Weather Forecasts
Renewable Energies
Air and Climate
Environmental IT

Genossenschaft METEOTEST
Fabrikstrasse 14, CH-3012 Bern
Tel. +41 (0)31 307 26 26
Fax +41 (0)31 307 26 10
office@meteotest.ch, www.meteotest.ch

Bern, January 21, 2010

Wind Park Feasibility Study for El Crucero, Nicaragua

Summary Report

Client:

REPIC
NET Nowak Energie & Technologie AG
Waldweg 8
1717 Ursern
Switzerland

Authors:

Beat Schaffner, *METEOTEST*
Sara Koller, *METEOTEST*
Tim Coone, ENCO Centroamerica SA
Ilkka Rissanen, Pöyry
Paula Kohvakka, Pöyry
Jarkko Vainamo, WinWinD

Contents

Summary

This report summarizes the results of a comprehensive wind power feasibility study which was carried out for the El Crucero region, located 30 km to the south of Managua in Nicaragua. The feasibility study was carried out by a consortium including the companies Meteotest (Switzerland), ENCO AG (Switzerland), ENCO Centroamérica SA (Nicaragua), Pöyry Energy Oy (Finland) and WinWinD Oy (Finland) in 2008–2009.

The study proved the feasibility of a wind power project in the El Crucero region from the administrative, meteorological, technical, financial as well as environmental points of view. The study will deliver major input for the next step – detailed planning for the installation of a pilot wind park at El Crucero.

Detailed assessments were carried out in the following fields:

- The **institutional, administrative and legal framework** for installing wind power in Nicaragua was examined and key factors to be taken into account for a wind power project were identified (Chapter 2).
- A **wind resource** assessment confirmed a very high wind power potential and resulted in a detailed wind resource map of the El Crucero region which served as the basis for **production calculations** (Chapter 3).
- Solutions for the integration of wind power into the **local grid** were analyzed (Chapter 4).
- The possibilities for wind turbine **transportation** and wind **park layouts** were analyzed (Chapters 5 and 6).
- **Technical wind turbine solutions** were engineered in order to meet the special meteorological conditions at the site (Chapter 7).
- **Financial modelling** showed possibilities for wind park financing and determined the most sensitive parameters (Chapter 8).
- **Environmental** studies including noise and shadow impact assessments as well as a study on flora and fauna identified restraints to be taken into account (Chapter 9).

1 Introduction

From October 2003 to July 2005, a Swiss-Nicaraguan consortium carried out the first detailed wind map study of Nicaragua with backing from the Swiss government (REPIC). Based on the resulting wind map, the El Crucero region was identified as very promising with a wind power generating potential of 160 MW (out of a national total of some 760 MW) that can be swiftly developed as the site is well accessible. Wind measurements have been performed in the El Crucero region which indicate excellent mean wind speeds of approximately 9 m/s at hub height of large wind turbines. The El Crucero area thus has the potential to become one of the principal wind power generation sites in Central America.

The principal drawback of the El Crucero area is that it lies in the path of the volcanic gas emissions from the Masaya volcano, 20 km to the east, which produce high levels of acid rain. Solving the corrosion problems associated with these emissions will contribute to wind energy development throughout Central America, where a number of promising sites are similarly affected by volcanic emissions.

In April 2005, ENCO S.A. signed an agreement with the El Crucero municipal council, to assist the municipality in the development of the wind energy potential of this zone. The installation of large wind parks could provide a significant source of income in the future to the municipality.

In May 2008, a Partnership Agreement was signed between Meteotest, ENCO, Pöyry and WinWinD in order to carry out a feasibility study for a wind park at El Crucero. Sponsors for the study were found with REPIC[1] and ALIANZA[2]. Subsequently, work on the feasibility study was begun.

The feasibility study was finalized by the end of 2009. This document contains a summary of the results. Detailed results are contained in (unpublished) individual task reports.

