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Renewable Energies
Sustainable Mobility
Communal Strategies

Final Report:

Development of local knowledge for the implementation of renewable energy production sites by means of "GIS-tools" in Central America

Production of a wind energy map for Nicaragua by local companies, based on wind measurements of the national weather service, measurements on potential sites and the modelling and site assessment know how of Swiss companies. The project includes the possibility to expand the activities to other sources of renewable energies.

Fig. 1 El Sauce, Nicaragua

Tim Coone / Robert Horbaty 19.7.2005

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1 Executive Summary

1.1 Conclusions

This first **wind power potential** map of Nicaragua has **identified a total area of 76.9 square kilometres in Nicaragua** that are areas for potential development of grid-connected wind farms.

It therefore indicates that the **country has a potential of some 760MW**. This is capable of being exploited for grid-connected wind parks, without the need for any significant new public-sector investments in transmission lines or access roads, and which can be economically viable under current price and market conditions. This is considerably more than the **current peak demand of 470MW in the Nicaraguan electricity market.** [1]

Economically interesting wind energy potential is estimated to be considerably higher, once additional measurements have been made to pinpoint high wind energy sites in less accessible zones, and with the appropriate infrastructural investment in transmission lines and access roads. Should oil prices rise higher in the future, producing more favourable tariff rates for power generated from renewable resources, the potential will be higher still.

In practical terms however, wind energy systems cannot normally provide more than around 20 to 25% of a country's total power demand, due to grid stability requirements, and the need for rolling reserves and back-up supplies to meet peaks in demand, if power interruptions are to be avoided.

Nicaragua thus has **sufficient wind energy resources for wind power to play a central role,** alongside the development of geothermal and hydroelectric resources, in the conversion of Nicaragua's power supply system from an oil-dependent one to one based on renewables over the course of the next 20-25 years.

Indeed, the wind energy potential in Nicaragua is such that the country is capable of being a supplier of power to the regional energy market in Central America. Should hydrogen and fuel cell technology develop significantly over the coming two decades, wind energy could also be a future major supplier of power for transportation purposes. There also exists **considerable potential for the development of isolated, non grid-connected systems**, for rural electrification where grid supplies are non-existent or unreliable.

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[1] The current and planned transmission grid capacity is adequate to cope with projected demand increases for approximately the coming fifteen to twenty years. A new 230kV transmission line is in the process of being constructed that will interconnect all of Central America (the project is known as SIEPAC) and will be completed in three or for years. This will form a backbone transmission line for the whole region, and any major new expansions to the generating capacity in Nicaragua can be connected to this. How much more the grid could take before additional transmission lines would have to be constructed is a technical question that is beyond the scope of this wind map study.

1.2 Results

This project has produced the following results. Details on goals, activities and results: see ***Annex 1.***

1.2.1 Wind map

A wind map has been produced in both hard copy and digital (interactive) versions. The interactive version can be seen on the website www.encocentam.com and is publicly accessible. (See ***Annex 2***). The map shows there are promising sites for future grid-connected wind parks on the Pacific coast in the El Crucero area (near Managua), in the Rivas isthmus and in the north and north-northwest of the country. The total potential that is readily exploitable is estimated at 760MW, sufficient to develop a very robust renewable energy strategy for Nicaragua, with wind energy providing up to 20% of total electricity supply for well into the 21st Century.

1.2.2 Technological transfer

In November 2004, two people from the Nicaraguan company Geodigital (part of the consortium of this project) came to Switzerland and received training on the software developed and used by the Swiss company Meteotest, Bern. With this training, the two Nicaraguans are now able to feed in the data in Nicaragua and to continue updating the wind map in the future. The two Nicaraguans took advantage of their trip to visit wind power generators in Switzerland, to get to know the company Meteotest and its range of software and to give interviews. ***(Annex 3)***

1.2.3 Alliances/Partnerships

ENCO S.A. has established important relationships with the **CNE (Nicaraguan Energy Commission)** and with the **Institute La Salle in Leon** who provided wind measurement data for the wind map. Contact with a **local radio station** allowed us to put up the measuring equipment on several of their towers, avoiding high costs for putting up towers for wind measurements (Details see Chapter 3).

Important contacts have been established with several municipalities, the IADB (Interamerican Development Bank), private companies, NGOs, ecological organisations and institutions in Nicaragua, Europe and Switzerland and there are currently several possible wind power projects, which have come about as a result of the wind map project.

1.2.4 Sensibilization

Special emphasis has been put on the issue of making the project known to the general public in Nicaragua, in Switzerland and on the Internet. The CNE (Comisión Nacional de Energía) and ENCO SA held a joint **press conference** on July 27th in order to announce the completion of the wind map and its publication on the Website. An **article** on the Technological Transfer from Switzerland to Nicaragua was published in the Magazine "*energeia*" of the Office of Energy, Bern, Switzerland. ENCO AG/ENCO SA has published **two new websites** http://www.enco-ag.ch, http://www.encocentam.com, including special links and explanation about the wind map.

Fig. 2 Presenting the Wind Map to the Nicaraguan Public
Press Conference of the Comision Nacional de Energía,
Managua, July 27, 2005

1.2.5 Two new projects completed

Two projects have come about as a direct result of the wind map project.

- Wind assessment for Community Radio Transmitter in El Jocote
- Wind park pilot study Corn Island 3.1 MW

1.2.6 Two new projects initiated

Two further projects have been initiated as a result of the wind map**:**

- Rural electrification and small scale projects: The 5kW Aerodyn turbine project
- Development of a rural electrification scheme in the Rivas isthmus

1.2.7 Three additional projects for future Private Public Partnerships

During the course of this project, three concrete projects have been laid-out and discussed with the local actors (municipalities, energy producers, private entrepreneurs) and possible financial sources been approached, amongst them SECO and SOFI.

- El Crucero 1MW wind turbine pilot project
- Corn Island 3.1MW wind farm project
- El Castillo 2.2MW run-of river hydroelectric project

1.2.8 Two possible future projects

Further on, two possible projects are being considered in the future:

- Elaboration of policy on renewable energy for the National Energy Commission (CNE) on how to improve framework conditions in Nicaragua for investors in renewable energy and to optimise a renewable energy strategy.
- A second stage measurement campaign including wind measurements on the Atlantic Coast

2 Introduction

A wind measuring campaign was begun in Nicaragua, Central America, on October 2nd 2003, as **a private initiative of ENCO AG**, a Swiss-based energy consulting firm, **and Meteotest**, another Swiss firm specialised in meteorology, wind potential evaluations and GIS. The aim of the campaign was to **create a wind map of Nicaragua** with the purpose of identifying favourable sites for the generation of electricity from wind turbines, and to assess the potential of wind power in meeting the country's future electricity demand in the coming decades.

A consortium to carry out the project was established on the 28th October 2003 between these two companies and **GeoDigital S.A.**, a Nicaraguan company specialised in digital mapping. ENCO AG took responsibility for the data collection and overall project management, Geodigital for the provision of the digital mapping data and subsequent map and website creation, and Meteotest for the data analysis and technology transfer to Geodigital.

In May 2004, ENCO Centroamérica S.A. (ENCO S.A.) was established in Nicaragua as an affiliate company of ENCO AG, to carry out all the work in Nicaragua for this project and to develop other projects in Central America in the fields of renewable energy, energy saving and natural resources. In November 2004, the consortium agreement was revised to formally include ENCO Centroamérica S.A.

The project has been **co-ordinated with the National Energy Commission (CNE),** the governmental body in Nicaragua in charge of formulating energy strategy, and with whom a co-operation agreement was signed in August 2004.

For almost a year, the project was financed out of the partnership's own resources. However in August 2004, agreement was reached with **REPIC**, the Swiss interministerial agency for the promotion of renewable energy in international cooperation, to **part-finance the project with 50,000 Swiss Francs**. First disbursement of the funds was made in September/October 2004, and final disbursement was scheduled for mid-2005 on completion of the measurement campaign and production of the website-based wind map.

Details of the project proposal dated 12/4/2004, can be found in the document entitled:

"Development of local capabilities for the implementation of renewable energy production sites by means of "GIS-tools" in Central America"

This is referred to henceforth as the project proposal document. An updated résumé of the sections on the **energy situation and the electricity market in Nicaragua** are included in section 12 of this report.

An interim report was presented on the 20th December 2004, describing the progress of the project, the various alliances and partnerships that were created to carry out the project and the various data sources that have been incorporated into the map. This report is the final report scheduled under the agreement that was reached with REPIC, to be prepared in June 2005. Its purpose is to present the results of the project and highlight **future possible developments in the wind energy sector.**

3 Alliances/Partnerships

3.1 Local agreements

Three different agreements were signed by ENCO between October 2003 and August 2004 with different Nicaraguan organisations. These were necessary to obtain permission to use the various radio towers at the sites anticipated in the project, upon which the measuring equipment would be mounted, and to obtain additional data sets to include in the wind map.

The first agreement was signed on October 2nd 2003 **with Radio Primerísima**. This allowed the consortium to install a set of measuring equipment on a radio transmission tower owned by Radio Primerísima in the municipality of El Crucero, (a windy site near Managua) and to install additional sets on towers that Radio Primerísima is able to obtain the use of for free. Radio Primerísima was able to offer this service, as it sells and distributes radio station equipment throughout Nicaragua, and maintains very good relations with scores of radio station owners throughout the country.

In exchange, ENCO agreed to make a wind assessment of a mountain top site near the town of El Sauce in north-west Nicaragua, to evaluate this site for the installation of a wind turbine to power a radio transmitter station there.

A second agreement was signed on the 6th August 2004, **with the Instituto La Salle in León, Nicaragua**, a technical training school that includes renewable energy as an optional course in its training program for adolescents. The Institute has four sites at which it has measured wind speed and direction since 2001, and is a local wind energy pioneer in being the first to install a medium-sized wind turbine of 230 kW in Nicaragua, in December 2004. This agreement is a data sharing agreement between the consortium and the La Salle Institute, which exchanges summaries of the data collected by ENCO with summaries of the data collected by the La Salle Institute.

A third agreement was signed **with the National Energy Commission (CNE)** on the 18th August 2004, which is again a data sharing agreement for the creation of the wind map. ENCO will exchange summaries of its data with data collected by the CNE at four sites in southern Nicaragua during the 1990s.

Between December 2003 to May 2004, attempts were made to make a formal alliance with ANPPER (Asociación Nicaragüense de Productores y Promotores de Energía Renovable), to work together to develop a wind map of Nicaragua and Central America. These efforts were abandoned however due to a lack of commitment to an agreement by ANPPER. Some six months were lost by this effort, and delayed the installation of two sets of equipment which would have been sited on ANPPER's recommendations.

Blue Energy, a US NGO, began measuring three sites on 10 m towers around Bluefields on the Atlantic coast of Nicaragua in late 2004. However, discussions to include their data in the wind map, in a similar manner to the agreements reached with the La Salle Institute and the CNE, had not produced an agreement by the time of writing of this final report. It is hoped that a future update of the map will be able to include their data.

3.2 International Cooperation

Since 1993 ENCO AG has been supervising the Swiss Energy Research Programme “Wind” for the Federal office of Energy and since 1998 has been directing the Branch office of Suisse Eole, the Swiss Association for Wind Energy which is linked to the European Wind Energy Association (EWEA) and the World Wind Energy Association (WWEA). The company is deeply involved and actively participating in projects run by the International Energy Agency “Decentralized Wind Energy Systems“ and “Wind Energy in Cold Climate“. The results of this study will be made known through this network on a national and international level. Additional contacts have been made with wind energy specialists in Mexico and Honduras with a view to possible future cooperation in developing wind maps for neighbouring countries in Central America.

The United Nations Environmental Programme (UNEP) based in Paris, and the National Renewable Energy Laboratory (NERL) based in Golden, Colorado USA, have meanwhile completed a two-phase project known as “Wind Resource Mapping for Central America and Cuba”.

The first phase was to produce a regional wind map to identify potential wind sites based on existing measurements, meteorological stations and atmospheric models, combined with satellite-derived topographic data. The project is not undertaking any of its own measurements. As far as mapping is concerned, the project is completed and no update is planned.

The second phase involves the development and teaching of a so-called “SWERA Geospatial Toolkit”, by which it is intended to define potential sites close to power lines and roads and calculate possible energy yield.

The Beta version of the SWERA toolkit has been tested by the consortium, and is an easy to handle mapping and analysis tool for a rough analysis of solar and wind energy potentials. It is a useful tool to estimate regional or country potentials but is inadequate to estimate a specific location's potential as the wind map's resolution is only 1 km.

Our consortium’s wind map project has a pixel resolution of 250 metres by 250 metres (compared to 1 km in the SWERA map), **has more complete coverage of the country, and will be updated continuously** as additional measurement become available. A 90 x 90m resolution map will be produced in the next map update.

Initial contacts have been made with SWERA to consider co-operation and data sharing between the two projects. A SWERA representative made a presentation of their project when the ENCO project was presented at the CNE **press conference on 27th July.**

Fig. 3 Visitors inspect the Wind maps produced by ENCO and SWERA at the CNE press conference

4 The Wind Measurement Campaign

The **wind measurement campaign** of this project has lasted a total of twenty months, **from October 2003 to May 2005**. It has involved the gathering of measurements from five sets of wind measuring equipment sited at different locations across Nicaragua, and combining these with existing data and those collected by private and university sources, to create the first map of wind energy potential of Nicaragua. Three sites in the Pacific Coastal region, two sites in the Central Region and one site in the Atlantic Coast region have been measured during the campaign. The first set of equipment was installed in October 2003.

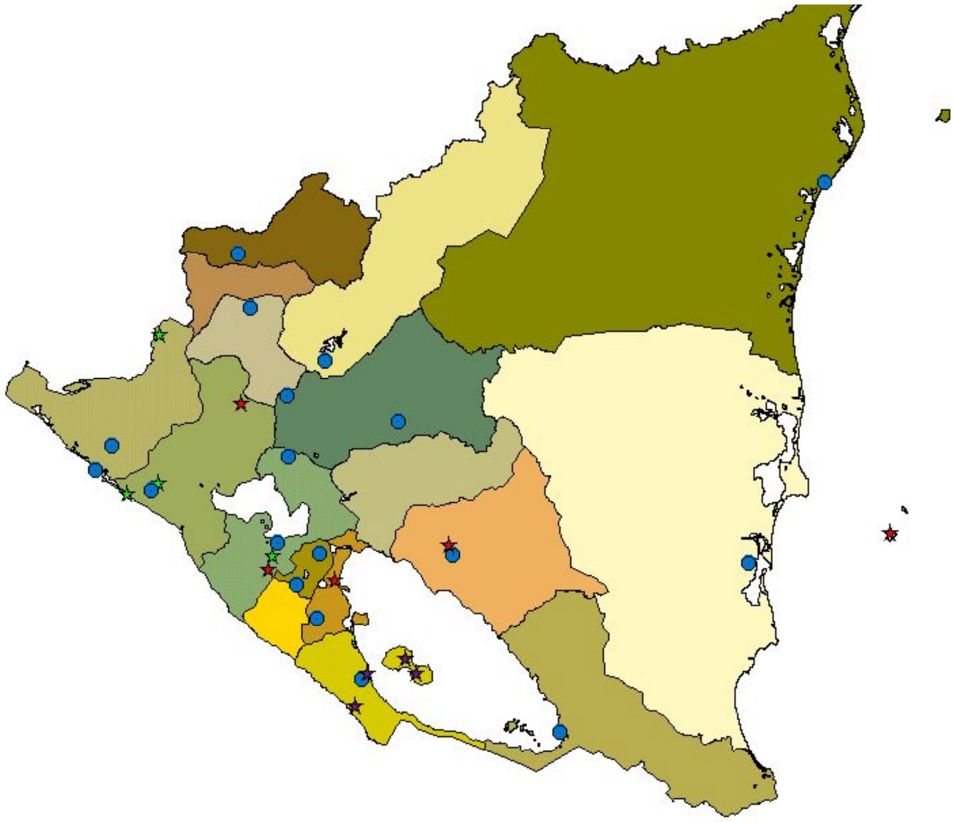
Measuring equipment was installed by ENCO at the following **sites:**

- El Crucero: (Radio Primerísima) 2nd October 2004 to present.
- El Sauce: (Own tower) 5th February to 14th July 2004
- Granada (Radio Sultan): 19th February to 8th January 2005.
- Corn Island (Radio Morena): 29th July 2004 to present.
- Juigalpa (Radio Centro) 2nd September to 8th January 2005
- Rivas: (Own tower) 20th January 2004 to present

Measurement continues at three sites in order to provide ongoing data for three new planned projects.

