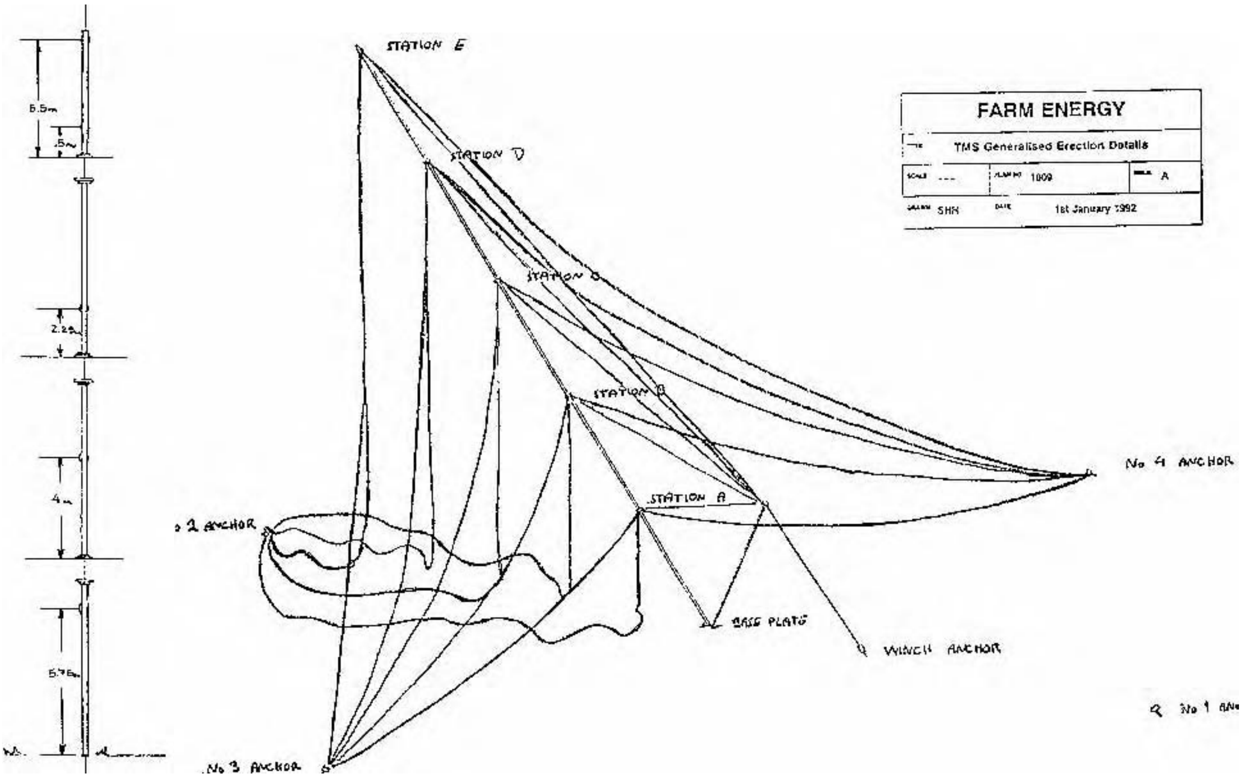
18) see Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH (B. Jargstorf), "Wind Energy Programme TERNA – Training Documents – Part 1", January 2005

19) 6th of January, 2005, 15.35 h, note the trees growing in the immediate vicinity of the measuring mast

The training material was handed out to the participants on CD, and was complemented by additional guidelines for the data retrieval.[20] Between 5 and 14 participants attended the training course. Most of them EEPCo staff, but also participants from EREDPC (SWERA wind project of UNEP), the Addis Ababa University (AAU) and from the co-financing institution, the Austrian Development Agency (ADA) joined the classes.

The major capacity building measures of this phase, however, will be conducted during the next mission, when at least 6 months of data from the Ethiopian stations are at hand. Then wind data handling and evaluation with real world data will be practised, and different procedures for output estimations and wind park effect calculations will be trained and practiced.

Figure 1-14
30 m Tower with Gin Pole (from EREDPC)



Harena-Messebo

20) see **Annex 9**

2. Site Selection

2.1 Search Areas

2.1.1 Why Search Areas?

To identify the 10 most suitable sites for wind parks in an area covering 1.13 million km^2 is not an easy task, considering the lack of reliable wind data. Identifying the sites and installing the meteorological stations within a mission scheduled for just three weeks, seems even more difficult.

To work efficiently, therefore, GTZ and EEPCo decided to concentrate its efforts to search areas with the following characteristics

- close distance to electric load centres and/or major substations or dispatch centres;
- within easy reach for public transport (road network) considering the special requirements of transporting bulky items such as tower segments and rotor blades;
- not too far away from (larger) towns with a good infrastructure (to ensure adequate support during installation and for the long-term operation and maintenance)[21]; and. last but not least
- good wind resources, meaning, in practice an average minimum wind speed of more than 6 m/s in 10 m a.g.l.

Even before the preliminary SWERA wind map was edited, the four major search areas for the site selection mission were defined (see **Figure 2-1**).

Figure 2-1:
Search Areas for Site Selection Mission

Figure 2-2:
List of Search Areas / Selected Sites

Area 1	**Aksum – Mekelle – Alamata – Desie**
installed:	Harena Messebo 30 m Harena Messebo 30 m (Telecom) Maymegden 10 m Ashegoda 10 m
Area 2	**Gonder – Bahir Dar – Debre Markos**
installed:	Gondar (Bilagig) 10 m Bahir Dar (Substation) 10 m Nefas Meewcha (Debre Tabor) 10 m
Area 3	**Dire Dawa – Harar**
installed:	Harar (Ghiorgis Meda) 10 m
Area 4	**Addis Ababa – Nazaret – Shashemene – Awassa**
installed:	Suluta (Gorodima) 10 m Nazret (Sire Ababune) 10 m Debre Berhan (Beryu Meda) 10 m

21) with a project of this size (50 MW), the wind turbine manufacturer is expected to establish a permanent service post close to the wind park. To do this “in the middle of nowhere” would add considerable cost and individual hardships for the service personnel

As can be seen in comparison with **Figure 1-5**, three of our search areas are identical with areas with above-average wind speeds in the SWERA map, namely the Mekelle area, the Nazaret – Awassa area and the Dire Dawa – Harer area.

Figure 2-2 lists the major towns of the search areas and indicates the actual sites selected for the installation of anemometers. These areas have also been selected on the grounds as to serve as suitable, workable areas to be covered within on field trip of approx. 4-5 days each.