---

[1] Interdepartmental Platform for Renewable Energy and Energy Efficiency Promotion in International Cooperation (REPIC): A platform by the Swiss government designed to be a market oriented service centre for the promotion of renewable energy and energy efficiency in international cooperation. Website: http://www.repic.ch.

[2] Energy and Environment Partnership with Central America: An initiative supported by Finland's Ministry for Foreign Affairs in coordination with the Central American Integration System (SICA) and the Central American Commission on Environment and Development (CCAD) with the objective to promote the renewable energies in the region, contributing to sustainable development and the mitigation of the global Climate Change. Website: http://www.sica.int/energia.

2 Institutional, administrative and legal framework

2.1 Electricity sector overview

2.1.1 The electrical power market in Nicaragua

Power generation has been growing at an average rate of 5.8% per year over the past 15 years, with petroleum imports growing at practically the same rate. In effect, fossil fuel imports are currently doubling every 12 years. Some 67% of electricity production comes from fossil fuel sources (see Figure 1).

Fuel imports comprise a major portion of the country's overall import bill, currently around 25% of the total, and consume almost 60% of annual export earnings.

Annual electricity demand is projected to triple from 3'000 GWh at present to more than 12'000 GWh per year over the next 25 years, due to growth in both the population and per capita income.

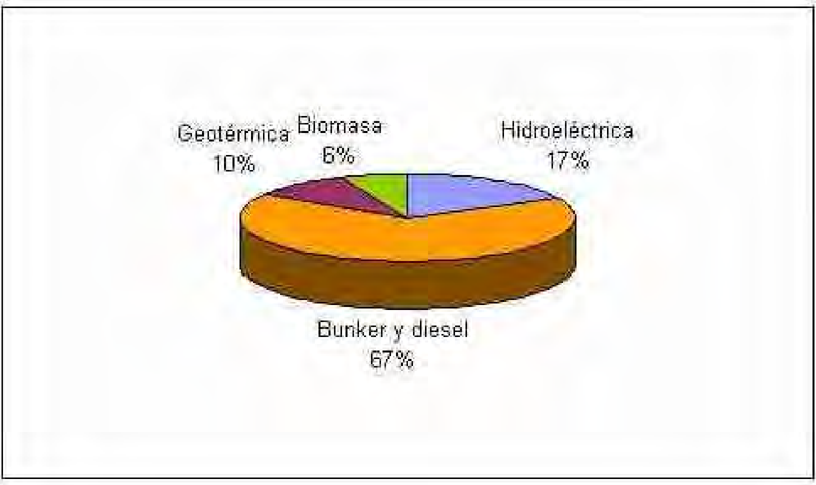

Figure 1: Power generation in Nicaragua by energy source, 2008 (Source: Ministry of Energy and Mines, Nicaragua).

Total generating capacity is almost 900 MW. Effective capacity at any moment however is less than 700 MW. Peak demand is currently in the region of 500 MW, base load around 280 MW (Figure 2).

Total losses from the system amount to a very high 30% of the total generated. This is due primarily to extensive power theft through unauthorised connections to the distribution lines. Losses in transmission lines are estimated at around 2.5% and normal technical losses in distribution lines are estimated at around 10–15%.