Additional wind speed and direction data sets have been included from four sites in southwest Nicaragua, gathered by the **CNE** in the late 1990s. Similarly, three further data sets from northwest Nicaragua gathered by the **La Salle Polytechnic Institute in the city of León**, have also been incorporated. Wind speed and direction data sets from the National Meteorological Network, operated by the Nicaraguan Institute for Territorial Studies **(INETER)** have also being incorporated into the map for correlation purposes as well as data from meteorological stations in neighbouring countries. Although the INETER and meteorological stations sites are inappropriate for the purposes of accurate assessments of wind energy potential, (being designed primarily for agricultural purposes and the estimation of evapo-transpiration) they nonetheless enable long time series to be created out of the new data being collected.

The list of stations included in the map, along with their principal characteristics is shown in the table in ***Annex 4***.



Map Symbols: Red Star - ENCO sites
Purple star - CNE sites
Blue circle – INETER meteorological stations
Green star – La Salle Institute sites

Fig. 4 Map of measuring stations used in the project

4.1 Future Updates

With the measuring campaign now completed in June 2005, the consortium will take responsibility for any further updating of the map as any new wind data become available. We expect this to take place once or twice per year. ENCO SA will be responsible for the ongoing collection of data from its own measuring sites and those of third parties, and overall coordination between the consortium partners. Meteotest will update the table of long-term wind averages for the sites included in the wind map. Geodigital will use this updated table, to update the wind map in both its printed and interactive website forms, and **ENCO AG will be responsible for updating the website itself as the map is hosted on a server in Switzerland.** New data will include that still being collected by three sets of ENCO equipment (El Crucero, Rivas and Corn Island), new data obtained from installing measuring equipment associated with new projects and any additional data that may be made available by the La Salle Institute, the CNE or private developers. The wind map in an interactive, zoomable format is now publicly available over the Internet at www.encocentam.com.

Fig. 5 Wind measurement continues at Corn Island

The consortium will carry out this follow up measurement campaign within the framework of the measurements that will be conducted for our own follow up projects and the collection of data from other sources and contacts of different projects. Should the development of activities in the area of wind energy increase to larger scale in Nicaragua, the consortium is very interested in providing further wind data.

5 Technical data and methodology

5.1 Hardware

The **equipment used** for this project consists of the following:

- 7 **anemometers** manufactured by the firm NRG which have been tested and calibrated in a wind tunnel in Berne, Switzerland, using a reference anemometer which has been calibrated by the German Wind Energy Institute (DEWI) using the MEASNET standards. Two of these were reserve pieces of equipment, to be used in case of failure of the tower-mounted anemometers.

- 7 **wind direction vanes** manufactured by the firm NRG, which have also been calibrated in Berne. Again, two of these were spares to replace failed equipment.

- 5 "Wind Explorer" **dataloggers** manufactured by the firm NRG. These are powered by two 9-volt batteries that provide sufficient power for up to six months operation of the logger. The logger records average wind speed and direction at ten-minute intervals, as well as gust speed and direction. These data are recorded to a removable dataplug that stores up to five or six months of data.

- 10 **data plugs** manufactured by the firm NRG.

- 2 data **plug readers** and 1 set of dataplug reading software, also manufactured by the firm NRG.

Fig. 6 The NRG data plug can store up to six months of data

Over 200 metres of cable to connect the anemometers and windvanes to the dataloggers, once mounted on their towers. The cables are shielded to protect against interference from radio and electro-magnetic emissions. The data loggers are also earthed independently from the tower installation, to protect against lightning strikes and other possible electrical short circuits.

Fig. 7 The NRG data logger "Wind Explorer" used in this project

Transport of the equipment to the measurement sites, some of which are in remote locations over extremely bad dirt roads, was carried out with a Toyota pick-up truck, owned by the President of ENCO Centroamérica. Actual installation of the measuring equipment on the towers was sub-contracted to a specialist, under the supervision of ENCO. The equipment is tested and checked for proper functioning once installed.

5.1.1 Hardware monitoring and maintenance

Once installed, **the equipment was checked** at monthly, two-monthly, four-monthly intervals or even six-monthly, depending upon the accessibility of the site. The El Sauce site for example, which is only accessible by horseback during the rainy season, was checked only once when the equipment was removed. In contrast, the El Crucero and Granada sites were checked monthly. Each maintenance visit involved a check of the battery voltage, a change of the desiccating bag inside the logger box, to keep it free of humidity, and a change of the data plug. Oiling of hinges and padlocks on the security box of the logger was also done if necessary.

Fig. 8 Installing first Wind Speed Measurement equipment in October 2003

Gust speed and average speed were recorded, as were any other data that might be relevant such as general equipment and site conditions. A visual inspection by binoculars of the anemometers and windvanes was also made, to check for any failures or irregularities.

5.2 Software and data processing

The data plug that was removed from the data logger at each site maintenance visit, was placed in a sealed plastic bag to protect it from moisture and dirt. Once returned to the ENCO S.A. office in Managua, they were connected to the NRG data reader, which in turn is connected to the serial port of the office computer, and the data was downloaded as a raw data file by the **NRG Wind Data Retriever software**, version 10. This same software can convert the downloaded file, to make it readable by standard database software such as MS Excel.

The Managua office then made a **preliminary analysis of the data** to check that the results were conforming to expectations and that no anomalies were occurring. Average wind speeds and direction were being calculated at each site and updated with each site maintenance visit.

The raw data files and the initial analysis results were subsequently sent to Meteotest and ENCO in Switzerland by e-mail, for more advanced data processing and for development of the wind map.

The **principal software used** by the project includes:

- Wind Data Retriever. Version 10
- ESRI Arcview ArcInfo, ArcIMS
- RSI IDL
- EMD Windpro
- ALPHORN
- WasP
- Algorithms developed in-house by Meteotest.

6 Limitations of the data collection methodology

6.1 Reliance on existing radio towers

There have been two principal limitations in the methodology used to gather the data for the wind map.

The first is due to the fact that we have relied primarily on existing radio transmission towers in different parts of the country to mount the measuring equipment, to gather data from new sites. This was the case for El Crucero, Granada, Juigalpa and Corn Island. In the cases of El Sauce and Rivas, ENCO built and erected its own towers. **The idea of using the radio towers was to keep the costs of the measuring campaign to a minimum.** The cost of manufacturing towers, erecting them and more importantly still – ensuring their security against theft and vandalism during the measurement campaign – would have added considerably to the overall budget. The use of the radio stations, under our agreement with Radio Primerísima enabled us to use these sites for free, as well as have security vigilance of the measuring equipment for free also.

Fig. 9 The Juigalpa site was sited in a valley that proved to have a poor average annual wind speed

In the cases of Juigalpa and Corn Island, the siting of the **radio towers was not optimal** for the purposes of evaluating the best wind energy sites. The Juigalpa site was in the town of Juigalpa and within a valley and where the long-term average wind speed proved to be only 3.5 m/sec. In the case of Corn Island, the tower receives wind from the northeast, which according to locals is the direction of the prevailing winds. However, a hill to the east created a possible shadow effect for winds from that direction and which are also important in the overall wind regime of the island. For this reason we suspect that the calculated average annual wind speed of 5 m/sec at the measuring site, is more likely to be around 6 m/sec or even higher on more exposed sites on the north and east coasts of the island. This is also likely to be the case on top of the two main hills of the island, although both hills are covered with tall trees and location of measuring equipment would present difficulties there.

6.2 Limited coverage of Atlantic Coast region

The second limitation has been that the **Atlantic Coast region has not figured prominently in the map.** Corn Island has been the only site on the Atlantic Coast with new measurements to be included in the map. Plans to install a set of equipment at Kukra Hill on the Atlantic Coast for a period of six months, did not materialise due to a failure to reach agreement with the radio station owners to use their transmission tower there.

However, for the purposes of identifying future grid-connected wind farms this shortcoming is not a major drawback, as much of the **sparsely populated Atlantic Coast has yet to be connected to the national power grid**.

Fig. 10 Large areas of the Nicaraguan Atlantic Coast are not connected to the national power grid

One of the reasons for not focussing on this part of the country in this campaign, was that the National Energy Commission had planned to launch its own measuring campaign there during 2005, with financing from the Interamerican Development Bank. The project was part of a package of studies planned for the Atlantic Coast region, and which would have been disbursed through the Office of the Presidency. However, this loan was rejected by the National Assembly in May 2005, seemingly due to political frictions between the Presidency and Legislature that have come to dominate the Nicaraguan political scene over the past 12 months.

On the basis of the measurements made in Corn Island however, we suspect that the Atlantic Coast does not have a major potential for grid-connected wind energy projects. So in this respect, the lack of additional measurements is not a major shortcoming. However, for identifying potential sites for isolated (i.e. not grid-connected) wind energy converter systems, we recommend that any future measuring campaign seek **to measure at least half a dozen sites in the Atlantic Coast**

region. Even sites with average wind speeds of just 5 metres/sec can potentially be exploited where the cost of power generation from diesel-powered systems is typically in the region of US$150/MWh. The power output of a 1MW turbine in such a location would typically be around 1000 MWh per year, around a third of the power generated at a site with an annual average of 8 metres/second. However, the cost of generating power from diesel systems is very expensive, and given the rising trend in oil prices is going to be more expensive in the future. And so wind power generating systems can be financially viable even in isolated sites with relatively modest average wind speeds.

6.3 Summary data sets from Third Parties

The sites measured by the La Salle Institute were sites showing no major wind energy potential. They appear to have been chosen more on the basis of agreements with the owners of specific sites, rather than having been selected for high potential. Nonetheless they have served to confirm the relative lack of wind power potential in the north west of the country. Monthly summary data rather then 10-minute averages were provided under the data exchange agreement.

The data from two private sites that have been included in the map have been provided under informal agreements with the site owners. In the case of the Rivas site, the owners were unwilling to release anything but the most minimal data, due to commercial negotiations that are underway with potential site developers. The National Energy Commission was able to confirm the measured average at this site at 8.5 m/sec, having received the full data sets from the site developers.

In the case of the Ventus site in Juigalpa, details were again only a bare minimum. Their claim of an annual average of 10.5 m/sec is very suspect, given the estimates we have made for surrounding areas, and given the fact that there are sites at higher altitudes lying to the west of this area in the path of the prevailing winds producing an average of 8.5 m/sec.

The National Energy Commission has not been provided with the original data sets for this site, and is also sceptical of the 10.5 m/sec claim.

In the mapping process, **we therefore downgraded the long-term average** for this site to 8.5 m/sec. This may eventually prove to be either an over- or an underestimate.

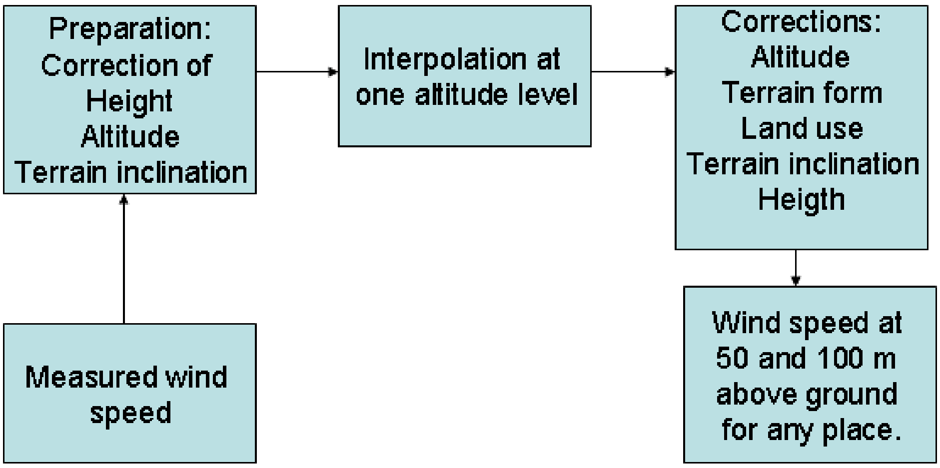
7 Creation of the Wind Map

7.1 The Model

It was decided to adapt a statistical modelling methodology formerly used to compile a wind map for Switzerland[1]. It was possible to adopt many of the empirically determined parameters from the former model (**Annex 5**).

The spatial interpolation is performed with the help of altitude gradient corrections and the Kriging interpolation method. The following three steps are performed:

- Preparation
- Spatial interpolation with Kriging method
- Corrections



The diagram above shows the most important steps from measured wind speed to wind speed maps at 50 and 100 m above ground. Details of the procedure are given in Annex 5.

Input of the model is wind data from 56 stations, and topographical and roughness information. Long-term as well temporal wind measurements were used. Temporal data was adapted to long term means, where possible.

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1 http://stratus.meteotest.ch/mme/winfo/

7.2 Technology transfer

Part of the wind map project proposal was to transfer know-how to local partners in Nicaragua, to provide a capability to continuously update the wind map, as new data sets become available in the future.

The two directors of **Geodigital S.A. made a week-long trip to Switzerland** in November to learn the techniques of wind mapping from Meteotest, and the setting up of an interactive website to display and consult the wind map data. Workshops were held in the offices of Meteotest in Berne during the week of November 8th to 12th 2004.

There were several points of technology transfer. **Input data** was gathered mainly in Nicaragua. The **techniques of wind mapping** and how to run the i**nterpolation software** were explained in workshops at Meteotest. The software was made with IDL language (http://www.rsinc.com) in form of an IDL runtime program. This runtime version can be run at Geodigital (the IDL runtime software can be downloaded and run on any PC for free).

It was also explained what kind of geographical information is used to make such maps. The digital elevation model with original 90 m resolution was taken from NASA's Space Shuttle Radar Topography Mission (SRTM). This elevation model was then reformatted by Geodigital to a slope map. **A roughness map of Nicaragua was also delivered by Geodigital.**

The wind mapping algorithms used by Meteotest to create the wind map were transferred to Geodigital at the end of the workshops, and Geodigital is fully capable of updating the wind map once Meteotest relinquishes responsibility for this in mid-2005.