With the exception of Area 3, at least three stations per search area were installed.

2.1.2 Are the Search Areas Representative?

Without other sources of wind data than the scant data from meteorological stations, it is difficult to answer this question. However, from the test run of the SWERA supported KAMM model we know, that, apart from the Ogaden region, only two regions offer above average wind speeds in Ethiopia (Mekelle and Yabelo).[22] Both Ogaden and Yabelo do not have an electric grid currently. While this is likely to stay for a long time in the case of Ogaden, a grid extension to Yabelo might be possible in the medium time scale. At present, an extension of the 230 kV transmission line from Dilla to Agere Mariam is planned (see grid map on **Figure 2-17**).

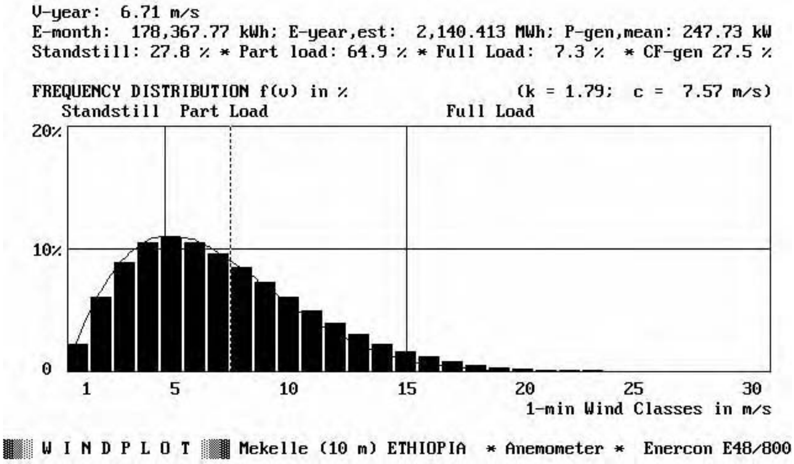
Thus, the Yabelo region could become an interesting for grid connected wind parks, one day. Thus, after 6 months of measuring for stage 1, EEPCo might consider to look for appropriate sites in the Yabelo area and move some of the anemometer stations not used anymore under the stage 2 measurements to Yabelo.

Even if there is no realistic chance for a transmission line to Yabelo within the short or medium run, the measurements can be used to validate the SWERA model.

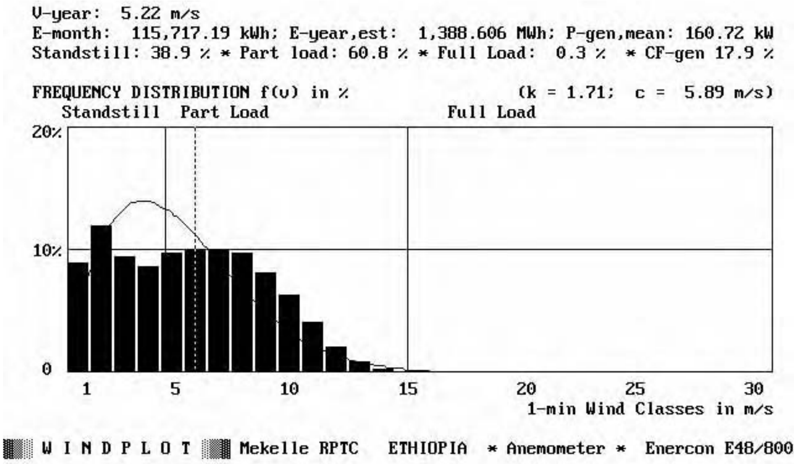
22) see **Section 1.2.2**

Figure 2-3:
Comparison of Wind Data Mekelle Airport – RTPC

a. Airport



b. Rural Technology Promotion Centre (RTPC)



2.2 Selected Sites

2.2.1 Search Area 1 (Mekelle)

For search area 1 we have a particular situation, as wind speed data from a classifying wind data logger are available. These are the data obtained through a one-year measurement campaign at the premises of the Rural Technology Promotion Centre, close to the airport in Mekelle.

The airport data from 1988, as published by the Ministry of Mines an Energy in 1995,[23] showed promising values (annual average of 6.71 m/s in 10 m a.g.l., based on monthly mean values, see **Figure 2-3 a.**)

23) Ministry of Mines an Energy, Ethiopian Energy Study and Research Center “Tigray Energy Resources, Household Energy Consumption and Policy Issues”, 1995, for the indicated average wind speeds a Rayleigh distribution (Weibull k-factor = 2) has been assumed, as no further data were available

Thus a validation of these data was undertaken in ca. 3 km distance from the airport at the same plateau. The measurements at the RTPC anemometer gave an annual average of 5.22 m/s – a plausible result, since the micro-location at the RTPC is not as open as the airport anemometer (some trees and a fence around the RTPC compound).

The increased wind speeds of Mekelle are a result of local pressure and temperature differences – mainly between the mountainous regions West of Mekelle town and the lowlands in the East (Danakil depression, see **Figure 2-4**). As such, these winds are a direct result of solar radiation and show a marked annual variation with low wind speeds during the rainy season (June – August), when solar radiation intensities are low. **Figure 2-5** uses solar radiation data measured within the frame of the GTZ project “Photovoltaic Pumping Systems”.

With this knowledge it was decided to install the 30 m tower from EREDPC in Mekelle, at the previously pre-selected site in the North of Mekelle town – the Harena – Messebo plateau.[24]

While this location offers favourable conditions for a multi-MW wind park, the wind regime has to be established in a broader scale. Therefore, two other 10 m meteorological masts were installed: one 16 km South-East (up-wind) of Harena (Ashegoda), and the other 8 km down-wind (Maymekden). In measuring at these three sites, we can establish the overall picture of the wind regime in the Mekelle area and will show the regional distribution of the wind resource. This will indicate the relative wind regime of the pre-selected site(s) and collect valuable information for a final site selection.

Normally, such a procedure - i.e. establishing the wind speeds some kilometres up-wind and down-wind of a pre-selected wind park site – would have been carried out in Phase 2 of the site selection process. But as Mekelle is already singled out as a potential site, these additional measurements are undertaken already during Phase 1. Naturally, for the two other sites of the Phase 2 evaluation, a similar procedures will be employed, i.e. should another site in another search area hold a promising wind energy potential, additional measurements in the vicinity of this site have to be carried out in order to get a more complete picture of the regional wind resources.