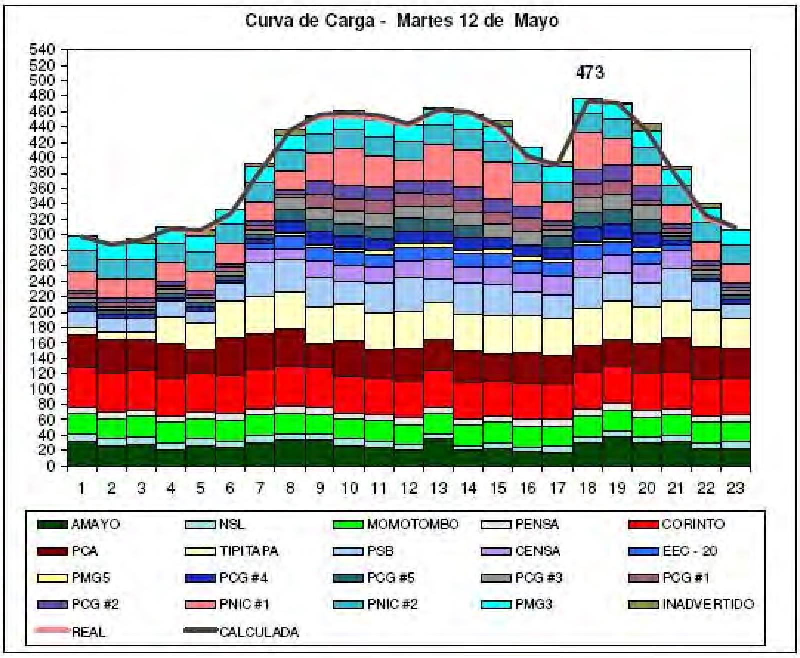

Figure 2: National Grid Load Curve (MW) 12th May 2009 (Source National Load Despatch Centre, Nicaragua).

2.1.2 Electrical power market development in the past 15 years

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.

Around 250 MW of generating capacity comes from obsolete plants that have been in operation for 30 years or more. These still provide more than 40% of the power to the grid but will be phased out over the coming 4 to 5 years.

Power transmission is operated by the government agency Entresa, which also runs the National Load Despatch Centre (CNDC). A new high voltage line known as SIEPAC (Interconnected Electricity System for Central America), to carry electricity for the Central American power market, is due to be completed in 2010.

Power distribution, involving the management and maintenance of all lines and transformers below 69 kV capacity, was privatised in 2000 and came under the control of the Spanish firm Union Fenosa, with minority Nicaraguan interests.

2.1.3 Supply and demand projections

Electricity demand forecasts made by the Ministry of Energy and Mines (MEM) predict that peak power demand will rise to around 1'200 MW over the next 12–13 years, with total energy demand rising to 7'800 GWh per year. Over this period, an increase in generating capacity of more than 100% will be required.

The government is giving priority to the development of renewable energy supplies, and will require sustained levels of new investment averaging some US$ 100–120 million per year over this period. Of some 1'120 MW planned to come on-line between 2007 and 2014, 300 MW will be from fossil-fuel plants, the remainder from renewables.

2.2 Legal framework

Nicaragua‘s electricity sector is regulated by a series of laws, decrees and regulations which are quite extensive and detailed. Full texts can be found on the websites of the Ministry of Energy (MEM, www.mem.gob.ni) and/or the National Assembly (www.asamblea.gob.ni)

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

- Law 127: Foreign Investment Law (1991)
- Law 217: General Law of the Environment and Natural Resources (1996)
- Law 261: Municipalities Law (1997) (incorporating Law 40 of 1988)
- Law 272: The Electrical Industry Law (1998)
- Law 532: Promotion of Electricity Generation from Renewable Resources (2005)
- Law 554: Law of Energy Stability (2005)

Relevant decrees in chronological order are:

- Decree 24-1998: General Regulation of the Electrical Industry Law
- Decree 128-1999: Reform to decree 24-98
- Decree 12-2004: Specific Policy for Support of Development of Wind and Run-of-River Hydroelectric Resources (derogated by Law 532)
- Decree 13-2004: Creation of National Energy Policy
- Decree 41-2005: Reform to decree 42-98

2.2.1 Legislation for the wind sector

Electric power generated from wind is not subject to specific legislation other than that contained in Law 532: Promotion of Electricity Generation from Renewable Resources.

Developers interested in developing wind farm sites require a provisional licence from MEM. Exclusivity is not presently given to any particular site.

Any wind generation project greater than 1 MW requires a generation licence from MEM to be connected to the grid. Any new wind projects must demonstrate that the additional capacity will not create load management problems or instability in the network.

2.2.2 Incentives

The incentives available to generators of renewable-sourced power, under various pieces of legislation, have been consolidated under the Promotion of Electricity Generation from Renewable Resources Law 532.