During the same week, the president of ENCO S.A. also participated in two specially prepared workshops on wind evaluation techniques and equipment maintenance. These workshops were also prepared and conducted by Meteotest.

The two Nicaraguans took advantage of their trip to **visit wind power generators** in Switzerland, to get to know the company Meteotest and its range of software and to **give interviews**. ***(Annex 3)***

Fig. 11 Workshop at Meteotest in Bern: Maria (left) and Nicolás Arróliga from Geodigital S.A., Managua are being instructed by Jan Remund with the technology of wind-modelling.

7.3 Preparation of Digital Databases

During September and October 2004, **Geodigital produced a digital elevation model (DEM) of Nicaragua**, based on a digital map of 100 m contours at 1:250,000 scale produced by Geodigital. The DEM resolution is 250 metres x 250 metres per pixel. A land use map at 1:250,000 scale was also produced by Geodigital, and two additional data sets were derived from this and the elevation model namely: slope and roughness.

The DEM, slope and roughness models are the **essential input data** to the wind map and are required to run the wind mapping algorithms. These data sets were supplied to Meteotest in early November 2004. The DEM proved to be quite coarse due to the initial data (height contours at 100 m interval). Therefore, the DEM was refined by Geodigital and Meteotest using SRTM (Space Shuttle Radar Topography Mission) data. Geodigital in Nicaragua subsequently produced slope and roughness data sets with a 90 x 90 metres per pixel resolution with the STRM data.

Geodigital produced digital maps of road access and transmission lines in April and May 2005, which enable the creation of a map of wind potential defining areas of high wind energy with good access to roads and power line transmission.

The high tension (69kV and above) transmission lines were digitised from 1986 topographic maps of Nicaragua. Some changes have been made since then, in particular a new line to San Rafael del Sur, and the removal of the old 69kV line through El Crucero. The El Crucero zone still remains within 10 kms of the new transmission line going to San Rafael del Sur.

7.4 Wind Map Classification

For the purposes of clarity and keeping file size down for the website version, (to keep loading times over the Internet to a minimum), it was decided to show three categories of wind speed only

- **6 to 7 metres/second**
- **7 to 8 metres/second**
- **over 8 metres/second**

With these areas identified from the model, a grid was then produced and processed in ArcView software, to identify those sites with most potential for development. The criteria to select these sites were to identify those that lie within a distance of 2 kilometres of an all-weather road, and 10 kms of a high-power transmission line.

Using local cost estimates provided by specialist engineering consultants, it has been assumed that one kilometre of a new 69kV transmission line costs US$50,000, as does one kilometre of an all-weather dirt road. A smaller distance has been chosen for the distance to an all-weather road, to allow for possible repairs and bridge strengthening on existing access roads to the site, which have budgeted here at another US$400,000.

Total access costs are therefore assumed to be a maximum US$1m for a 10MW windfarm, for a site to be included in the areas defined as those with most potential for development.

Environmentally **protected areas, areas within 500 metres of an urbanised area** and within **300 metres of individual villages** or settlements, **have been excluded from the areas selected** with the above criteria.

The algorithms used in developing the map are **sensitive to altitude,** so those areas in low-lying zones may have a possible underestimate of their potential. Nearby meteorological stations, which are not sited for estimating wind power potential but more for agricultural purposes, can often cause the average wind speed over a broader area to be lower in the model than it actually is. This is the case in the Rivas isthmus for example, where it was decided to exclude the Rivas meteorological station data. The station itself is located in a hollow, and as such the wind measurements from the station are considerably lower than wind speeds in areas surrounding the station.

8 The Financial Model

ENCO SA has developed a **financial and capital structure model** incorporating a standard **Capital Asset Pricing Model**, to analyse the economic viability of developing wind parks **under a wide range of technical and financial variables**. The model uses some 18 different variables and includes the overall power generation (MWh/yr) under different wind regimes, different tariff, tax and discount rates, as well as a series of other financial variables such as loan interest rates, capital gearing, and debt and equity Beta.

The model **generates the Net Present Value** of the project as well as the overall Internal Rate of Return, as well as the rate of return required by equity investors which is influenced by the level of debt leverage. The model was used to select the three categories to be displayed in the wind map on the basis that the typical cost of developing a 10MW wind farm in Nicaragua would be US$1.1m per Megawatt. This allows US$1m per MW for the turbine and installation costs, and an additional US$1m for the road and transmission line access costs for the 10MW park as a whole.

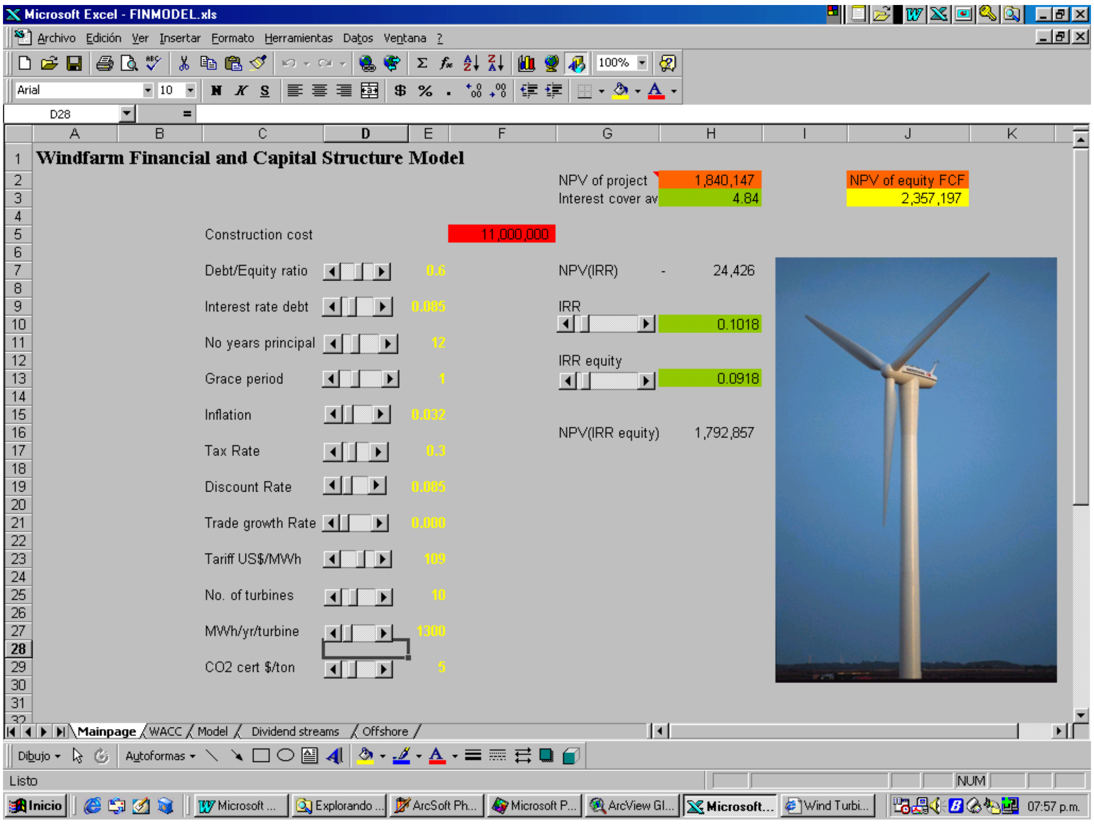


Fig. 12 Screenshot of ENCO's wind farm financial model

8.1 ENCO's wind farm financial model

Projects sited in areas of an annual average of **8m/second** or more have been chosen as those having the **most likely development potential.** The financial model shows that these areas are economically viable at the lower end of the US$55-65/MWh feed-in tariff range fixed under new legislation favouring renewable energy development (see Section 12).

Those areas shown with an average annual wind speed of **7–8 metres per second** could be **economically viable** with electricity feed-in tariffs at around US$70/MWh, while those with an average annual wind speed of 6–7 m/sec can be viable with feed-in tariffs at around US$110/MWh.

6 metres/sec has been chosen as the **lower limit to display on the map** for the time being, as the commercial viability of projects below these speeds becomes marginal, under the current tariff and regulatory regime.. It is important to point out however, that isolated power generation systems, currently using diesel generators, have generation costs around US$150/MWh, and so wind energy converters are capable of also playing a significant role is providing an alternative to diesel generation in isolated areas. Sites with average wind speeds as low as 5.5 m/sec can be economically viable with feed-in tariffs of US$130/MWh for example, according to the ENCO model. For example, on Corn Island on the Atlantic Coast of Nicaragua, which has an isolated diesel-generated power supply system, the current consumer tariff for electric power is US$0.25/kWh or US$250/Mwh.

		Average wind speed (m/sec)			
		5	6	7	8
Average feed-in tariff	**US$55**				
	NPV (US$m)	-6.7	-2.9	1	4.8
	IRR %	3.6	5.4	9.5	12.8
	IRR% (equity)	0	4.2	11.4	18.6
Average feed-in tariff	**US$70**				
	NPV (US$m)	-5.2	-0.6	4.3	9.1
	IRR %	2.7	7.9	12.4	16.1
	IRR% (equity)	0	7.6	17.4	26.4
Average feed-in tariff	**US$110**				
	NPV (US$m)	-1.4	5.4	13.4	20.5
	IRR %	7.1	13.3	19.1	24.2
	IRR% (equity)	6.2	17.5	30	41.3
Average feed-in tariff	**US$150**				
	NPV (US$m)	2.3	11.7	21.9	31
	IRR %	10.6	18.1	25.1	31.5
	IRR% (equity)	12.4	27.7	43.4	57

Fig. 13 Net Present Value(NPV) and Internal Rates of Return (IRR) of a 10MW wind park: Wind speed varying from 5 to 8 metres/sec and feed-in tariffs varying from US$55/MWh to US$150/MWh

Fig. 13 is the output of a series of runs of the financial model, that used two of its principal variables to analyse the financial viability of a 10MW wind park under different wind regimes (from 5m/s annual average to 8m/s annual average) and different feed-in tariffs (from US$55/MWh to US$150/MWh).

A Nordex 54 1MW wind turbine was chosen as the standard turbine for the model runs. The “Wind Turbine Power Calculator” of the Danish Wind Industry Association (available on their website: www.windpower.org) was used to calculate the number of MWh annual output at the different wind speeds, and which was then used as data input for the financial model.

The following assumptions were used in running the Wind Turbine Power Calculator:

- Average temperature: 24º Celsius
- Altitude: 500m
- Wiebull Shape parameter: 2
- Turbine hub height: 50m

The estimated power output from the Nordex 54 turbine using these criteria is as follows:

Average wind speed (m/sec)	5	6	7	8
Power output (MWh/year)	950	1566	2248	2910

The values of 24º C average temperature and 500m altitude were chosen as representing a mean value between a low-lying site and a mountaintop site. For example, a Nordex 54 turbine receiving an annual average 8m/sec wind speed at a site near the Lake of Nicaragua at 40m altitude would experience a mean annual temperature of 26º C and produce 3,051 MWh pr year. Located at a site at El Crucero at 900m, it would experience a mean annual temperature of 23º C and produce 2,810 MWh per year.

Fig. 13 thus demonstrates how the **threshold of financial viability for a “typical” 10MW wind park,** costing US$11m to construct, is lowered as the feed-in tariff increases. The grey and yellow-shaded areas highlight greatest financial viability.

A positive NPV is normally considered adequate to justify investment in a project if it is all-equity financed. However, if debt is also used to finance the project, as most projects are, the equity suppliers normally expect a higher rate of return on their part of the investment, as debt holders have first call on the profits and the assets of a project. The line in Fig. 13 above labelled IRR%(equity) is the Internal Rate of Return on the equity investment in the project, assuming in this case a gearing ratio of 65%, i.e. the project is financed with 65% debt and 35% equity. The line above

(IRR%) is the overall Internal Rate of Return on the project for debt and equity combined.

For those familiar with the Capital Asset Pricing Model, the following variable values were used in calculating the discount rate for the stream of cash flows from the project, and the required rate of return for equity:

- Power sector Beta 0.7
- Ratio of fixed costs to operating costs of the project 0.9
- Ratio of fixed costs to operating costs of market 0.25
- Risk-free interest rate (i.e. government bonds) 3%
- Market premium 6%
- Corporate tax rate 30%

These variables were considered appropriate for an investment in the Nicaraguan electricity market, for a foreign company with good credit rating and access to international funds.

Using these variables, the discount rate was calculated to be 8.5% and which were applied to the future stream of cash flows over a 25-year period. The required rate of return for equity was calculated to be 17.1% per annum.

Fig. 13 thus demonstrates how the model reveals the feasibility of projects in sites with an average wind speed of 8m/sec, 7 m/sec and 6 m/sec as the feed-in tariff is raised successively from an average US$55/MWh to US$110/MWh and the 17.1% threshold for the return on equity is surpassed with each increase (yellow-shaded squares).

The blue-shaded squares show that a site with 5m/sec is marginally viable with a feed-in tariff of US$150/MWh, but that it could be viable depending upon the capital structure of the project (e.g. using a higher level of equity).

Other assumptions used in this set of runs of the financial model were as follows:

- Annual interest rate on debt 8.5%
- Number of years of principal repayment 12
- Inflation rate 3%
- CO2 credits (US$/ton) US$5

9 Wind Map Results

The wind map project has identified a total area of **76.9 square kilometres in Nicaragua** that are areas for potential development of grid-connected wind farms (See Map ***Annex 2*** and Website http://www.encocentam.com). These are the areas with long-term average annual wind speeds greater than 8 m/sec, and lying within a distance of 2 kms of an all-weather road and 10 kms of a high tension transmission line (69kV or higher). Urban areas within 500 metres of these sites, rural settlements within 300 metres, and environmentally protected areas have been excluded.

Municipio	Departamento	Area Km2
Cardenas	RIVAS	0.5400
Ciudad Dario	MATAGALPA	0.0100
Comalapa	CHONTALES	2.7200
Condega	ESTELI	0.8300
El Crucero	MANAGUA	11.1900
Esteli	ESTELI	17.2700
Granada	GRANADA	0.7200
Jinotega	JINOTEGA	0.8700
Juigalpa	CHONTALES	0.3800
La Concepcion	MASAYA	2.6200
La Trinidad	ESTELI	7.0300
Matagalpa	MATAGALPA	1.6400
Pueblo Nuevo	ESTELI	0.1400
San Dionisio	MATAGALPA	0.1200
San Isidro	MATAGALPA	0.5900
San Juan de Limay	ESTELI	2.1700
San Juan del Sur	RIVAS	0.5500
San Marcos	CARAZO	2.1100
San Nicolas	ESTELI	24.8400
Santa Rosa del Penon	LEON	0.3900
Ticuantepe	MANAGUA	0.1900
	Total	76.9200

Fig. 14 Potential areas of wind park development by municipality (Km^{2})

The **municipalities in which these areas are located a**re shown in the table above. There are essentially three main areas; the upland regions around the city of Estelí amounting to two-thirds of the total, the 800–900 metres high mountains at El Crucero around 25 kms south of the capital Managua, and a small area near Rivas on the western side of the Lake of Nicaragua. Another potentially important area near Juigalpa on the eastern side of the same lake, lies just outside the areas defined as being relatively close to road and transmission line infrastructure. Although Rivas has been mentioned frequently as a site with high potential, this study indicates there are other sites with higher potential. Only along the immediate lakeshore are there likely to be sites with an average annual wind speed greater than 8 m/sec.