Figure 2-4:
Understanding the regional Wind Speed Amplification in the Mekelle Area

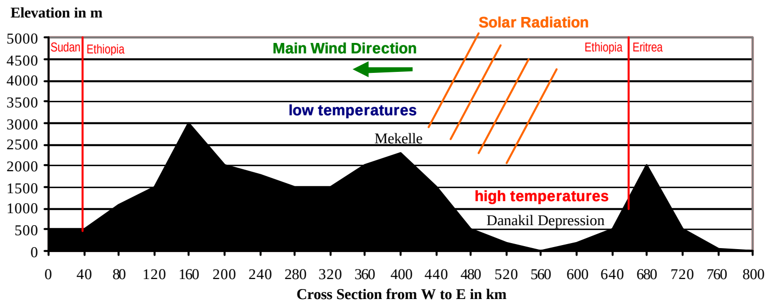
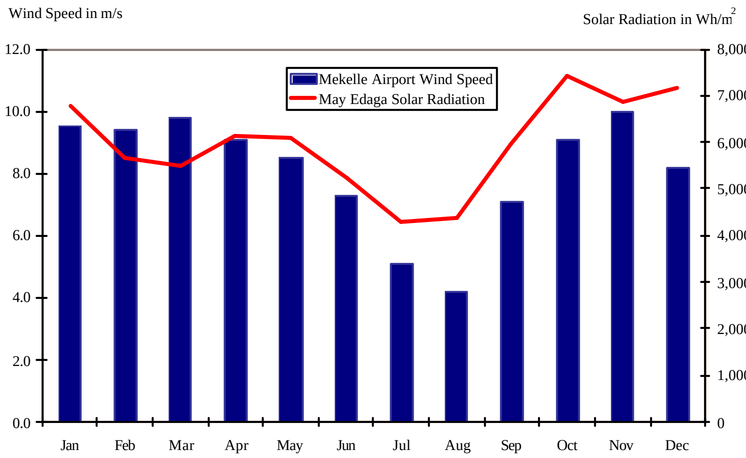


Figure 2-5:
Comparison of Solar Radiation and Wind Speeds (Tigray)



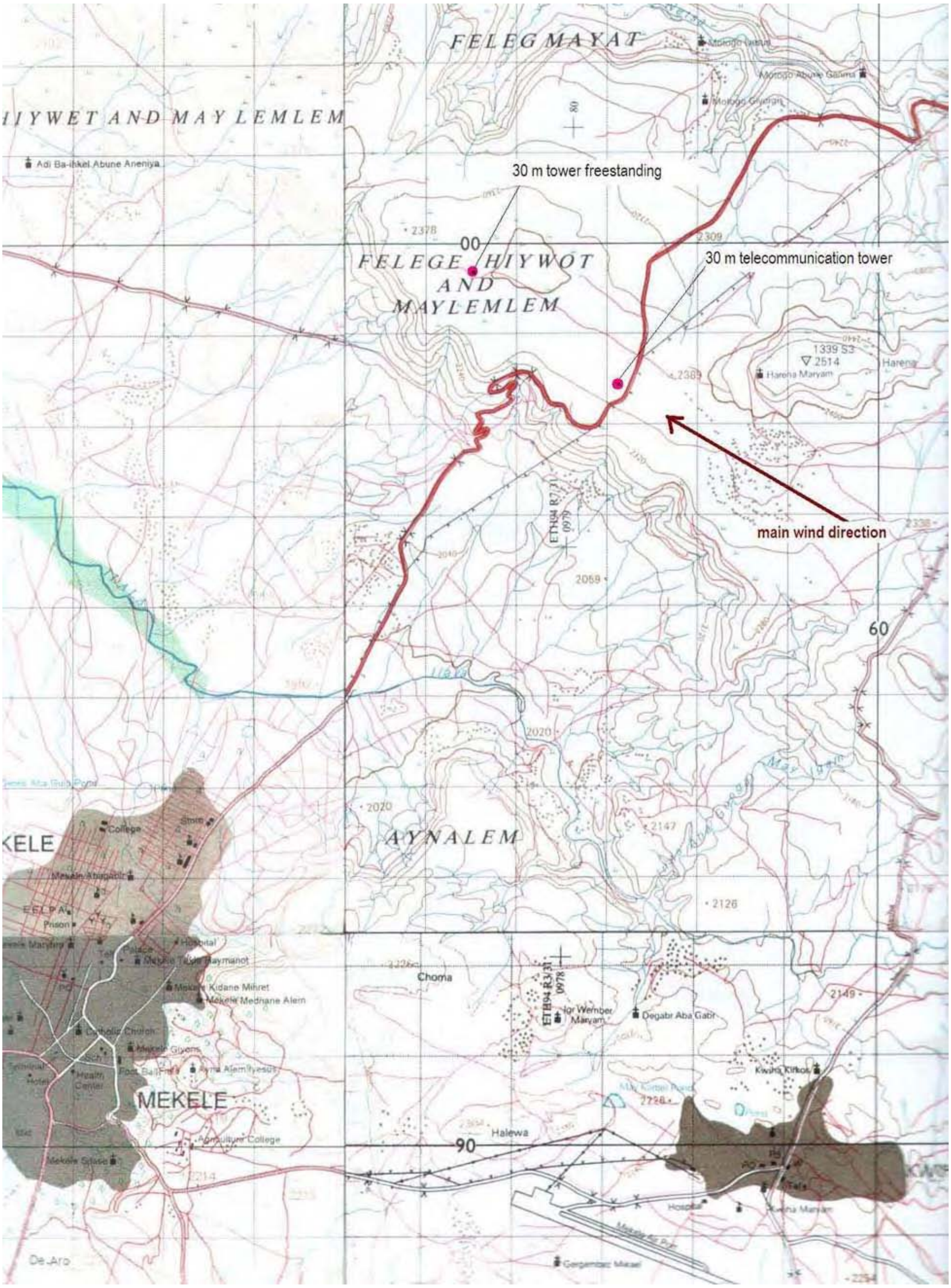
Source: Factor 4 Energy Projects (B. Jargstorf), “Photovoltaic Pumping Systems – Three Years Evaluation Ethiopia”, 2001, p. 36