2.3 Procedures to obtain a license or concession

2.3.1 Company formation and registration

Company formation is the first step for any project and is usually as a limited private company. The principal city of each department in Nicaragua maintains a public registry where a company must inscribe its books and a copy of its legal statutes.

2.3.2 Environmental Permit

Any power generation project with a capacity greater than 5 MW must conduct an environmental impact assessment (EIA). The application is made directly through the Environmental Quality Office at Marena. Once completed Marena has up to 120 days to approve or reject the study.

2.3.3 Provisional and Generation Licences

Provisional and generation licences are issued by MEM. Provisional licences are issued for up to two years. Once the exploration phase is complete, the developer can then opt for a generation licence. The generation licence will be awarded on the basis of the technical, financial and economic merits of the proposal.

2.3.4 Electricity Market Permit

The final step for a power generator to participate in the wholesale electricity market, is to obtain a permit from the National Load Despatch Centre (CNDC).

2.4 The wholesale electricity market

2.4.1 The contract and spot markets

There are two products traded in the wholesale electricity market: power and energy. They are traded under contract or in the spot market. Currently 80% must be traded under contract. Prices agreed in the contract market are private and their details are not publicly available. Spot market prices however are determined through the process of load despatch and are published monthly by the CNDC.

The spot market and load despatch

The CNDC is the body charged with assigning loads and generating capacity for each generator on an hour-to-hour, daily and seasonal basis, and is obliged to do so with the aim of keeping the overall energy cost to a minimum. The CNDC has no obligation to organise load despatch according to these contracts – only according to the overriding requirement to minimise costs and to maintain power quality and availability.

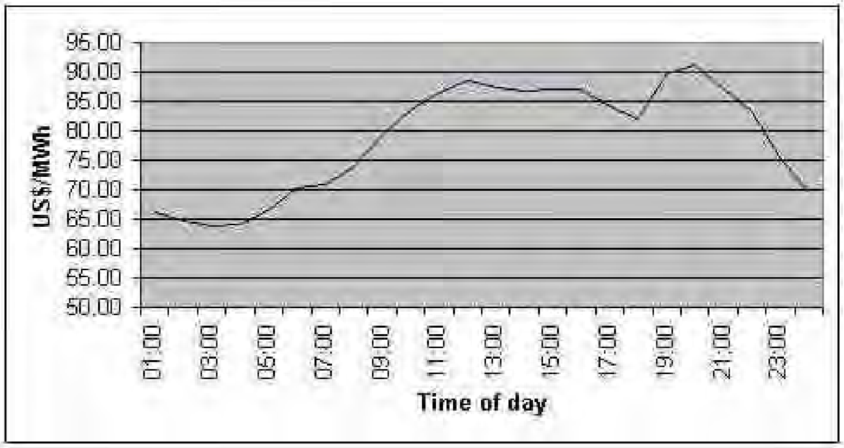

Figure 3: Energy prices in the spot market, March 2009 (Source: CNDC).

2.4.2 Auxiliary services

Additional payments and charges are made for auxiliary services or system losses. These include transmission losses, connection losses, black start, rolling reserve, and cold reserve.

2.5 The regional electricity market

A regional electricity market will become a reality in 2010 with the completion of the new 230 kV SIEPAC (Sistema Interconectada de Electricidad Para América Central) transmission of 300 MW capacity. The regional market consists of 35 million people and has a generating capacity of 7'000 MW, an annual energy demand of 40'000 GWh and is growing at some 6% per annum. The line will be expanded to 600 MW capacity at a second stage.

Figure 4: Nodes in the Central American SIEPAC line.

Once fully operational, import or export contracts in the regional market will be treated on an equal footing with contracts made locally between market agents, and the CNDC must not discriminate between them.

2.5.1 Wind energy in Nicaragua

A wind mapping project published in 2005, by the Swiss energy consulting consortium ENCO/Meteotest, identified the most favourable sites in the country. The map can be found at www.encocentam.com

There is an estimated potential of 760 MW with good road and grid access, and other high potential areas which are currently less accessible, could add a further 2'000 MW.