In addition, there are some **500 square kilometres with average annual wind speeds** in the range of 7 to 8 metres per second, and a further 1,770 square kilometres with wind speeds of 6 to 7 metres per second. These areas also lie within the parameters of 2 kms of an all-weather road, and 10 kms of a high-tension transmission line.

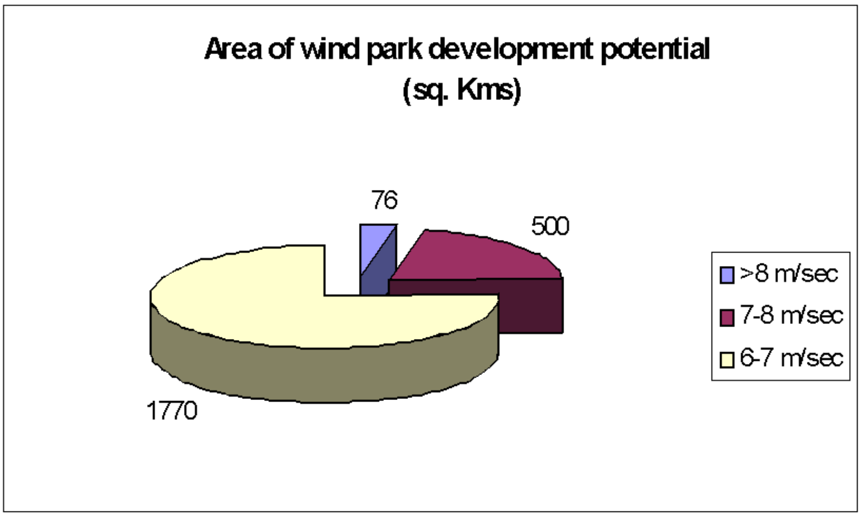


Fig. 15 Area of Wind Park Development Potential by average wind speed

The wind map (see Annex 2) identifies the better locations suitable for the siting of wind turbines and wind parks that can be connected to the national electricity network. It is also a **useful tool for the siting of smaller turbines**, for example in agricultural applications for water pumping, or for rural electrification in isolated locations which cannot be connected to the national power network due to the costs of transmission line installation.

The **map will thus enable investors in wind energy**, whether for large or small projects, to significantly reduce their feasibility study costs by helping them avoid unfavourable sites, and to focus their attention for more detailed measurement campaigns at promising sites.

10 Website display of the map

The ENCO Centroamérica SA website (http://www.encocentam.com) was established in March 2005, and a preliminary non-interactive map that had been developed up to November 2004, was displayed on the site from that moment, along with background on the Nicaragua wind map project.

The final measurements of the campaign, and additional data from private developer sites were sent to Switzerland at the end of May, and these were processed by **Meteotest to produce the new data table of long-term wind averages** for each of the sites to be included in the final map.

This completed data table was returned to Nicaragua in June, and the final version of the map was then produced with the model that had been transferred to Geodigital from Meteotest last November.

Geodigital worked on developing the zoomable interactive map version during May, and in creating the map server with an applet software available freely on the Internet.

The first **zoomable map using this software was tested** on Geodigital's website (not public access) to test download times and reaction from the various partners, and to smooth out any problems.

This test version displayed the 7 to 8 metre and over 8-metre/sec categories only. Download times over a standard telephone line in Nicaragua were 20 minutes, and 20 seconds in Switzerland with a broadband connection. Due to this disparity, it was decided to produce a "thumbnail" version of the map of around 200kb, which could be quickly downloaded over any connection to give a viewer an idea of what the map consists of. A link to the zoomable, interactive version, with an indication of the file size, was made alongside. Interested persons could then decide whether they want to download the full version or not.

This map was **finalised at the end of June** and placed on the ENCO Centroamérica SA website on July 15th. www.encocentam.com

11 Wind Power Potential in Nicaragua

We assume that around 10 one-Megawatt turbines can be located on a site of one square kilometre in area, allowing for adequate spacing and slope limitations. Turbines are usually spaced between 5 and 9 rotor diameters apart in the direction of the prevailing wind, and between 3 and 5 rotor diameters apart in the direction perpendicular to the wind. As we have used a “standard” Nordex 54 turbine in our financial model runs, which has a rotor diameter of 54m, this would imply a maximum of some 15 1MW turbines per square kilometre. We have reduced this 15MW/Km^2 maximum to a more conservative 10MW/km^2 to allow for terrain and slope limitations.

This indicates that Nicaragua has a potential for developing up to 760 MW in wind energy power generation, around 20% more than the country’s existing installed capacity from all generating sources.

In practical terms however, wind energy systems cannot normally provide more than around 20 to 25% of a country’s total power demand, due to grid stability requirements, and the need for rolling reserves and back-up supplies to meet peaks in demand, if power interruptions are to be avoided. The variability in wind power generation, due to daily, seasonal and geographical fluctuations in the wind, means that wind power must always be developed in consort with other sources of power generation.

ENCO SA has developed a model to analyse the incorporation of wind power projects to the national grid, and utilises some 20 variables to optimise the balance between different renewable power supplies including hydroelectric, geothermal, wind and solar (absorption and pv). The model can analyse a wide variety of different supply and demand scenarios over the next 50 years or more. (see illustration below)

Modelling Nicaraguan energy supply and demand over the next 25 years, and assuming a steady 5% growth in power demand per annum, current demand will grow from 2,800 GWh per year today, to around 9,500GWh in 2030.

Under such a scenario, peak demand rises from around 470MW today to some 1,400MW in 2030.

Alternative sources of supply have to be on call during windless or low-wind periods to avoid any interruptions or rationing of supplies, especially during the months of September and October – the months of typically lower wind speed. Nicaragua’s geothermal and hydroelectric potentials are both estimated to be in excess of 2,000 MW.

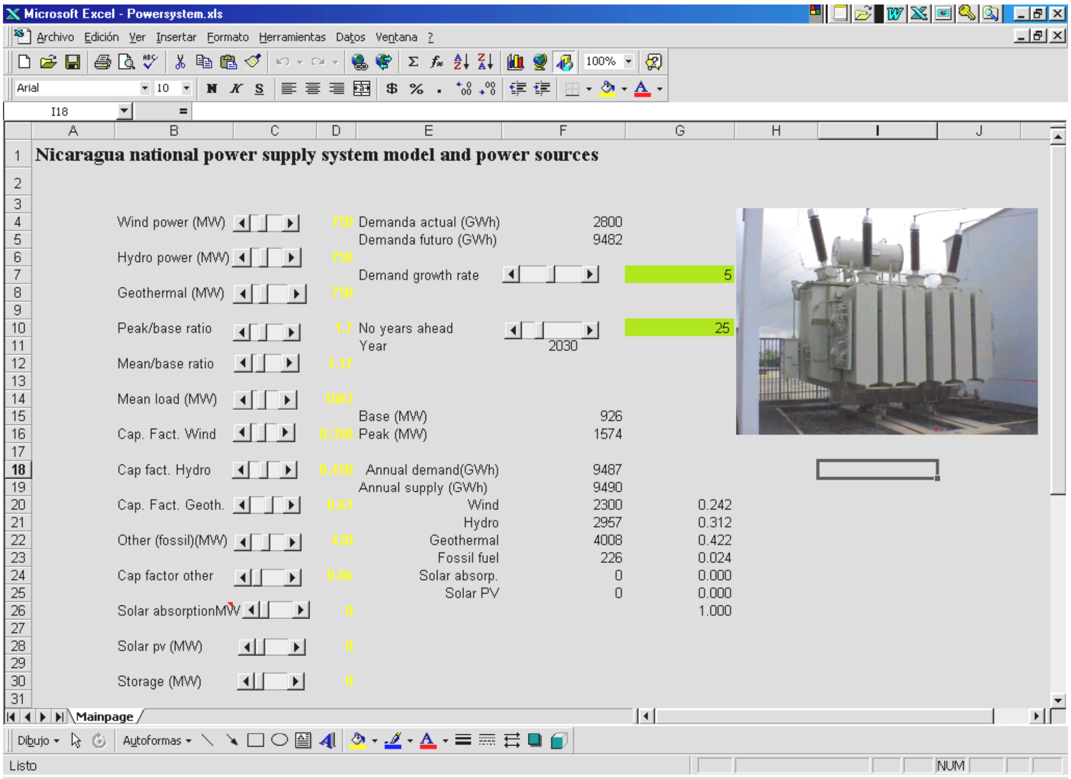


Fig. 16 Snapshot of the power supply system model developed by ENCO SA

11.1 The power supply system model developed by ENCO SA

Incorporating an average of 30MW of generating capacity per year, from each of **wind, hydroelectric and geothermal power** sources, and operating with capacity factors of 30%, 45% and 60% respectively, **would result in 95% of the total power demand being met by renewable sources in 2030**. Only 5% would be generated by fossil fuel sources as a back-up during demand peaks. Wind power, with 750MW of installed capacity by that date, would be providing 24 % of a total projected demand of 9,480 GWh per annum. Total installed capacity of all renewable generating sources would amount to 2,250 MW. Of this total, hydroelectric, geothermal fuel sources amount to 1,500MW - sufficient to meet any peak demand (projected at 1,540MW) with a little back up from the fossil fuel plants, during low wind periods when the wind turbines would be idle.

12 Regulatory framework / Implications for future Energy Policy in Nicaragua

12.1 Energy situation in Nicaragua

Nicaraguan energy use amounts to almost **3 million tons of petroleum** equivalent per annum, of which around **half is in the form of wood** which is used in the countryside as fuel for cooking. Power generation, currently coming from a mix of thermal (71%), hydroelectric (17%) and geothermal (10%) generation sources, has been growing at a rate of almost 6% per year over the past decade, with petroleum imports growing at practically the same rate. In effect, fossil fuel imports are currently doubling every 12 years.

Imports of petroleum and petroleum products amount to around 1m tons of petroleum equivalent per year, of which approximately 30% goes to electricity generation and 36% to transport. Industry, agriculture, fisheries etc consume the rest.

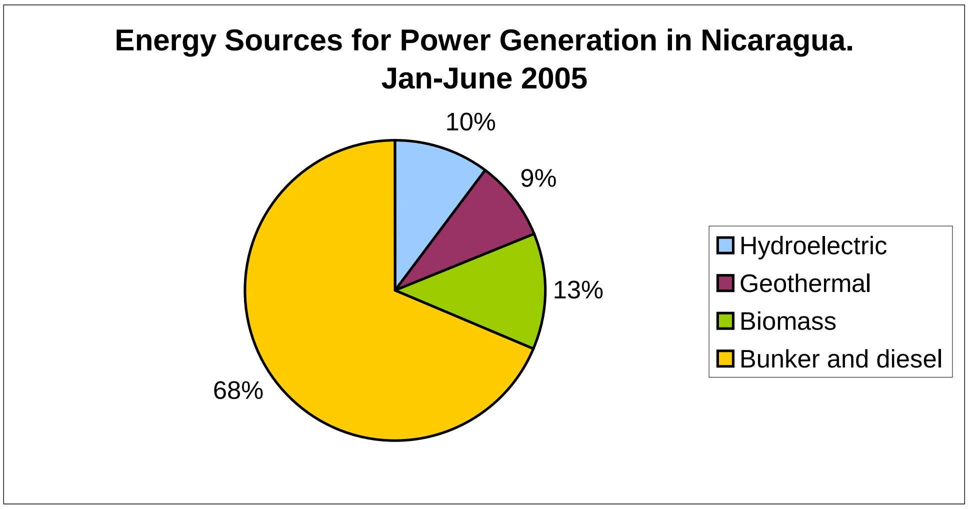


Fig. 17 Energy Sources for Power Generation in Nicaragua. Jan-June 2005

Not being an oil producer, (although exploration is underway) Nicaragua is highly dependent upon imported fuel for electricity generation and transportation, and any increase in the price of oil has an immediate impact on practically all sectors of the economy, through higher electricity and transportation costs. The most recent hike in oil prices to new record highs has dramatically underlined this vulnerability, with the outbreak of **violent protests** involving students, trade unions and transport sector workers during April 2005 over fuel and transport costs.

The power distributor Union Fenosa is also now calling for a 12% hike on power tariffs, to cover its own losses, and faces possible bankruptcy if the increase is not authorised.

The **privatisation of the power generation** sector over the past five to six years has led to an increased dependence upon imported fuel supplies. It has also been done in such a manner that the power supply contracts have ensured that the new fossil-fuel burning power plants have a guaranteed market for a decade or more to come, making it difficult for renewables to compete.

However, the current president, Enrique Bolaños, who took office in 2003, set **new guidelines for the national energy policy** through two decrees issued on 4th March 2004, numbered 12-2004 and 13-2004, which has greatly changed the perspective for renewables, and for wind energy and small run-of-river hydroelectric projects in particular.

These decrees set new precedents by prioritising the development and u**se of clean and renewable energy sources t**o meet the national energy demand, and to establish a framework to facilitate the assignment of financial resources and to develop incentives to exploit these resources to their maximum potential.

Such incentives were then **approved in new legislation** passed by the National Assembly in April 2005, which provides tax incentives for renewable power sources and sets feed-in tariffs at US$55-65/MWh, based on a petroleum reference price of US$39/barrel. This tariff range may be adjusted to reflect the recent increases in the price of petroleum.

12.2 Nicaraguan Electricity Market

Nicaragua currently **generates some 2,800 GWh per year** of electricity from a total **installed capacity of approximately 560 MW**. Peak demand is currently in the region of 450-500MW, base load around 280MW and reserve capacity varies between around 10 and 30% of the peak load.

The privatisation process of the electricity sector in the late 1990s divided the electricity market into three segments: generation, transmission and distribution. More than 80% of the power generated in Nicaragua now comes from private generators. Only around 20% comes from state-owned hydroelectric plants.

Around 70% of the total power generated comes from fossil fuel sources, and only 30% from renewables. This is the opposite of neighbouring **Costa Rica, where over 80% is generated from renewables.**

Power transmission remains in state hands, through Entresa, which manages a national network consisting of around 60 transformer stations, 320 kms of 230 kV line (and which connects with neighbouring Honduras and Costa Rica), around 900 kms of 138kV lines and 650 kms of 69kV lines. A new high voltage line to carry electricity for the Central American power market, known as SIEPAC, is due to be completed in 2007.

Distribution, involving the management and maintenance of all lines and transformers below 69kV capacity, was privatised in the late 1990s also, but due to a lack of suitable offers ended up as a **private monopoly run by Union Fenosa**, a Spanish company with minority Nicaraguan interests. This manages the distribution network on the Pacific coast through two divisions: Dissnorte and Dissur. The Atlantic coast of the country, which is not part of the national network, is open to offers for power companies to generate, transmit and distribute power.

Power demand forecasts made by the National Commission of Energy (CNE) predict that peak demand will rise to between 800 to1000MW over the next 12 years, with total annual generation rising to between 5,000GWh and 6,500GWh.

Over that period therefore, an **increase in generating capacity of almost 100 % will be required,** or as much as 600MW of additional plant capacity. Given Nicaragua's signing of the Central America Free Trade Agreement (CAFTA) with the United States, and the potential for additional inward industrial investment that this creates, it would be reasonable to assume that the eventual demand will be at the higher end of the range rather than the lower.