2.2.2 Search Area 2 (Gonder – Bahir Dar)

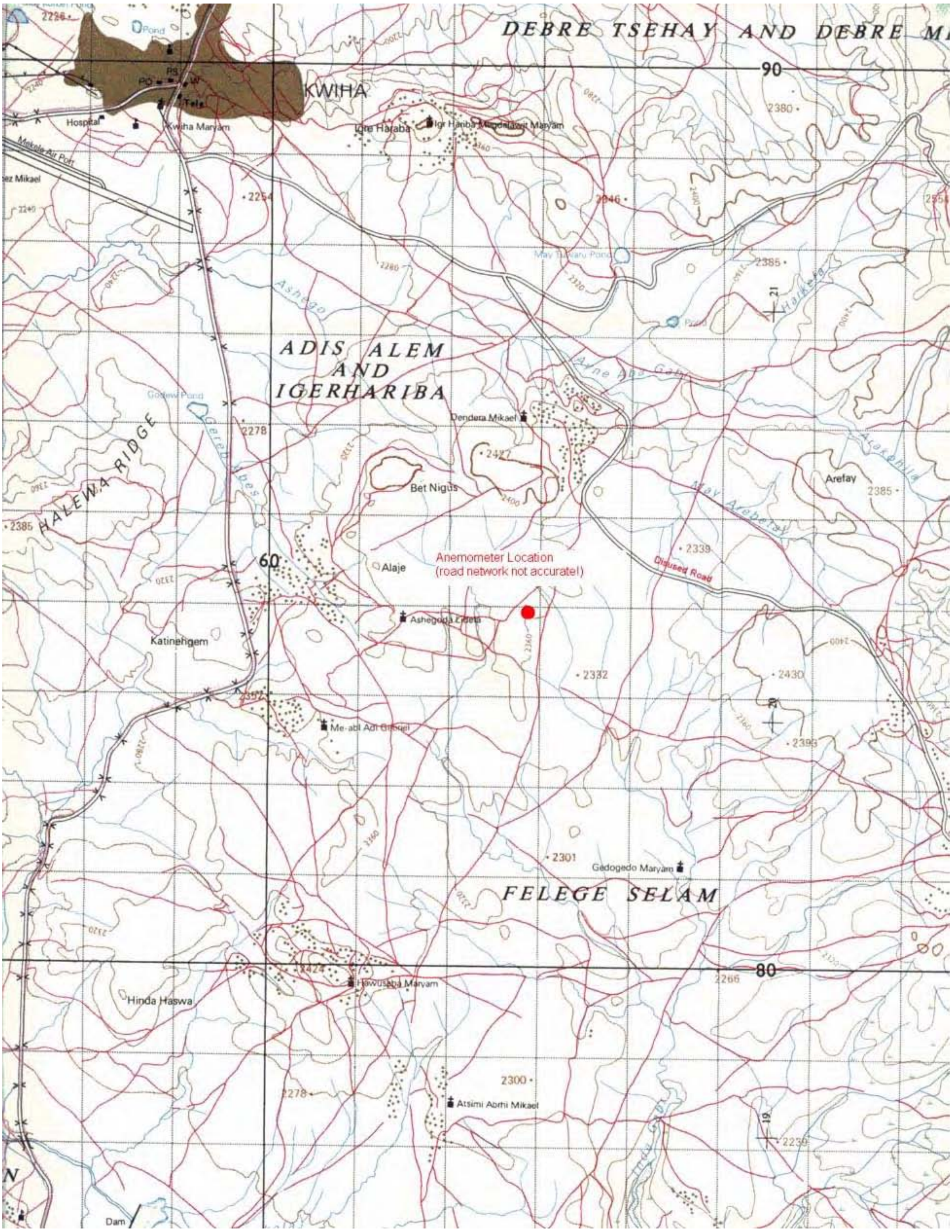
Here three measuring stations were installed. The first at a hill just outside of Gondar town, in close vicinity to the (old) 66/15 kV substation. A topographic map of the area was not at hand – it will be evaluated during the next mission of the consultant.

24) see Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH (B. Jargstorf), “Wind Energy Programme TERNA, Information for Project Appraisal – Ethiopia”, May 2004, Section 6 throughout, p. 51ff

Figure 2-6:
Topographic Map of the Harena-Messebo Plateau (Mekelle)



<u>Figure 2-7:</u>
Topographic Map of Ashegoda (Mekelle)



<u>note:</u> Airstrip of Mekelle Airport NW of Ashegoda

<u>Figure 2-8:</u>
Topographic Map of Maymekdan (Mekelle)

<u>note:</u> Harena-Messebo Plateau SW of Maymekdan

Figure 2-9:
Bilagig, Gondar - Erecting the Pole

Figure 2-10:
Bilagig (Gondar) – View towards Main Wind Direction

Figure 2-11:
Nefas Meechwa – 230 kV Overhead Line

Indication for better than average wind speeds at the pre-selected site Bilagig was the extreme flagging of trees on this hill (see **Figure 1-9**).

Due to time constraints, all the mountains around Gondar could not be evaluated. Thus, the Bilagig site might not hold sufficient space for a 50 MW wind park. However, the next mountain ridge South of the Aba Antinos Mountain with the Bilagig site, (close to the new substation of Gondar 230/66/15 kV, 40 MVA), seems to be large enough. The mountain could not be visited, but is expected to have similar wind conditions as Bilagig.

Also in search area 2, EEPCo selected a site close to the substation in Bahir Dar. No further information is available.

Along the 230 kV line from Alamata to Bahir Dar (see grid map in **Figure 2-17**) a small town is called Nefas Meewcha, Amharic for "origin of wind". Since the topography in close vicinity to the h.v. line looked suitable (see **Figure 2-11**), is was decided to install a 10 m tower with data logger there. Topographic maps were presently not available.

2.2.3 Search Area 3 (Dire Dawa – Harar)

Similar to the local wind speed increase for the Mekelle area, we expected increasing wind speeds when coming closer to the Jijiga region, where the mountainous part of Ethiopia change to the savannah- and desert-like regions of Eastern Ethiopia.

However, signs of local wind speed amplification could not be identified in that area. In addition, the local topography poses problems for the installation of wind turbines (see **Figure 2-12**).

Instead, a site was selected in close distance to Harar and the substation of this town. At present, no topographic map for that area is available (see **Figure 2-13**). The site Giorgis Meda lies only a few 100 m away from the main road on a slightly rounded hill top.

2.2.4 Search Area 4 (Addis Ababa – Nazareth - Awassa)

Due to time constraints, this search area has only been evaluated in the Northern part: the Awassa region and Yabelo further South has not been visited.

A total of 3 stations were installed by EEPCo after the termination of the consultant's mission: Sululta in the North of Addis Ababa (**Figure 2-14**), Nazareth East of Addis and Debre Birhan close to the 230 kV line from Addis to Alamata.

For Nazareth and Debre Birhan no topographic maps and further information was available.