Nicaragua's first wind farm (40 MW) was inaugurated at the beginning of 2009 and in May was generating some 700 MWh daily. A second phase, adding 23 MW, was authorised in November 2009.

Currently, there are a total of five wind farm projects at different stages of development, representing a total capacity of almost 300 MW. Most of these new projects will have to wait the coming on-line of the SIEPAC project and the creation of the regional electricity market, for them to be integrated into this larger regional grid.

Otherwise, grid stability problems would be likely to occur due to the high wind penetration rate that all these additional projects would represent for the Nicaraguan grid alone.

2.6 Tariffs and prices in the electricity market

The tariff regime is classified into two categories: unregulated and regulated. The unregulated regime covers electricity transactions in the wholesale market while the regulated regime covers transactions in the retail market (distribution) and wheeling charges for use of the transmission and distribution networks. The regulated tariff schedule is revised and published on a monthly basis.

Spot market prices for renewable energy are currently restricted to the US$ 83 to US$ 85 per MWh range. This range is subject to periodic review by INE.

2.7 Institutions in the electricity market

Regulation, supervision and management of the electricity market come under the control of the executive branch of government, through the Ministry of Energy and Mines (MEM). Three other line ministries also have regulatory functions that impinge on the electricity sector, namely the Environment and Natural Resources Ministry (Marena); the Development, Industry and Trade Ministry (MIFIC) and the Finance and Public Credit Ministry (MHCP). The Nicaraguan Energy Institute (INE) and Enatrel, the grid operator, also have regulatory functions.

3 Wind assessment

3.1 Wind measurements

3.1.1 Measurement sites

Wind measurements have been carried out at three sites in the El Crucero region. Figure 5 shows the location of the project area in Nicaragua and the position of the 60 m measurement masts.