The phasing out of ageing steam turbine plants over this period could add a further 100MW to the demand for additional capacity.

Given the government's new priorities for the development of renewable energy supplies, there will thus be **significant opportunities for suppliers of these technologies** over the next 10-15 year timeframe. See also our own projections for 25 years ahead in Section 11 above of this report.

12.3 The Regulatory Framework

Nicaragua's electricity sector is regulated by a series of laws, decrees and regulations which are too long and detailed to be included here, but which can be found on the website of the National Energy Commission (www.cne.gob.ni)

Key pieces of legislation for the purposes of wind energy investment are :

- The Electrical Industry Law (Law 272) of 1998
- Decree 24-98 General Regulation of the Electrical Industry Law
- Decrees 12-2004 of 2004 Specific Policy for Support of Development of Wind and Run-of-River Hydroelectric Resources
- Law 532 of 2005 Promotion of Electricity Generation from Renewable Resources

In essence, the **power generation market in Nicaragua is open to private investment.** Generators cannot simultaneously be retail distributors nor can they operate trunk transmission lines. The grid system is managed by the National Load Despatch Centre, a government-run agency, while regulation, licensing and supervision of the country's electricity industry is carried out by the Nicaraguan Energy Institute (INE) but which has recently been replaced by the Superintendency of Public Services (SISEP).

Developers interested in **developing specific wind farm sites require an exploration permit** from INE (SISEP) and once the exploration phase is complete, the authorities will then open the site for bids to develop the site. Exclusivity is not given to any particular site. This procedure has met with considerable criticism as the tendering process may discourage developers from investing in the initial exploration stage. However, a number of exploration licences have been issued over the past four to five years.

Any generation project greater than 1MW requires an operating licence from the authorities to be connected to the grid. Individual projects of 1MW or less however do not require such licensing.

A ceiling of 20MW currently exists as the maximum amount of wind power generating capacity that can be connected to the national grid system. Larger amounts can be connected however if studies are presented that show the additional capacity will not create load management problems or instability in the network.

The development of **off-grid systems face less restrictions** and red tape.

12.4 New developments in the regulatory framework

12.4.1 New Renewables Incentives

An important new development took place with the approval of Law 532 by the National Assembly on 13th April 2005, which **provides new incentives to the wind energy sector,** along with other renewable sources such as biomass, hydroelectric, solar and geothermal.

Machinery and equipment will in future be able to be introduced into the country **free of import duties and value-added tax,** and payment of income tax is exonerated for 7 years from project start-up. Renewable energy projects are also exonerated from paying municipal turnover and property taxes for up to ten years.

Natural resource taxes, of which none exist at present but which could be introduced in the future, are exonerated for a period of five years from project start-up.

Most importantly, **grid feed-in tariffs have been fixed** in a range of US$55-65/MWh, based on a reference rate of US$39/barrel of crude oil. With crude prices currently around US$60/barrel, this signifies a range of US$85-100/MWh for wind power generation. How this price mechanism will be updated to reflect the shifts in the reference oil price, and with what frequency, remains to be determined and tested in practice however.

An upper limit of 20MW still exists for the connection of wind projects to the power grid, but additional capacity can be connected if appropriate studies are presented that demonstrate that such additional capacity will not create instability in the grid, or create load balancing difficulties in the grid's management.

The new legislation is thus a very positive development for the sector, and essentially creates a basis for a steady and increasing role for wind energy power production in Nicaragua over the coming decade or more.

12.4.2 Political infighting stalling investments

On a less positive note, **a political stalemate has developed** between the executive and legislative branches of government. This has centred on recent constitutional reforms approved by the legislature, which seek to wrest control of the regulatory bodies for energy, water and communications from the executive and pass these to the legislature. The legislature is controlled by the two majority parties – the Sandinista Liberation Front, and the Constitutional Liberal Party. These two parties also control the Supreme Court, the Supreme Electoral Council, and the Comptroller General's Office.

The executive refuses to recognise the new heads of the regulatory bodies that have been named by the legislature under the reforms, basing its arguments on a ruling of the Central American Court of Justice, that the reforms were unconstitutional.

The result is that the **work of the regulatory agencies has effectively been paralysed**, and creates great uncertainty for investors wishing to start any new projects in the energy sector. Efforts are currently underway with the mediation of the Organisation of American States to find a negotiated solution to this impasse.

12.5 Implications for future energy policy

If the regulatory and policy framework can be shaped such that adequate investment will be channelled into renewables, the result could be a reduction in fossil fuel dependency in power generation from 70% today, to just 5% in 25 years. This represents a reduction from 1960GWh today generated from fossil fuel sources, to around 370GWh in 25 years' time, **signifying a reduction of 80% in the current annual fuel import bill for power generation**.

We consider this to be a realisable and realistic target, using available technology, and allowing for current power purchasing agreements from the fossil fuel generators to expire over the coming two decades.

Extension of the transmission lines and all-weather roads to the areas of highest wind energy potential, would probably double the potential for wind energy development to over 1,500 MW. With further measurements in the north of the country where there appear to be further promising sites, we anticipate the upper limit to be even higher still.

Fig. 18 Extension of power transmission lines to less accessible areas could potentially double the area for wind energy development to 1.500MW

Moreover, with oil prices likely to rise steadily over the coming 25 years, there is a likelihood that the **economics of wind energy will similarly show an improvement** such that areas with wind speeds as low as even 6 meters per second will become economically viable to exploit.

For example, large areas of the Lake of Nicaragua have wind speeds in the 7 to 8 metres per second range. Even under the current tariff system, it could make sense to install several thousand more megawatts of capacity in the shallower parts of the lake, especially towards its eastern shore, were there the demand to justify this. The 760 MW capacity refers to areas with an average wind speed greater than 8 metres/second, as explained at the beginning of section 9. The lake of Nicaragua has large areas in the 7 to 8 metres per second range and which could be developed given the appropriate tariff (see table 13). For example, a feed-in tariff of US$70/MWh would produce a viable project with 35% equity financing for areas with a 7 to 8 metres per second average. We have focussed on those areas immediately developable in the report. The Lake of Nicaragua is a longer-term potential bringing additional areas into production with lower wind speeds, but which can be financially viable given the right feed-in tariff.

The main limitation to any major expansion of wind power development at present is the restriction of 20MW maximum that can be connected to the national power grid, unless it can be demonstrated that the grid will not suffer instability as a result of connecting larger quantities of wind power. It is expected that this limit will be gradually relaxed as experience is gained in managing the grid with significant wind power resources feeding into it.

This project has shown that Nicaragua has a substantial wind energy potential, compared to future projected demand over the coming 100 years. These resources are capable of being exploited to meet the country's electricity demand throughout the 21st Century without any significant technological changes to those in existence today. They could supply the other Central American countries through the

SIEPAC 230kV transmission line to be completed in 2007, when it is envisaged there will be a Central American power market in operation.

Should hydrogen and fuel cell technology develop significantly over the coming two decades, wind energy could also be a future major supplier of power for transportation purposes.

13 Feasibility and risk for future projects

13.1 Technical

The technical feasibility of wind projects has been proven in many industrialised and developing countries. This wind map project has shown that there is a major potential for the development of wind energy projects in Nicaragua, and that sufficient wind resources exist to play a major role in a future renewable energy strategy for the country.

In the case of the specific projects laid out in section 16, **more detailed feasibility studies need to be carried out** before any final technical conclusions can be made for these particular sites.

As we explain elsewhere in this report, the consortium has investigated numerous possible sources of finance to complete these studies, but so far without success. Without the initial capital to carry out the feasibility studies, it will be difficult to proceed further.

The first wind turbine of any significance (250kW) was connected to the national power grid in December 2004, by the La Salle Institute in León, one of the associate organisations in this wind map project. The National Load Despatch Centre is thus now gaining its first pilot experience in handling variable loads from wind turbines, as is Union Fenosa, the national power distributor.

ENACAL, the national water supply company, is to tender shortly for the supply of 10MW of wind power to partially meet its water pumping requirements. Once connected to the power grid, these turbines **will provide the first significant experience** of load-management experience involving wind turbines.

Any technical difficulties arising from load management problems are likely to be ironed out over the coming two years therefore.

13.2 Legal-political

Over the past 15 years, Nicaragua has received a vast amount of finance from the international community to **improve the investment climate in the country.** Privatisations have been carried out in electricity, telecommunications, banking, insurance, agriculture and industry, all formerly dominated by the state sector under the socialist Sandinista government in the 1980s. Trade liberalisation measures have been enacted, and Nicaragua is moving steadily towards a Customs Union with the other Central American countries, and is likely to ratify the CAFTA treaty before the end of 2005. From a commerce point of view, Nicaragua now has **one of the most open economies in Central America**. With now **solid financial institutions and a modern transport infrastructure** – the latter largely rebuilt in the aftermath of hurricane Mitch in 1998 – the country is well positioned to take advantage of the plans to remove remaining trade barriers in North and Central America. The macroeconomic prospects for sustained economic growth are good, and which in turn are capable of sustaining a steady growth in demand for electrical power.

A major obstacle however remains on the political front, where a **political pact** between the two populist former presidents Alemán and Ortega has resulted in them sharing out power in all of the major public institutions. These include the National Assembly, the Electoral Council, the Supreme Court and the lower courts, and the offices of the Comptroller General and the Attorney General.

The democratic concept of an independence between the powers of state has been deeply eroded over the past five or six years due to “The Pact”, and there is growing concern that the consent of the governed upon which the concept of democracy rests, is in danger of breaking down.

The current president Enrique Bolaños is struggling to govern with the little power he has remaining, and is having to turn increasingly to the international community for support. He is backed by the other Central American presidents, by the United States, by the Organisation of American States and the Central American Court of Justice that has ruled some recent constitutional amendments unconstitutional. He also retains control of the Police and the Armed Forces, but there is doubt over their ability to retain control in the event of any break with the constitutional order.

Over the past few months, a series of moves by the two populists have attempted to cut Bolaños’ powers even further. But he has decided to draw the line and there is a growing groundswell of public outrage at the efforts of the two populists to try and seize control of all the levels of power of the State through the back door.

Fig. 19   First signs of opposition to the political pact (Foto La Prensa)

A major demonstration in June of over 50,000 people organised by civil society figures and minority political parties and leaders, has been the first signal that opponents of the pact have the power to bring as many people on to the streets as do the leaders of the pact themselves.

At the same time, the **government is facing enormous pressure on the economic front,** due primarily to **rising oil prices** that have triggered student and transport protests. The populist leaders through their control of the National Assembly and their control over the government's budget, are resorting to short-term fixes using fuel and energy subsidies, but which have not been agreed with the International Monetary Fund. Likewise, **key structural and budget reforms agreed with the IMF are being delayed by the Assembly**, and Nicaragua is now technically in default with the Fund.

On a more positive note, **Nicaragua has many non-governmental actors involved in environmental issues.** Together they represent a **powerful lobby group** that has helped frame a positive environmental public policy. A large number of projects have been carried out, thousands of people have been trained or attended courses and environmental-awareness workshops, organic farming and eco-tourism businesses are being actively promoted and many of these start to show genuine sustainable success and to create jobs.

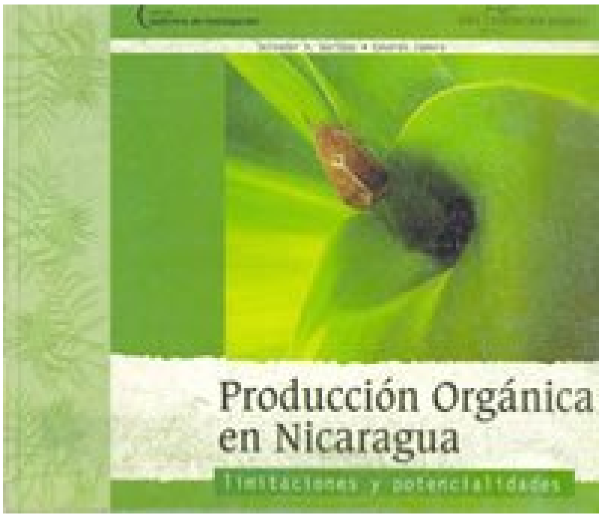


Fig. 20 Nicaragua has a positive environmental public policy (Foto SIMAS, Nicaragua)

One of the core problems of this country though **lays in its lack of industrialisation,** especially outside of a few main cities, the only growing sector being the "maquilas", which produce cheap clothes for export. **Rising electricity costs** however, could eventually undermine the rationale for them to continue in Nicaragua, despite the very cheap labour, when neighbouring countries such as Costa Rica have their power produced primarily from renewable energy sources and are less vulnerable to future rises in the price of oil.

Energy production in Nicaragua is thus a highly sensitive issue, as it is indeed in many other parts of the world, but is critically so here due to the country's high **dependence upon imported fossil fuels.** The National Energy Plan and the CNE have committed the country to developing its renewable energy resources as a national priority and one expression of that has been the CNE's support and interest in the elaboration of a wind map with this current project.

13.3 Economic

The economics of wind power generation are now well known and established as a result of decades of development, and of wind power now playing an important role in the power supplies of many industrialised and industrialising countries.

ENCO SA has developed its own financial and capital structure model for assessing the financial viability of establishing wind parks in Nicaragua. Some 18 different variables can be set to test a wide range of economic and financial scenarios.

The model indicates that **wind power is now an economically viable option** for Nicaragua, given the new regulatory framework and tariff structure. Practically all serious forecasts for the future movements of oil prices predict a secular upward trend over the coming two decades, which will make wind energy all the more attractive as an alternative to fossil fuel powered generating plants.

Nicaragua's economy has been **growing steadily at an average 4-5% per annum**, and trade volumes at twice that level, for more than five years now while inflation has been kept in check in single digits. New trade agreements in the pipeline are likely to accelerate the economic growth rate further. Any economic instability ahead, is more likely to be caused by political factors such as those mentioned above, or external factors such as runaway oil prices. Provided Nicaragua's political leaders are able to come to the negotiating table and step back from any further escalation of the looming constitutional crisis, the economy should stay on course for sustained, accelerated economic growth for the foreseeable future.

Under such circumstances, and provided the current regulatory framework, tariff structure and foreign investment legislation is allowed to function correctly without political interference, there should be **no economic constraints to Nicaragua developing a potential of up to 760MW in wind powered generation** during the course of the coming decades. The primary constraints will be that of demand and the need to balance wind power with other sources of renewable energy.

14 Project Financing

14.1 Contacts made to date

The following steps have been taken:

ENCO SA and its parent company ENCO AG have **spent more than a year sounding out financing possibilities** for the various projects that it is attempting to develop in Nicaragua.