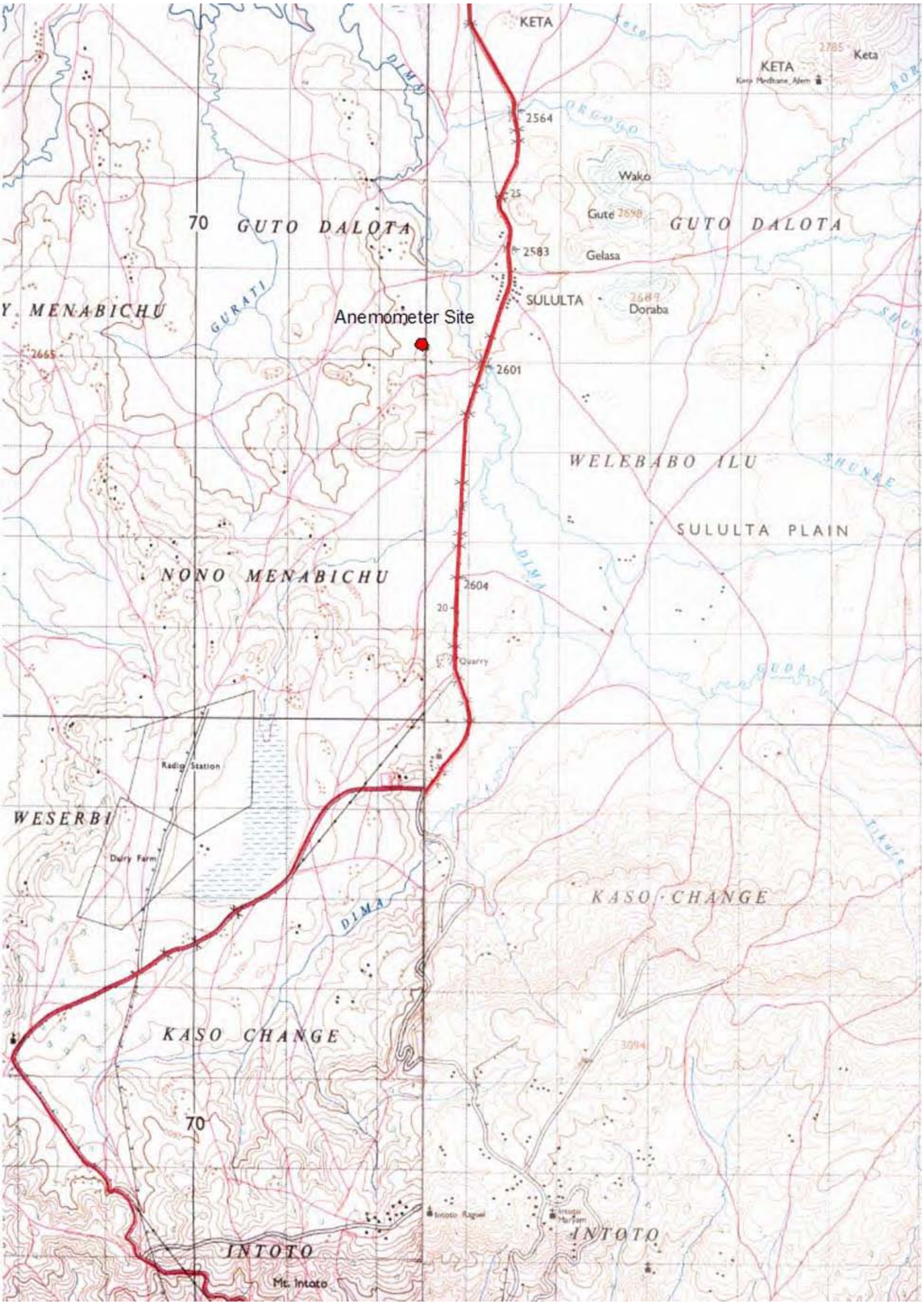
In order to get a better picture of the potential of Search Area 4 it is proposed to install at least one measuring station in Southern Ethiopia, preferably in the Yabelo area, where the SWERA test run indicates higher than average wind speeds. One of the anemometer stations from phase 1 could be installed there to check the results of the SWERA model.

Figure 2-12:
Topography on the Road from Harar to Jijiga

Figure 2-13:
Map of Dire Dawa - Jijiga

Source: http://www.maps2anywhere.com/Maps/maps_-_ethiopia_sample_map_itmb.htm

Figure 2-14:
Topographic Map of Sululta (North of Addis Ababa)



***note:* in the South the northernmost part of Addis Ababa (Mt. Intoto)**

2.3 Summary of Site Selection

During the three-week site selection mission a total of 11 anemometer stations at 10 different locations were pre-selected. Of this, 7 locations had been chosen jointly by EEPCo and the consultant, and three sites were selected by EEPCo personnel by themselves (Debre Birhan, Nazareth, Bahir Dar). This was necessary, since the preparation of the measuring equipment took much more time than anticipated.

It is proposed to check these last three sites during the next mission of the consultant, along with an evaluation of further sites, such as the Southern part of search area 4 (Yabelo) or other sites of interest for EEPCo.[25]

Figure 2-15 shows the main information about the installed meteorological stations, while **Figure 2-16** indicates their location.

The majority of sites lies in altitudes between 2,000 and 2,400 m, with the exception of Debre Birhan (2,818 m), Sululta (2,624 m) and Nefas Meewcha (3,119 m). Only Nazareth is situated at altitudes below 2,000 m (1,811 m). In any case, in these heights above sea level, standard utility wind turbines produce considerably less than at sea level, on account of the reduced air density. As a rule of thumb, for each 1,000 m one could expect 10 % less production than on sea level.

Therefore, measures have to be prepared to compensate for the low air density. Principally, one could increase the rotor diameter – which seems possible, as the wind speeds in Ethiopia are expected to have a "Monsoon-like" frequency distribution, with no wind speeds in excess of approx. 20 m/s. The first results of the measuring campaign confirm this expectation (see **Section 3**).

Another possibility for air density compensation lies in an increase of the rotor speed. In doing so, the amount of air passing through the rotor can be increased per time unit. This makes the turbines louder, which is not an immediate disadvantage for sites far away from human settlements.

This is just a preliminary discussion of the altitude problem – further work has to be done at a later stage of the project.

To see the location of the measuring sites in relation to the electric grid of Ethiopia, refer to **Figure 2-17**. Further discussions of the feed-in points will be undertaken in connection with the site selection of phase 2.

In the next section the first results of the measuring campaign are presented. They show that – even under consideration of the high altitudes of the sites – a high wind resource exists in Ethiopia.

Figure 2-15:
List of Installed Measuring Stations

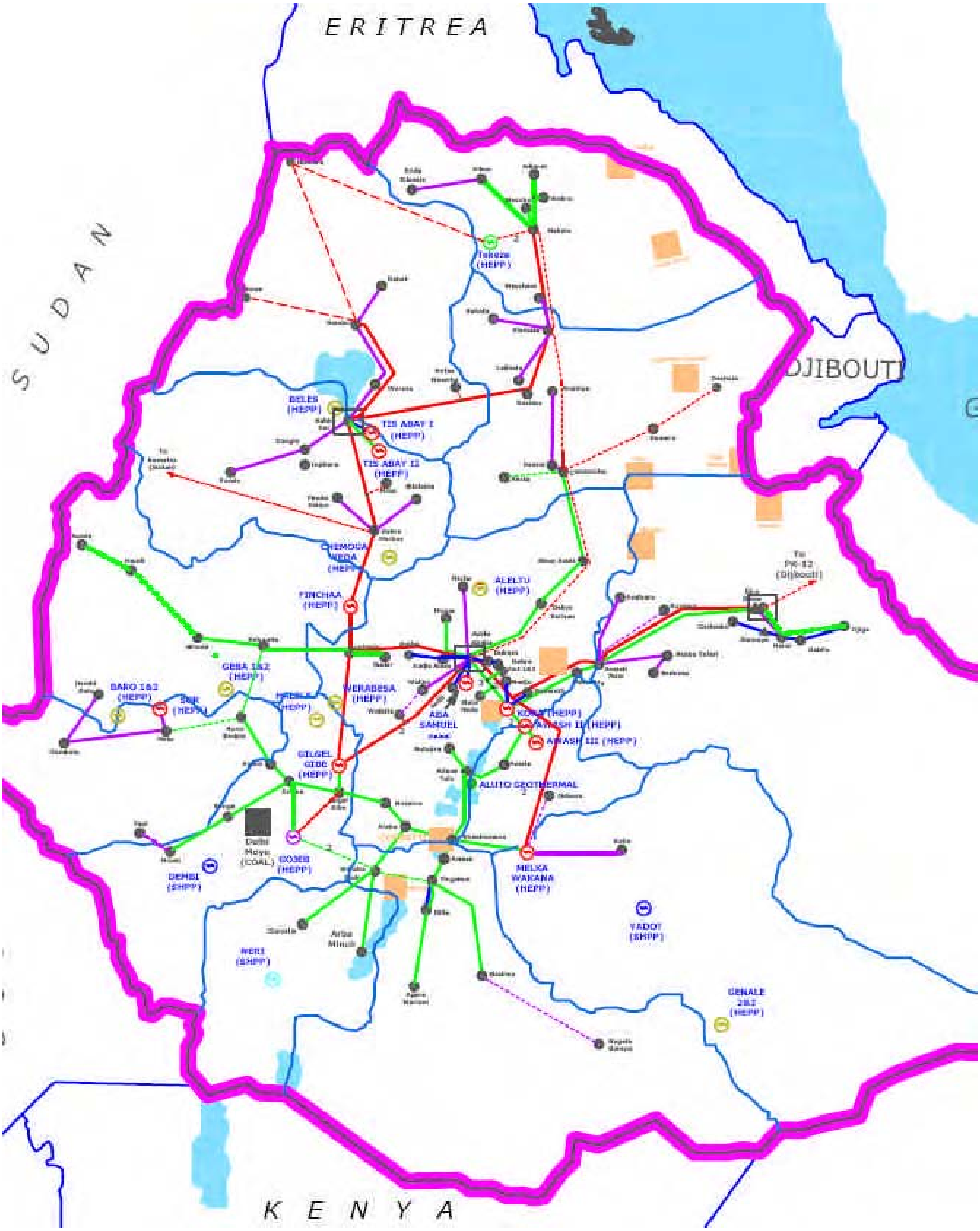
No	Name	Erected	Altitude	Coordinates	Remarks
1	Harena/Messebo 30 m	16/01/2005	2,401 m	N-0555254, E-1499706	pre-selected final site
2	Harena/Messebo 30 m (Telecom)	16/01/2005	2,394 m	N-0557265, E-1498839	pre-selected final site
3	Ashedoga 10 m	15/01/2005	2,391 m	N-0562882, E-1484021	to validate Harena
4	Maymekden 10 m	14/01/2005	2,356 m	N-0561039, E-1504106	to validate Harena
5	Gondar (Bilagig) 10 m	20/01/2005	2,521 m	N-0328666, E-1971063	West of Gondar
6	Harar (Ghiorgis Meda) 10 m	29/01/2005	2,105 m	9° 19.51 N, 14° 99.70 E	North of Harar
7	Nazareth (Sire Ababune) 10 m	01/02/2005	1,862 m	N-0560849, E-1071845	by EEPCo staff
8	Debre Berhan (Beryu Meda) 10 m	09/02/2005	2,818 m	N-0560849, E-1071845	by EEPCo staff
9	Sululta (Gorodima) 10 m	11/02/2005	2,624 m	N-0472536, E-1014090	North of Addis Ababa
10	Bahir Dar Substation 10 m	17/02/2005	1,811 m	N-03233003, E-127830	by EEPCo staff
11	Nefas Meewcha 10 m	19/02/2005	3,119 m	N-0441319, E-1296313	East of Debre Tabor

note: coordinates as indicated by EEPCo

25) for instance the region around Assela, where EEPCo suggests to install an anemometer station. See email of Ato Tarekegn Kelemu from April 5th, 2005.