In order to find finance for follow-up projects, we have made contact with the following institutions:

- Swiss Agency for Development and Cooperation, Managua, Mr. Jürg Benz
  (personal meeting in Managua)
- SECO, Bern, Mrs. Providoli, Mr. Denzler
  (personal meeting in SECO)
- SECO, Bern, Mrs Dagmar Vogel
  (writing a special report for her office)
- SOFI, Zürich, Mr. Andre Calame
  (sending detailed material and telephone contact)
- InterAmerican Development Bank, Washington: Maria Bouroncle
  (e-mail contact)
- InterAmerican Development Bank, Managua:
  Eduardo ValCarcel (Country representative),
  Eduardo Soto (Infrastructure specialist),
  Jaime Cofré (local technical cooperation funds administrator and sectoral specialist)
  – all personal meetings
- GEF-Funds, Alan Miller, GEF Coordinator, International Finance Corporation
- BASE, Basel, Michael Schlup
- Brugger Consulting, Private Sector Development in Central America, Mr. Ernst Brugger
- Centre for International Forestry Research, Indonesia, David Kaimowitz,
- UNRISD, Geneve, Mr. Peter Utting
- Several private companies and businessmen in Nicaragua, (Mantica Supermarkets, Gabriel Pasos, Lafise, all personal meetings)

14.2 Lack of feasibility study finance

A key problem is that **none of the institutions mentioned above are financing feasibility or pre-feasibility studies for projects initiated in the private sector.** The Nicaraguan public sector does not have the resources to start such projects and faces restrictions on public sector investment under its finance program agreed with the IMF. Under the conditions of the electricity privatisation scheme carried out in the late 1990s, the government will not in future be investing in power generation. Venture capital funds are thus urgently required that are prepared to invest equity at this initial project development phase. No such funds exist in Nicaragua, and Nicaraguan capital owners are extremely risk-averse. Nicaraguan banks - and the same is true of most international banks also - **will not finance projects at this early stage of development**, only once detailed feasibility studies have been completed, and customers for the power supply from the turbines have been identified and contracted. Likewise the development banks such as the Inter-American Development Bank and World Bank will only finance private sector projects once they have passed the feasibility stage.

Our consortium has developed the projects El Crucero and Corn Island **at our own expense through the pre-feasibility stage and is seeking funding** for the feasibility studies. We face a **circular problem** however: we have identified good potential projects, but finance is required to develop these sites to make them bankable projects. And we cannot get that finance until we can prove they are bankable projects.

For this reason, we have structured the three projects in sections 15.3 to 15.5 as **public-private sector partnerships** and sent them to **SECO** to the Deputy Division Head, Dagmar Vogel, as we had indications that SECO might be willing to finance the pre-feasibility studies for these projects. Up to now, no decision has been taken.

We consider that a key factor for attracting investors into the renewable energy sector will be to **further improve the framework conditions** in this sector. Given its relationships established before and during the current project, the consortium would be most interested in co-ordinating such a project.

15 New developments in the wind energy sector in Nicaragua

15.1 La Salle Institute

In December 2004, the La Salle Institute in León, which has provided some of the data for this project's wind map, installed a second-hand 250kW wind turbine on its grounds to provide power for the Institute, and to feed any surplus into the grid.

This is the first wind turbine of any significant size to be installed in Nicaragua. Although the site is not ideal for power production, (average 4.6 m/sec) the turbine was a donation and it is being used for demonstration and teaching purposes at the renewable energy technical department at this vocational school.

Being the first wind turbine to be **connected to the distribution grid**, it is also the first opportunity to see in practice how the new legislation will function regarding feed-in tariffs and their adjustment for oil price rises (the feed-in tariff being linked to an oil price reference level). It is also giving the National Load Distribution Centre its first experience of feeding in power to the grid from a variable wind source.

Fig. 21 The 250kW turbine installed at the La Salle Institute, León (Photo courtesy La Salle Institute)

15.2 ENACAL

Nicaragua's National Water Company, ENACAL, is positioning itself to be the **first major consumer of wind-generated electrical power in Nicaragua,** following an international call in March 2005 for potential wind park operators to qualify for an eventual tender to supply 10MW of power to the company for pumping water.

ENACAL announced in June that three companies had qualified, one of them being Ventus SA, which supplied the data for the Hato Grande site near Juigalpa and with the claimed 10.5m/sec annual average.

ENACAL have not yet announced when the tender will be formally announced, nor when they expect to have the 10MW on-line.

15.3 A follow-up measurement campaign

As noted in the earlier discussion, the 760MW potential identified in this study is sufficient for the development of a renewables-based electricity strategy in Nicaragua for well into the 21st Century, as part of a technology package also including geothermal, hydroelectric and eventually solar power.

We suspect that Nicaragua's full wind energy potential is considerably higher, once less accessible sites have been evaluated, especially in the north-centre of the country, where this map seems to indicate there could be considerable potential. For example, the El Sauce site was measured with just a 6m tower and yet due to those measurements, most of the sites in the Estelí region have been identified, and which comprise some 60% of the 760MW potential.

Previous to this study, the sites considered to have most potential in Nicaragua were Rivas and El Crucero.

We therefore consider that **a series of hilltops in northern and central Nicaragua,** which have been highlighted by this first measurement campaign as having considerable potential, could prove to have a higher potential still by placing measurement equipment at these specific sites.

As noted earlier, we also **recommend the inclusion of at least six sites in the Atlantic Coast region** in any future measurement campaign, to fill in the large "gaps" in the current wind map of this area. Even though we suspect average wind speeds will not justify grid-connected systems in this region, there are likely to be many locations where isolated systems can be economically developed even where average wind speeds are as low as 5 metres/sec.

Given the relative underdevelopment of the Atlantic Coast region compared to the rest of Nicaragua, there is an added urgency for measurements to be carried out in the region, especially since the **National Assembly turned down an IADB loan** which would have financed a wind measuring campaign there.

16 Conclusions

The Nicaraguan wind-mapping project, adapting the technology and methodology used to produce a wind map of Switzerland, **has resulted in the identification of 76 square kilometres** of territory in Nicaragua that have the potential to be readily developed for grid-connected wind farm projects. This represents a **potential of some 760 MW.** In comparative terms, this is considerably more than the current peak load of 460MW in the Nicaraguan power network.

This potential is adequate for **wind energy to play a central role in a new renewable energy strategy for Nicaragua,** alongside the development of the country's hydroelectric and geothermal potential. Employing existing technology, such a strategy could reduce the fossil fuel component of power generation in Nicaragua from 69% of the total today, to just 5% over the next 25 years. Wind energy could provide around 24% of a projected demand of 9,500GWh in the year 2030, by fully developing this potential of 760MW.

A follow-up measurement campaign, using new sites identified by this first map as showing promise, will most likely identify additional areas with good development potential, especially in the north and north-centre of the country. With extensions to the power transmission network, the readily developable potential could possibly double to some 1,500MW.

The **project has also demonstrated that there is great potential** for the development of small-scale wind energy projects in isolated and rural electrification applications.

As petroleum prices edge further upwards, additional areas will also become financially viable for wind energy development, including large areas in the Lake of Nicaragua. Should fuel cell technology continue to make steady advances over the coming decade, then development of this additional wind energy capacity would enable Nicaragua to embark upon a renewable strategy to also replace fossil fuels in transportation applications.

The wind mapping project has thus demonstrated that Nicaragua has sufficient wind energy resources to be able to design a realistic renewable energy strategy to reach energy self-sufficiency during the course of the 21st Century and without needing fossil fuels to meet future energy demand.

To produce this map, wind **measurements were carried out** over a period of up to 20 months at six different sites in Nicaragua and additional measurements were incorporated from a variety of different sources. A transfer of technology was carried out, that enables local specialists to update the wind map in the future with new data additions.

We have **analysed the technical, economic and political risks** associated with the development of wind energy in Nicaragua and conclude that the political risks represent the main obstacle to Nicaragua being able to realise its full potential in renewable energy development. However, by **working through local governments**

and keeping the projects to a modest scale that can be implemented without major bureaucratic impediments, we do not consider the political risks to be of a nature that will impede the new pioneer projects we have set in motion. These projects will present to the public and politicians alike with highly visible and viable examples of what wind energy can achieve now, and what it can provide in the future. As the conjunctural political issues are resolved, the outlook for foreign investment in the wind energy sector will also greatly improve.

Two wind evaluation projects were carried out simultaneously during the course of this project. Plans have been put in place to market and distribute a new 5KW wind turbine for small-scale applications in Nicaragua beginning in 2006, and which we also hope to introduce through a rural electrification scheme in the southern department of Rivas.

At the same time **three additional projects have been drawn up as Public-Private Partnerships for large-scale applications**. One of these will pioneer wind energy development in El Crucero, a highly promising area identified by the wind map, and another will be a pioneer wind energy project for an isolated generating system on an island with major economic and eco-tourism potential.

Within the context of this project, ENCO SA and its parent company ENCO AG have spent almost a year exploring **financing possibilities** in Nicaragua, US and Switzerland and international institutions for the various projects that it is attempting to develop in Nicaragua. However, we have come across a fundamental problem that **feasibility and pre-feasibility studies for projects initiated in the private sector are not being financed.** Our consortium has developed projects at El Crucero and Corn Island **at our own expense through the pre-feasibility stage and is seeking funding** for the feasibility studies.

During the course of this project , ENCO SA has built solid contacts with local governments and is able to present three projects as **public-private sector partnerships** (section 16).The mayors of El Crucero, Corn Island and El Castillo have all signed agreements with ENCO SA to participate actively in these planned projects (and Annexes 6 and 7).

We have also laid out the framework for a possible **follow-up wind measurement campaign** with particular emphasis on the Atlantic Coast region and the north-centre of the country.

Given the many contacts, the networking and the software tools that have been created in the course of this project, we are in a very strong position to work together **with the Comision Nacional de Energía in the development of a renewable energy strategy and planning project.** This would provide vital support to the international aid programme to Nicaragua in its efforts to bring about lasting and sustainable improvements to the Nicaraguan economy, by creating an excellent tool to plan the development of the country's **energy sector based on renewable resources.**

We can conclude that the **project has produced its planned results, and has been carried out on time and within the budget.** In addition, the consortium has already completed two other small projects and produced detailed proposals for several follow-up projects covering the full range of wind energy applications from a small-scale rural electrification scheme, to a medium-scale hybrid generation system, through to pioneering the development of a large-scale grid-connected wind park at one of the most promising wind sites in Nicaragua.

This wind mapping project has been greatly welcomed by the Nicaraguan authorities, **has placed wind energy firmly on the national agenda** as a technology to incorporate in a future renewables energy strategy, and is paving the way for the implementation of a number of new wind energy projects. We therefore **recommend to REPIC** and/or the Federal Offices involved in this platform, to consider the possibility of providing ongoing support to our consortium to help us follow through on the pioneering projects we have started and in particular to assist us with finding **ways to finance the feasibility studies for these follow-up projects.**

17 Annexes

18.1. Annex 1 – Summary of goals, activities and results

18.2. Annex 2 – Wind Map

18.3 Annex 3 – Article published in *energeia* magazine

18.4 Annex 4 – List of measurement stations

18.5 Annex 5 – Wind interpolation software and model

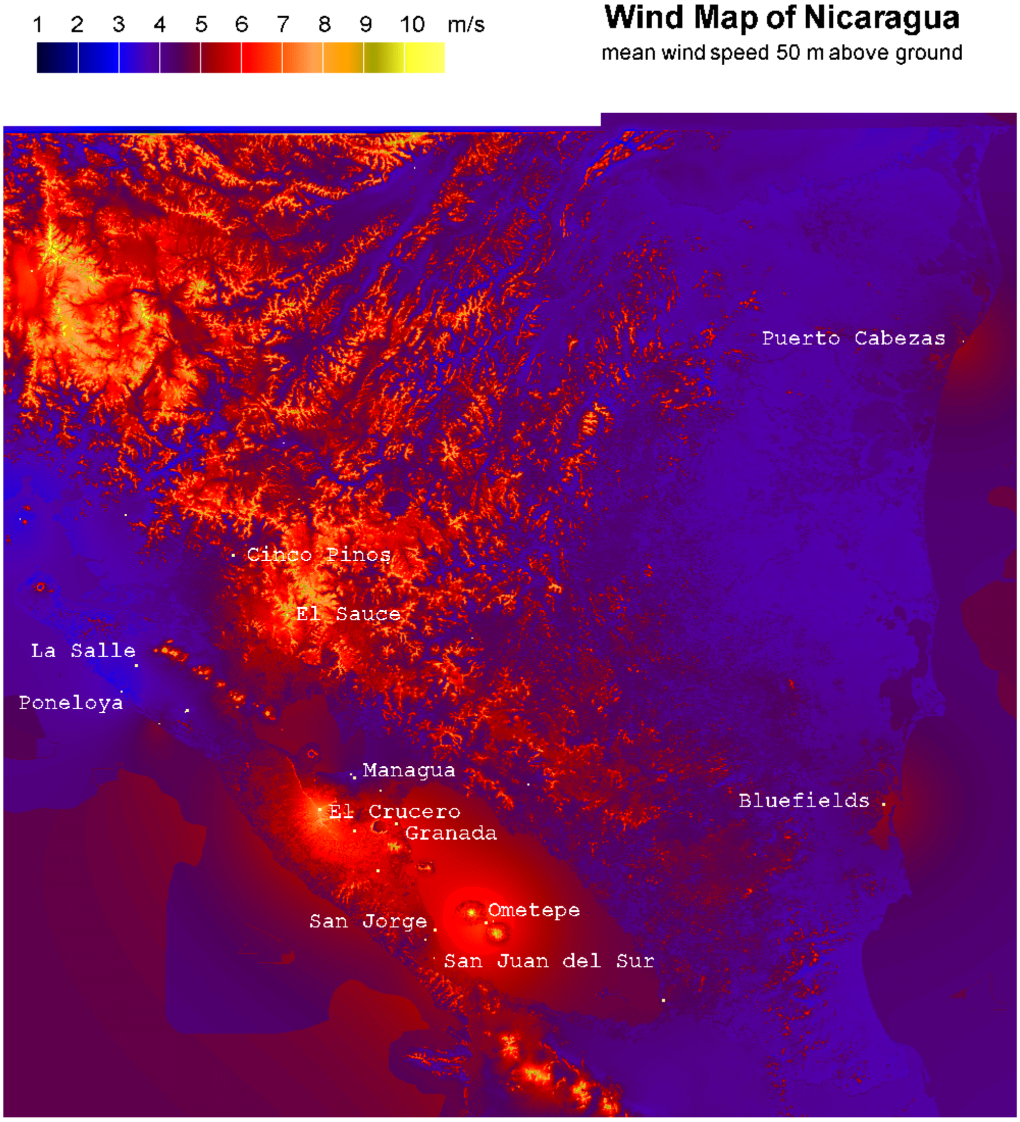
17.1 Annex 1 - Summary of goals, activities and results

Objectives	Activities	Results
Main Objective ➢ Improve the knowledge about potentialities and potential sites for wind energy supply in Nicaragua::	**Main Activities** ➢ Establish contacts ➢ Wind speed measurements ➢ Technological transfer ➢ Elaboration of Wind Map ➢ Sensibilization ➢ Checking out possibilities for follow up projects ➢ First draw ups for follow up projects	**Main Results** ➢ The project has established clear data indicating a wind power potential of 760MW. ➢ A wind map has been produced, is available in a zoomable form on the Internet for the use of investors ➢ 3 follow up projects have been or are being carried out ➢ 3 major projects have been laid out and steps towards their implementation have been taken. ➢ 2 further projects have been laid out ➢ A financial model for future projects and investment analysis has been developed
Preparation ➢ Preparation for this project	**Activities** ➢ Initial activities ➢ Establish contacts, inform national institutions ➢ Establish company agreement between Nicaraguan and Swiss partner companies, in order to have a close working cooperation and know-how transfer from Switzerland to Nicaragua, Define the measurement points ➢ Import 5 sets of wind measuring equipment ➢ Write agreement for the utilisation of the radio towers ➢ Check for other measurements on future wind energy sites by other companies and organisations.	**Results** ➢ The project has been carried out as planned, relationships established

Measurements	**Activities**	**Results**
➢ Include all existing (and future) wind measurements in Nicaragua – and make summaries of wind statistics from these sites available for all interested companies and institutions ➢ Install and analyse the wind regime on 5 additional sites for at least 6 months each	➢ Measuring time: 20 months ➢ Installation and measuring from 5 sets by ENCO SA ➢ Including date from CNE from the 1990s, 4 data sets from La Salle Institute from Northwest region, data from INETER, National Meteorological Network ➢ 2 sets from private developers	➢ The map identifies the better locations suitable for siting of wind turbines and wind parks
Wind Map production	**Activities**	**Results**
➢ Produce a wind energy map for Nicaragua, using ➢ - new measurements at six new sites by ENCO SA - existing digital information in Nicaragua, (provided by GeoDigital, Managua) - existing wind data in Nicaragua (available from the national weather service) - incorporating other wind data that has been collected by the CNE and other institutions ➢ Calculate the wind energy potential on sites with access to roads and power lines – as a wind potential study to assist energy planning by government bodies ➢ Apply the knowledge to the analysis of other renewable energies	➢ Modelling the wind energy map ➢ Generate digital elevation model with 90 m grid resolution by GeoDigital, Managua from existing digital data ➢ Generate wind statistics for all sites with available wind data (weather stations, own measurements, other measurements) ➢ Include long term data (20 years) of 10 weather stations, monthly mean, measured at 10 m above the ground ➢ Statistical wind modelling based on measurement and topography using METEOTEST algorithms ➢ Introduce the METEOTEST wind energy model at GeoDigital Managua	➢ Technological transfer ➢ Sensibilization ➢ Print wind energy map of Nicaragua ➢ Put map on the Internet, freely available ➢ Calculate potential on sites near roads and power lines ➢ Report about the achieved results, incl. how to use the model - description of a system of continuing optimisation of the database of the map - including further measurements, also by other partners and companies ➢ Evaluation of success and possible enhancements

Follow up Projects	**Activities**	**Results**
➢ Promote wind energy in Nicaragua via map and point possible investors towards best sites ➢ Continuous optimisation of the model due to new data from site assessments	➢ Development of financial model ➢ Contact and coordinate different actors of the energy sector in Nicaragua	➢ Financial model for wind potential ➢ Plans for future updating of Wind Map ➢ Realization of 3 follow up projects ➢ Design and preliminary contacts for 3 follow up projects designed as PPP ➢ 2 follow up projects as a result of the working relationship developed with REPIC on the wind map project ➢ Renewable power supply system model which could be used as a basis for improving framework conditions for investors and projects in renewable energy

17.2 Annex 2 – Wind Map



See Poster sized form in Original and the following Website

www.enco-ag.ch

www.encocentam.com

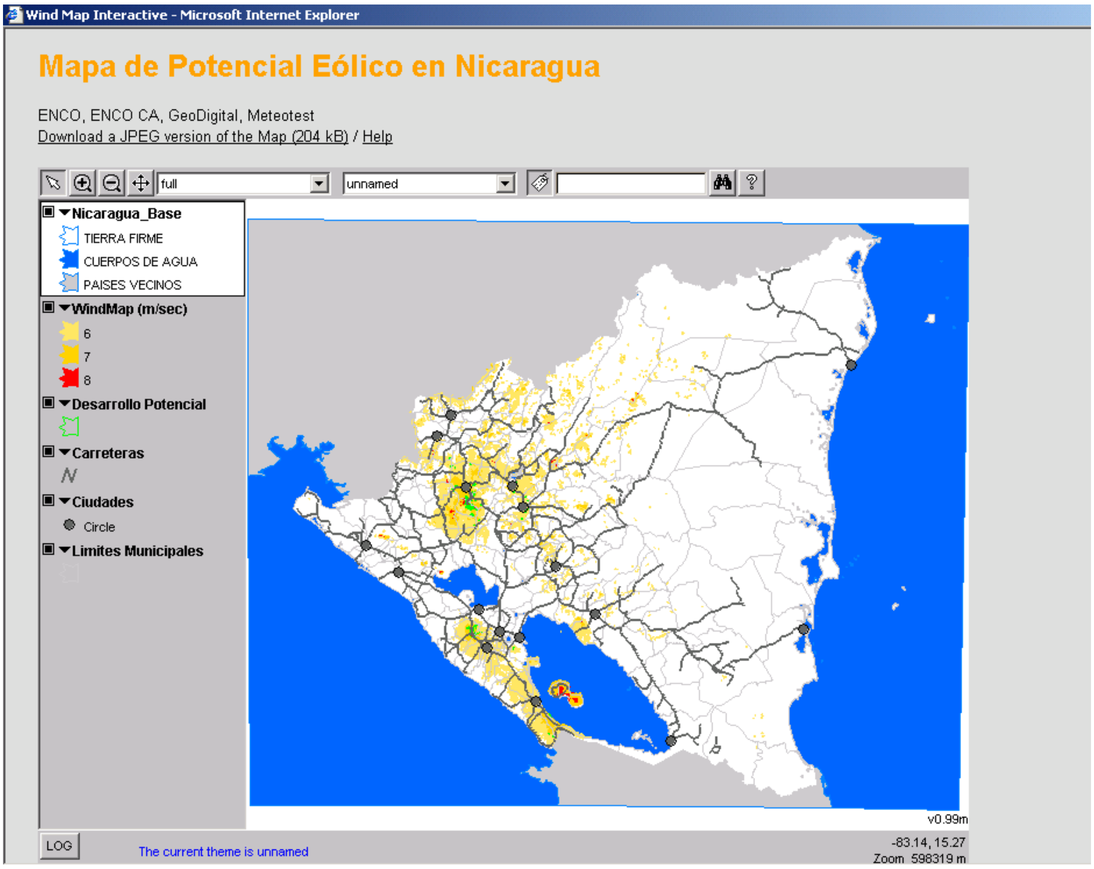


Fig. 22 Display of zoomable Wind Map on Website
http://ds1.dreifels.ch/enco-ni/page.asp?DH=33

17.3 Annex 3 – Article published

17.3.1 in energeia Magazine

Windkarten: Nicaragua setzt auf Schweizer Know-how

Maria de los Angeles Gutiérrez und Nicolás Arróliga wissen, dass auch bei ihnen im zentralamerikanischen Land Nicaragua der Wind bläst. Welche Standorte sich jedoch für eine Energienutzung eignen, muss zunächst untersucht werden. Die beiden Wissenschafter besuchen die Schweiz, um sich durch einen gezielten Know-how-Transfer mit der Modellierung von Windverhältnissen und dem Erstellen von Windkarten vertraut zu machen. Damit lassen sich die Potenziale ihres Landes exakter erfassen und für Evaluation und Projektierung von Windkraftanlagen nutzen.

INTERNET

Swiss Eole: www.wind-energie.ch

Meteotest: www.meteotest.ch

Ein wichtiges Instrument, das für die Beurteilung von Standorten und entsprechenden Windenergieanlagen eingesetzt wird, sind die Windkarten von Meteotest. Dieses Know-how wird in Schweizer Projekten genutzt, ist jedoch zunehmend auch international gefragt.

Meteotest berechnet Windenergiepotenziale

Kenntnisse und Erfahrungen des Berner Unternehmens kamen auch im Rahmen einer Zusammenarbeit mit Nicaragua zugute. Stefan Kunz, Geschäftsführer von Meteotest: «Neben den Wettervorhersagen – die einem breiten Publikum in der Schweiz bekannt sind – haben wir uns in den vergangenen Jahren mit BFE-Forschungsunterstützung auch auf die Datenbeschaffung und Datenauswertung für Windkarten und Modellierungen der zu erwartenden Windverhältnisse spezialisiert. So lag es nahe, mit BFE-Projektleiter Robert Horbaty von der Firma ENCO AG in Bubendorf und mit Partnern in Nicaragua ein entsprechendes Projekt zu lancieren – zumal die ENCO AG gute Beziehungen zu Zentralamerika pflegt.»

Gute Voraussetzungen für die Option Windenergie

Nicaragua ist bei der Stromerzeugung zu rund 80 Prozent vom Import fossiler Brennstoffe abhängig und daher interessiert, diesen Zustand in den kommenden Jahren zu ändern. Mit über 500 Kilometern Küstenlinie am Pazifik und an der Karibik kommt der Option Windenergie eine viel versprechende Chance zu. Ferner ist die Westseite mit der Hauptstadt Managua gut erschlossen und weist eine Infrastruktur auf, die sich für eine Windenergienutzung eignet. Der Strom lässt sich ins vorhandene Netz einspeisen. Ebenso interessant sind abgelegene Gebiete, zum Beispiel auch Regionen an der Ostküste, wo die Windenergie eine wirtschaftliche und ökologische Alternative bieten könnte.

In der Schweiz auf Erkundungstour

Maria de los Angeles Gutiérrez und Nicolás Arróliga von Geodigital SA, Managua, reisten kürzlich zusammen mit Tim Coone von ENCO Centroamérica SA in die Schweiz, um sich bei Meteotest mit der Windkartenmodellierung vertraut zu machen. Nicolás Arróliga: «Wir haben uns bei Geodigital auf Geografische Informations-Systeme (GIS) und auf die digitale Kartografie spezialisiert. Damit sind wir in der Lage, Behörden und Privaten geografische Grundlagen für verschiedene Projekte, Landnutzungs- und Bewässerungssysteme zu liefern. Was uns bisher fehlte, war die Möglichkeit, auf der Basis unserer Kenntnisse von Nicaragua auch repräsentative Windkarten zu erstellen, die für Regierung und Investoren als Entscheidungsgrundlage dienen

Nicaragua setzt auf die Karte Windenergie.

können.» Und Maria de los Angeles Gutiérrez ergänzt: «Ausgehend von digitalisierten topografischen Ansichten, bei denen unter anderem Vegetation, Besiedlung und Infrastruktur erkennbar sind, werden wir die Windverhältnisse berechnen und grafisch darstellen.»

Messstationen auf Radiosendermasten

Mit einigen Messstationen an klimatisch wichtigen Stellen des Landes konnten inzwischen Winddaten erfasst werden. Diese dienen nun dazu, die Modellierungen durchzuführen und dadurch mögliche Standorte für Windkraftanlagen festzulegen. Einzelne Messstationen konnte man an vorhandenen Radiosenderantennen montieren und so den Installationsaufwand gering halten. Als prognostizierte Standorte lassen sich aus heutiger Perspektive sowohl gewisse Küstenabschnitte als auch die entlang der Westküste verlaufende Vulkan-Kette erkennen, die bis 1000 Meter über Meer hinauf reicht.

Die Frage der Akzeptanz solcher Anlagen in der Bevölkerung ist bisher noch offen, allerdings werden die Nachteile durch das Verbrennen von Diesel in Stromgeneratoren sowie die Kostenentwicklung der fossilen Energie bereits heute erkannt.

Jürg Wellstein

20 Jahre Meteonorm

Sonnige Zeiten waren das! 1985 hat das Bundesamt für Energie ein Handbuch mit Daten zur Sonneneinstrahlung aller Gemeinden der Schweiz herausgebracht. Die Berner Firma Meteotest war beim Projekt Meteonorm von Beginn weg involviert und hat dieses nach offiziellem Projektabschluss weitergeführt. Heute – 20 Jahre danach – steht die Softwareversion 5.1 zur Verfügung, die sowohl national als auch international genutzt und geschätzt wird.

Über 7400 Wetterstationen rund um den Globus sind im System erfasst und vermitteln Zahlenmaterial zu Wetter, Klima, Sonne und Wind. Das Programm bietet fünf Sprachversionen und umfassendes Instruktionsmaterial, damit das Potenzial der Sonnenenergie überall voraus berechnet werden kann. Die über 1200 Nutzer in etwa 35 Ländern sind vorwiegend Planer, Ingenieure und Forscher aus der Solarbranche und Gebäudetechnik, aber auch aus Landwirtschaft und Architektur.

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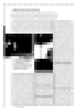
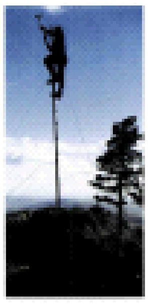
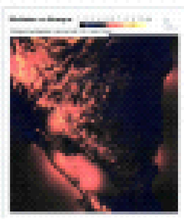
office@meteotest.ch
www.meteotest.ch

17.3.2 in ET Electro Tecnic Magazine

Windkarten für Nicaragua







17.4 Annex 4 - List of measurement sites and meteorological stations in the Wind map project

ID	x coord (UTM)	y coord (UTM)	Alti-tude(m)	Long-term average wind speed (m/sec)	Tower height (m)	From (year)	To (year)	Name	Country	Source
1	575584	1326041	939	8.3	24	3	5	El Crucero	Nicaragua	ENCO
2	612954	1319047	53	3.9	24	3	4	Granada	Nicaragua	ENCO
3	559526	1421164	1118	8.1	6	4	4	El Sauce	Nicaragua	ENCO
4	928949	1349212	5	5	21	4	5	Corn Island	Nicaragua	ENCO
5	624856	1251817	65	5.5	18	5	5	Rivas	Nicaragua	ENCO
6	666171	1339356	129	3.5	29	4	5	Juigalpa	Nicaragua	ENCO
7	632051	1267087	40	6.9	33	93	94	San Jorge	Nicaragua	CNE
8	631410	1253259	100	6.1	33	93	94	S.Juan del Sur/El Capulin	Nicaragua	CNE
9	656942	1270431	46	8.6	33	93	94	Santa Ana	Nicaragua	CNE
10	660418	1271212	74	8	33	93	94	San Pascual	Nicaragua	CNE
11	510500	1374500	113	4.6	45	3	4	La Salle Institute	Nicaragua	La Salle
12	533114	1450383	315	4.3	35	3	4	Cinco Pinos	Nicaragua	La Salle
13	496815	1368116	65	5.2	30	1	3	Poneloya	Nicaragua	La Salle
14	574987	1334156	413	4.2	12	4	4	Ticomo	Nicaragua	La Salle
15	667270	1332523	550	8.5	35	4	4	Ventus/Hato Grande	Nicaragua	Private
16	641175	1251542	40	8.5	30	2	4	AMAYO	Nicaragua	Private
17	592488	1341405	56	2.4	10	61	90	A.C.SANDINO	Nicaragua	INETER
18	608767	1446751	985	1.9	10	94	4	JINOTEGA	Nicaragua	INETER
19	677723	1338142	90	2.6	10	94	4	JUIGALPA	Nicaragua	INETER
20	509423	1373740	80	2	10	82	3	LEON	Nicaragua	INETER