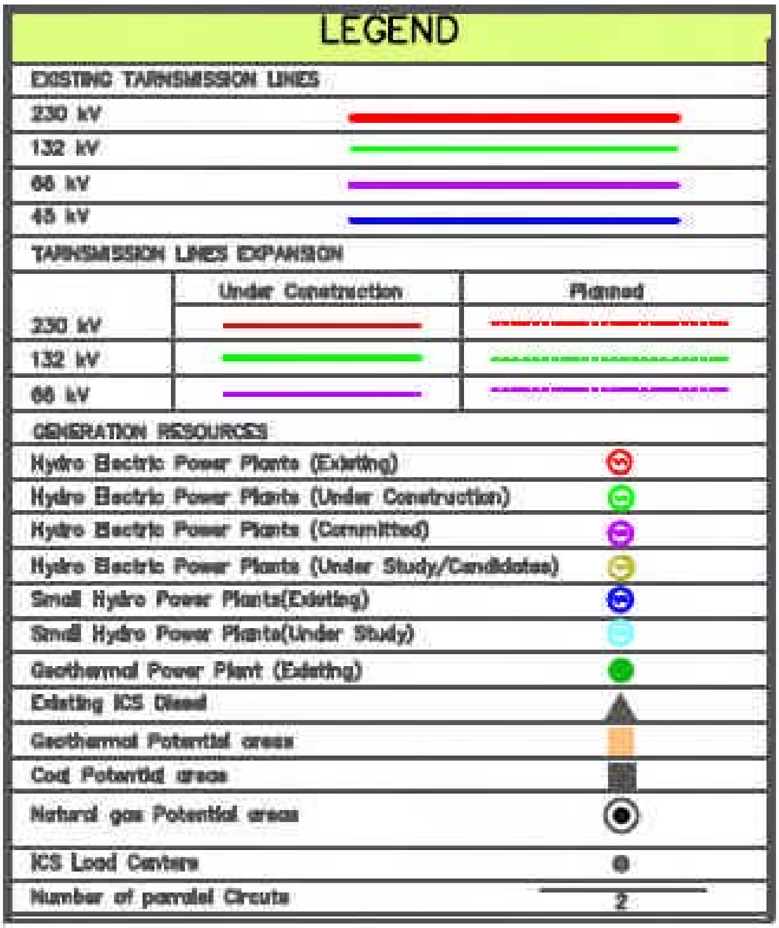
Figure 2-16:
All Installed Wind Measuring Stations

Figure 2-17:
Electric Grid of Ethiopia (Interconnected Grid System – ICS)



Source: EEPCo

see Legend on next page


LEGEND
EXISTING TARNSMISSION LINES
230 kV
132 kV
66 kV
45 kV
TARNSMISSION LINES EXPANSION
Under Construction
Planned
230 kV
132 kV
66 kV
GENERATION RESOURCES
Hydro Electric Power Plants (Existing)
Hydro Electric Power Plants (Under Construction)
Hydro Electric Power Plants (Committed)
Hydro Electric Power Plants (Under Study/Candidates)
Small Hydro Power Plants(Existing)
Small Hydro Power Plants(Under Study)
Geothermal Power Plant (Existing)
Existing ICS Diesel
Geothermal Potential areas
Coal Potential areas
Natural gas Potential areas
ICS Load Centers
Number of parralel Circuts
2

3. First Measuring Results

3.1 Average Wind Speeds

In March/April 2005 the first data retrieval from all stations has been carried out by EEPCo staff. The measuring results – at least one complete month from every station – can be included in this report and allow an immediate feed back about the efficiency of the site selection procedures.

Since the first quarter of the year has the highest solar radiation throughout Ethiopia – and, consequently, also the highest wind speeds – the results presented here are high wind resource months. It cannot be expected that the annual average will lie in the same range as the figures presented in **Figure 3-1**.

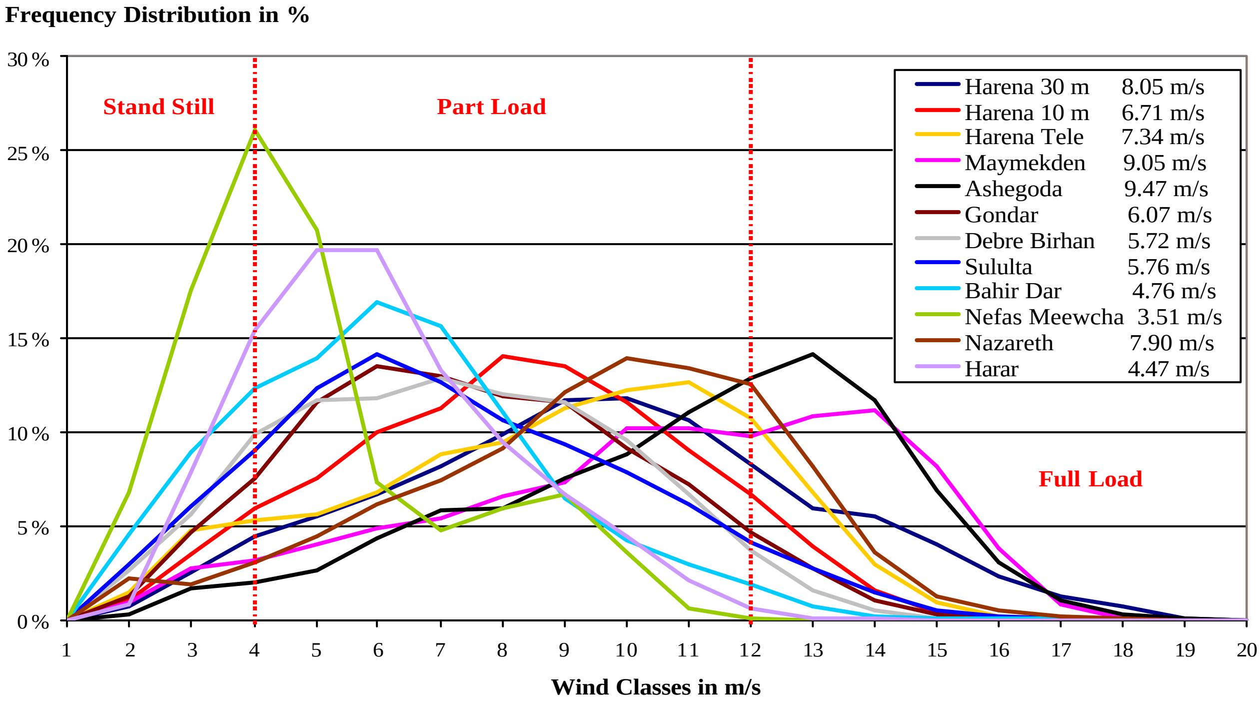
One can see that, with the exception of Bahir Dar, Nefas Meewcha and Harar – all stations measured monthly average wind speeds above 5 m/s.

Figure 3-1:
Average Monthly Wind Speed (Feb. 2005)

Harena 30 m	8.05 m/s
Harena 10 m	6.71 m/s
Harena Telecom	7.34 m/s
Maymekdan	9.05 m/s
Ashegoda	9.47 m/s
Harar	4.47 m/s
Nazareth	7.90 m/s
Gondar	6.07 m/s
Debre Birhan	5.72 m/s
Sululta	5.76 m/s
Bahir Dar	4.76 m/s
Nefas Meewcha	3.51 m/s

The highest wind speeds were recorded – as expected – in the Mekelle area, where we measured monthly wind speeds in excess of 9 m/s, at 10 m above ground level.