21	485556	1396555	60	2.1	10	94	4	CHINANDEGA	Nicaragua	INETER
22	557654	1505432	612	2.6	10	61	90	OCOTAL	Nicaragua	INETER
23	590632	1343279	50	2.3	10	94	4	MANAGUA/AUGUSTO	Nicaragua	INETER
24	650136	1409889	320	2.1	10	94	4	MUYMUY	Nicaragua	INETER
25	852113	1328620	5	3.3	10	97	3	BLUEFIELDS	Nicaragua	INETER
26	478270	1383699	5	2.7	10	91	3	CORINTO	Nicaragua	INETER
27	743980	1232567	40	4.1	10	97	3	San Carlos	Nicaragua	INETER
28	605361	1335343	70	3.9	10	87	1	Timal	Nicaragua	INETER
29	592600	1315604	470	3.5	10	83	3	Campos Azules	Nicaragua	INETER
30	565326	1477945	560	2.4	10	81	3	Condega	Nicaragua	INETER
31	603885	1295956	95	4.2	10	81	3	Nandaime	Nicaragua	INETER
32	890881	1555335	10	4.8	10	94	4	Puerto Cabezas	Nicaragua	INETER
33	312141	1908071	90	3	10	61	90	BELMOPAN	El Salvador	National Met. Authority
34	362011	1938991	5	3.3	10	94	1	BELIZE	Belize	National Met. Authority
35	271044	1515550	615	3.4	10	61	90	ILOPANGO/S.SALVADOR	El Salvador	National Met. Authority
36	404372	1474131	95	3.3	10	83	92	LAUNION	El Salvador	National Met. Authority
37	428508	1468195	5	2.9	10	94	4	AMAPALA/LOSPELONAS	Honduras	National Met. Authority
38	549886	1804058	5	4.9	10	94	4	ROATAN	Honduras	National Met. Authority
39	514249	1739406	3	2.4	10	61	90	LACEIBA/GOLOSON	Honduras	National Met. Authority
40	448250	1737691	3	2.3	10	61	90	TELA	Honduras	National Met. Authority
41	488183	1676026	670	1.7	10	94	4	YORO	Honduras	National Met. Authority
42	399905	1708316	31	2.4	10	61	90	LAMESA/PEDROSULA	Honduras	National Met. Authority
43	843830	1684850	13	3.2	10	94	4	PUERTOLEMPIRA	Honduras	National Met. Authority
44	306265	1635102	1079	2	10	94	4	SANTAROSADECOPAN	Honduras	National Met. Authority
45	621907	1640164	442	2.2	10	94	4	CATACAMAS	Honduras	National Met. Authority
46	434234	1589840	626	4.2	10	94	4	SOTOCANOAB	Honduras	National Met. Authority
47	374904	1584537	1100	3.3	10	94	4	LAESPERANZA	Honduras	National Met. Authority
48	476571	1553267	994	3.2	10	94	4	TEGUCIGALPA/TONCONT	Honduras	National Met. Authority
49	480179	1470319	48	3	10	61	90	CHOLUTECA	Honduras	National Met. Authority
50	933227	1108009	4	2.6	10	61	90	LIMONINTLAIRPORT	Costa Rica	National Met. Authority

51	737571	1102542	3	1.5	10	61	90	PUNTARENAS	Costa Rica	National Met. Authority
52	743375	1104019	2	2	10	94	4	CHACARITA	Costa Rica	National Met. Authority
53	805118	1106700	931	4.4	10	94	4	SANJOSE/SANTAMARIA	Costa Rica	National Met. Authority
54	812517	1101228	994	5.2	10	94	4	TOBIAS BOLANOS	Costa Rica	National Met. Authority
55	658629	1172121	93	4.6	10	94	4	LIBERIA/TOMAS	Costa Rica	National Met. Authority
56	1074579	1396805	1	3.9	10	94	4	SANANDRESISLAND	Colombia	National Met. Authority

17.5 Annex 5 – Wind interpolation software and model

17.5.1 Introduction

In this Annex the wind interpolation model is described. This text gives an overview of the interpolation software as well as the techniques used.

17.5.2 Software

The interpolation is done with IDL software. An executable file (**nica_windmap.sav**) has been produced, which allows executing the interpolation also without IDL run-time environment. The freeware IDL Virtual Machine is needed to run this sav-file. The Virtual Machine is downloadable from http://www.rsinc.com/idlvm/

Input data

All needed input data sets for the mapping are listed here:

- c:/temp/cmdlineinfo.ini: path for application is defined there
- nica_data.txt: Wind data at measurement stations
- roughness.bin: Roughness 250 m grid
- dem250c: Digital elevation model 250 m grid
- nica_slope: slope angle 250 m grid

The file nica_data.txt contains the list of all measurements. It includes number, WMO number, coordinates, altitude, mean annual long term wind speed, height above ground of measurement, measurement period and name. New stations can be appended. Only long term measurements should be added

Area

UTM Zone 16P is used.

The main area includes:

- Latitude minimum = 1134125
- Latitude maximum = 1734125
- Longitude minimum = 386875
- Longitude maximum = 960875
- Grid space: 250 m; number of points: 2296 x 2400

To include more stations in the surrounding and give a better result at the edges the area has been extended by 100 km at each side. This area is used for the horizontal kriging interpolation at sea level. After this interpolation the area is cut to the main area for further corrections.

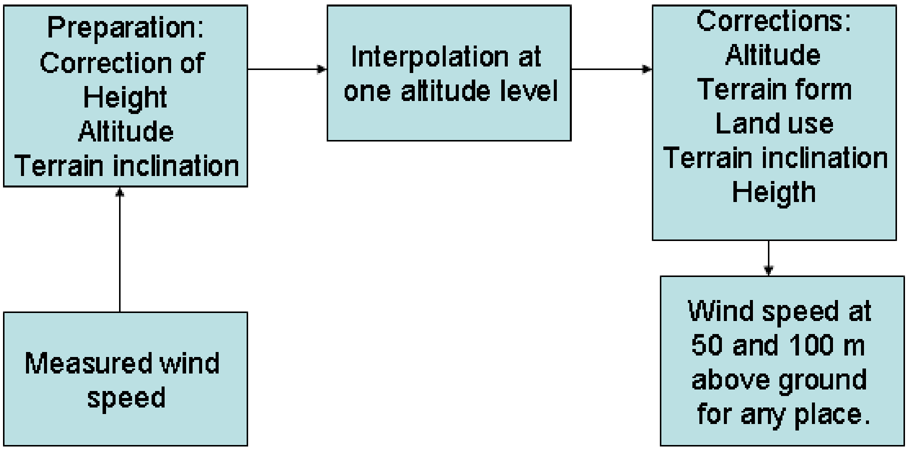
Installation

- Install IDL VM 6.1 (setup)
- Copy all data to an installation directory on the hard disc
- Copy cmdlineinfo.ini to the directory c:\temp\
- Change the path in the cmdlineinfo.ini to the chosen installation directory
- Doubleclick on the nica_windmap.sav to run the interpolation

17.5.3 Method

The spatial interpolation is made with the help of the altitude gradient and Kriging interpolation method.

The following three steps are made: Preparation, Kriging interpolation and correction.



Preparation

Calculation to 100 m above ground with help of roughness length map.

- Lowest value = factor 1.259
- Used for sea and mountain top as well as stations 999001 (El Crucero) and 999003 (El Sauce).
- Eqn. Heigth factor = ln(100/z0) / ln(10/z0)   z0 = roughness length [m]
- Eqn. FF_{100} = FF_{10} * Heigth factor FF_{100} must be at least 2.0 m/s (values lower than this are set to this threshold).

Correction of the altitude gradient and calculation to 0 m.a.s.l.

- Linear Regression between altitude (above 30 m) and wind speed.
- If r^2 value > 0.2 then the altitude is corrected to 0 m.a.s.l.
- Normally the gradient is about 0.6-1.5 m/s km

Correction of the slopes: FF_{100} = FF_{100} + 0.011*slope angle [°] (slopes have less wind speed).

Kriging Interpolation

An exponential form of the semi-variogram is assumed. Search distance (range) = 100 km, error at measurement points (nugget) = 1.0 m/s. No stretching and rotation is made. Calculation of a 230x250 grid and transformation (with cubic spline) to the original 250 m grid.

Corrections

The operations performed in the preparation step before Kriging interpolation are reversed in the corrections step. Now the operations are performed for the whole grid instead of only the measurement locations. A slope correction factor of -0.011 is again applied. The altitude correction is reversed.

Corrections based on the DEM

Five correction terms, based on the digital elevation model are added to the interpolated wind speed.

$$v_c = v + c_{rc} + c_{bv} + c_{sv} + c_{flat} + c_{sea}$$

v = wind speed after Kriging interpolation, with slope and altitude correction

v_c = corrected wind speed

The values of the corrections have been found making the Swiss map (chap. 3.3).

Five corrections are performed based on analysis of the digital elevation model:

1. Corrections for ridges and canyons (less wind speed in canyons, more on ridges):
   - Smoothing of the DEM with 11 grid points (approx. 2.5 km)
   - Calculation of the differences DEM – smoothed DEM (dZ_{11})
   - In a previous analysis the following relationships were found:
     - for dz_{11} > 20 m: c_{rc} = (dz_{11}-20)*(0.01)
     - for dz_{11} < -20 m: c_{rc} = (dZ_{11}+20)*(0.01)
     - $-1.5 < c_{rc} < 1.5$
   - Addition of c_{rc} to the interpolated field

2. Corrections for big valleys (enhanced wind speed at valley grounds):
   - Smoothing of the DEM with 41 and 161 grid points (approx. 10 and 40 km)
   - Calculation of the differences smoothed DEM 41 – smoothed DEM 161 (*dZ41_161*)

- In a previous analysis the following relationship was found:
  - c_{bv} = (0.7+ $dZ41\_161$ * 0.0025)
  - 0 < c_{bv} < 1.2
- Addition of c_{bv} to the interpolated field

3. Corrections for valleys (less wind speed in narrow valleys):
   - Smoothing of the DEM with 4 and 41 grid points (approx. 1 and 10 km)
   - Calculation of the differences DEM 4 – smoothed DEM 41 ($dZ4\_41$)
   - In a previous analysis the following relationship was found:
     - Eqn.: $dZ4\_41$< -20 m: c_{sv} = ($dZ4\_41$+20)*(0.01)
     - -1.2 < c_{sv} < 0.0
   - Addition of c_{sv} to the interpolated field
4. Corrections for flat areas (more wind speed in flat areas):
   - The whole grid is checked for areas with no changes in altitude. These areas are marked and a wind speed of 0.5 m/s is added.
5. Corrections for offshore areas (more wind speed at sea):
   - At sea level an extra wind speed of 1.0 m/s is added (c_{sea}, correction for offshore areas).

<u>Corrections due to roughness</u>

At 100 m above ground it is assumed that the roughness at ground does not influence the wind speed any more.

In contrast the roughness (z0) is very important when calculating the wind speed at 50 m above ground.

The following equation is used to do this:

$FF_{50} = FF_{100}$ *(1-0.5*(1-ln(50/z0)) / ln(100./z0)))

For z0 = 0: $FF_{50} = FF_{100}$ * 0.851 was assumed. At ridges the wind speed at 50 m was lowered only by half of the value, which was calculated due to z0.

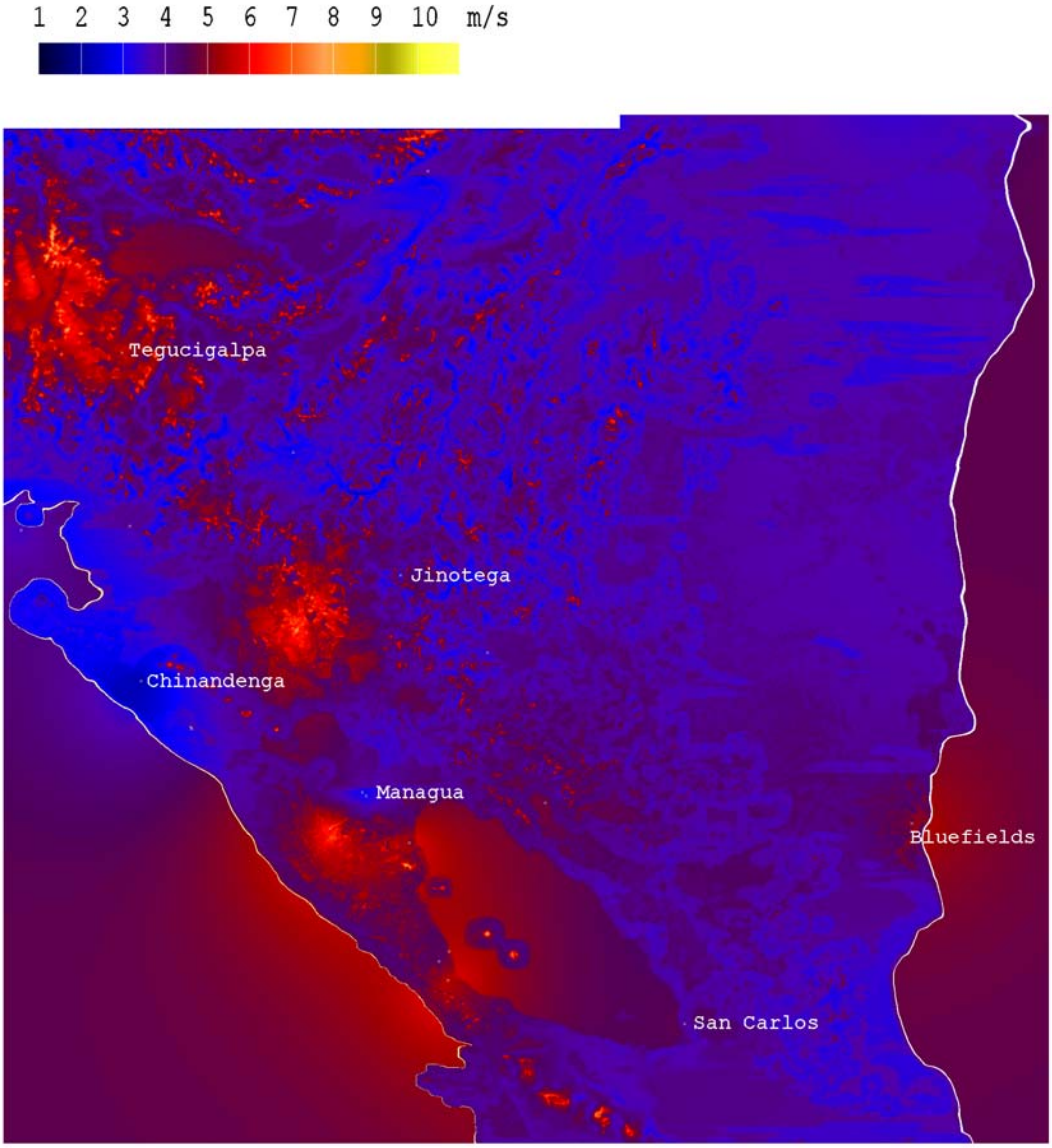
The wind speed at 50 m was set to a minimum of 1.0 m/s, the wind speed at 100 m to 1.2 m/s.

<u>Corrections of the results</u>

The deviation at the input stations is measured. If there is is a linear relationship with r^2 bigger than 0.9 then the grids are corrected.

17.5.4 Results

The results of the interpolation are maps at 50 and at 100 m classified and non-classified (4 maps) as well as Arc/Info Gridascii formatted output files with wind speed at 50 and 100 m in dm/s.



At 50 m above ground the wind speed varies between 1.0 and 8.4 m/s at 100 m between 1.2 and 9.0 m/s. The standard deviation at the measurement points is 0.9 m/s. The accuracy is about 1.5 m/s.

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