Figure 3-2:
Frequency Distribution for all Stations (February 2005)



3.2 Frequency Distribution

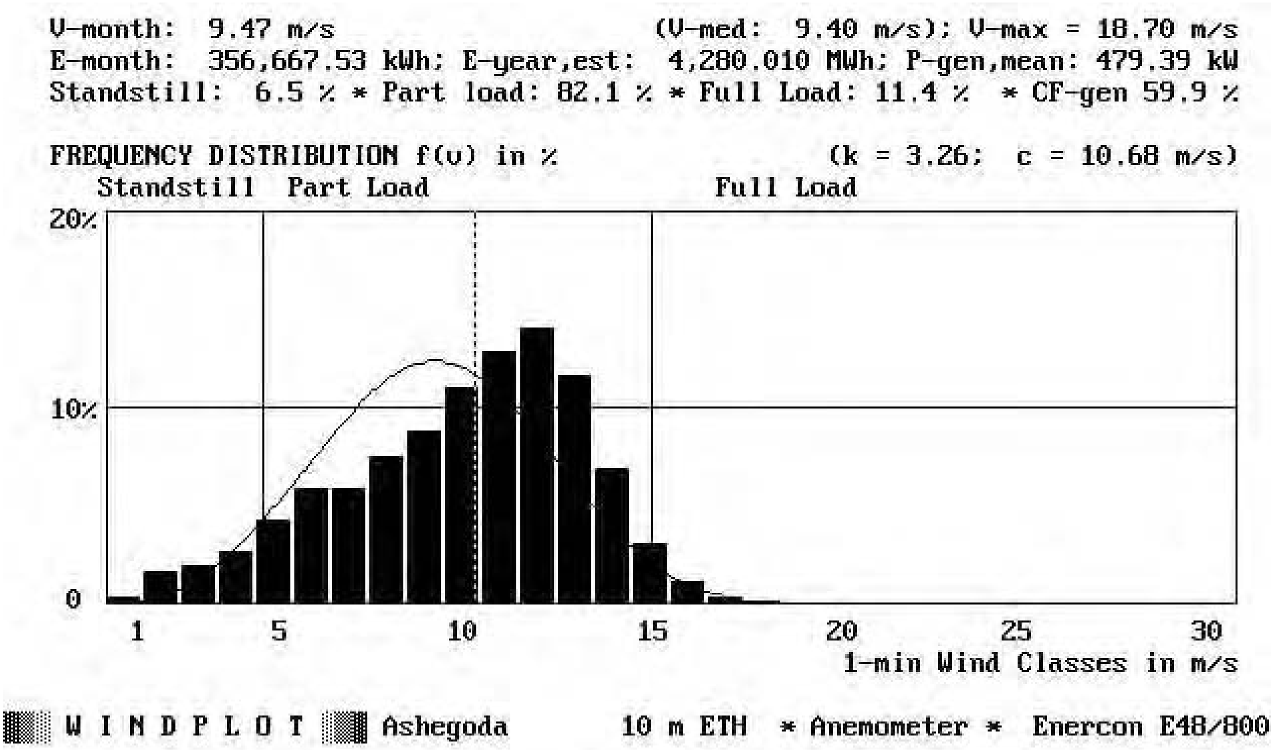
A glance on the frequency distribution in **Figure 3-2** shows the characteristic of the Ethiopian wind sites clearly:

While Nefas Meewcha has a frequency distribution with the highest probability at 4 m/s (and is, therefore, unsuitable for economic operation of electricity generating wind turbines), all other sites seem to offer, principally favourable conditions for wind power applications.

In the case of Maymekdan and Ashegoda (**Figure 3-3**) – with more than 9 m/s in 10 m above ground – the suitability for wind power utilisation must be regarded as excellent: The wind speed range with the highest probability lies in the 13 – 14 m/s range and, thus, in the full load range.

Higher wind speeds than 19 m/s were not recorded – thus, high loads on the turbines from storm control functions are not anticipated.

Figure 3-3:
Monthly Production of a 800 kW Turbine at Ashegoda (February 2005)



note: this diagram shows only the measurement of one month (February 2005), therefore the measured frequency distribution (bar graph) does not fit the Weibull curve (line graph with a k factor of 3.26). Furthermore, the excellent capacity factor (59.9 %) cannot be taken as an annual capacity factor, as well as the estimated yearly production (E-year,est). On the other hand, we have calculated the production based on data from 10 m above ground, but the turbine has a minimum hub height of 50 m.

4. Recommendations

4.1 Data Retrieval

The electronic data retrieval by means of the laptop computer should be done every two months, starting March 1st, 2005. Thus, during phase 1 of the measuring campaign, the following data retrieval times are scheduled: March 1st, May 1st, July 1st.

Before travelling, check your equipment, and take, as a minimum, the following:

a. a complete basic tool box (all the tools which were needed for installation);
b. the key to the pad lock of the data logger casing;
c. a small ladder, so that you can easily reach the logger protection box;
d. several fresh 9 V block batteries;
e. all the spare 12 V external batteries (check that they are fully charged before travelling);
f. the laptop including power supply and power cord (check that the internal battery of the laptop is fully charged before travelling);
g. the connection cable between COM serial port of the laptop and the data logger;
h. spare anemometers and wind vanes including cables;
i. operation manual for the data logger (Ammonit WICOM 32) and the laptop computer (Toshiba TECRA S1);
j. the spare logger no. 13.

The data retrieval is also meant as a regular inspection of the measuring equipment. Therefore, clean the logger box, if necessary and careful check the sensors for damages or signs of mylfunction.

Detailed recommendations for data retrieval can be found in **Annex 8**.

4.2 Preparation of Next Mission

The next mission is planned after a minimum of 6 months of data is available from all stations. The last measuring station has been erected in the first week of April. Therefore, the earliest time for the data evaluation mission would be in October, 2005.

By this time, three 40 m towers should be ready for erection. It is proposed to use the remaining 30 m tower of EREDPC as a sample and have 10 m extension tubes made as well as two other sets of guy wires (seven sets instead of 5 sets for the 30 m version).

During the next mission, the following major tasks are recommended:

- evaluation of the first 6 months of wind data
- a decision, which sites are to be included in the phase 2 measurements (40 m towers)
- a decision, which further sites should be evaluated with 10 m towers (following the recent SWERA modelling, or EEPCo proposals)
- erection of three 40 m towers with wind speed sensors in 40 and 10 m above ground
- intensive training of data evaluation, interpretation of data, calculation of Weibull parameters, output estimations etc.
- preparation of grid connection for the three selected sites (cost estimates)
- contacts with wind turbine manufacturers about possible modifications to the turbines for Ethiopia (altitude!)

Detailed recommendations for the preparations of the 40 m tower can be found in **Annex 9**.