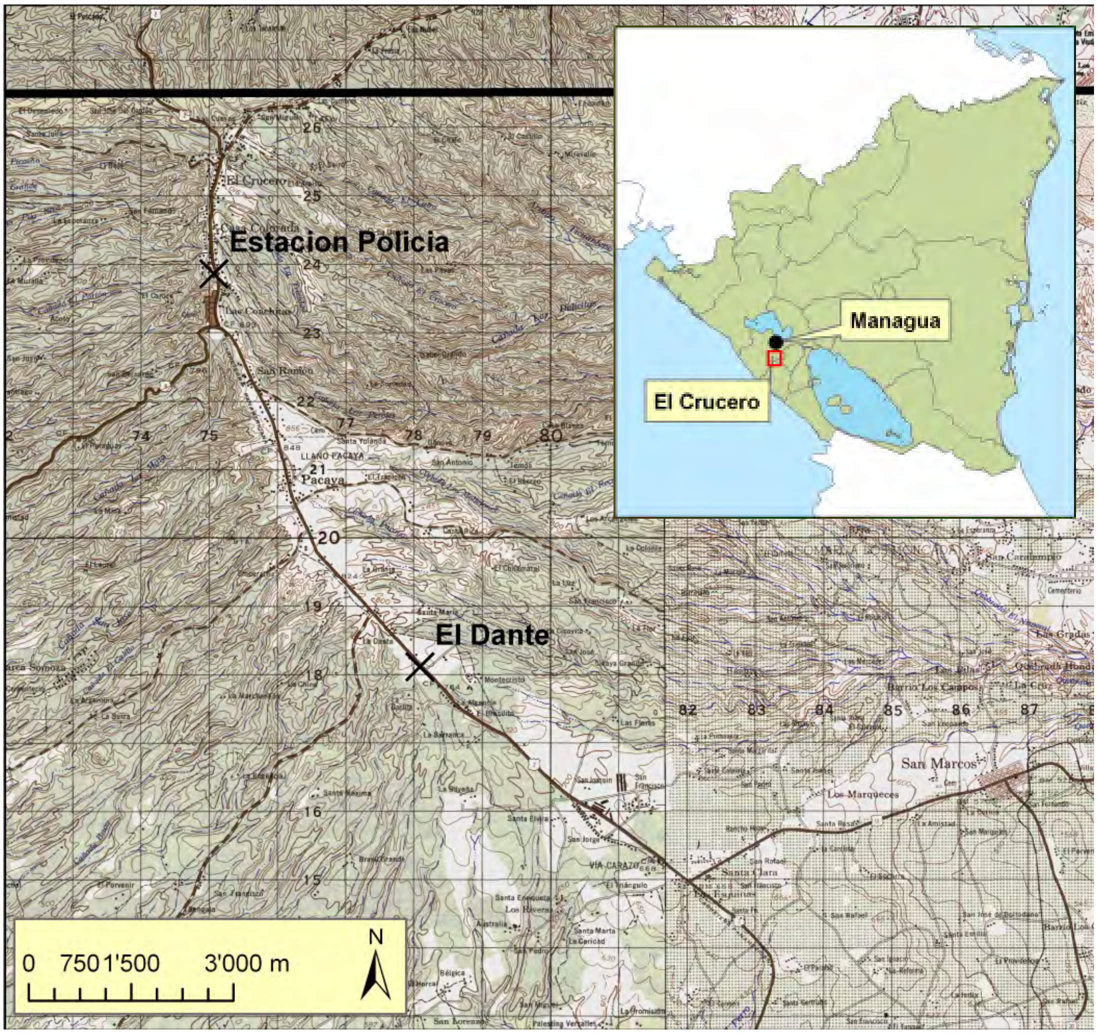

Figure 5: Location of measurement masts in the El Crucero region.

While the measurement masts at Estacion Policia and El Dante have been installed specifically for this study, the measurements at Radio Primerissima commenced in

2003 as part of a detailed wind map study carried out from 2003 to 2005 by a Swiss-Nicaraguan consortium with backing from the Swiss government (REPIC) [3].

3.1.2 Measurement equipment

All instruments at Estacion Policia and El Dante are of the make NRG and are mounted on a 60 m tall cell phone communication tower operated by Enitel. The top anemometer is mounted on a vertical pole support at the very top of the tower. The other anemometers are mounted on 2 m long side booms, perpendicular to the prevailing east-north-east wind. 10-minute mean values, gusts and standard deviations are recorded on a NRG 9200-Plus data logger.

The two instruments at Radio Primerissima are of the make NRG and are mounted on a 48 m tall radio transmitter tower, 6 m below the closest radio antenna. They are mounted on 2 m long side-booms, perpendicular to the prevailing east-north-east wind. 10-minute mean values, gusts and standard deviations are recorded on a NRG WindExplorer data logger.

All sites are exposed to highly corrosive conditions, due to emissions from a volcano situated around 20 km upwind in the direction of the prevailing winds. By the end of the measurement campaign, the exposed metal parts of the wind vanes showed superficial signs of corrosion, and the black plastic surfaces of the anemometers and the wind vanes had suffered a certain degree of bleaching or whitening, as a result of their exposure to the harsh acid rain conditions.

3.2 Measurement results

A reference period of 01.07.2008–31.06.2009 was chosen. After the data cleansing procedure, clean datasets with almost complete data series (availability of more than 98%) resulted for each site. These clean data sets were used as the basis for all further data analysis. The Radio Primerissima data is only used for long term comparison and not as an input climatology for modelling.

The measurements confirmed very favourable wind speeds with an average of more than 9 m/s. The general prevailing wind direction is east to north-east (60 to 90°) for the measurement sites. Especially strong winds occur solely from this prevailing direction. Figure 6 shows the wind rose for the measurement site El Dante.

Wind measurement data was correlated to Nicaraguan meteorological stations as well as NCAR/NCEP reanalysis data, resulting in long term wind statistics at the measurement site.

---

[3] Development of local knowledge for the implementation of renewable energy production sites by means of “GIS-tools” in Central America – Final report, ENCO, 03.08.2005.

Air density as well as wind turbine classes were calculated based on measurements.

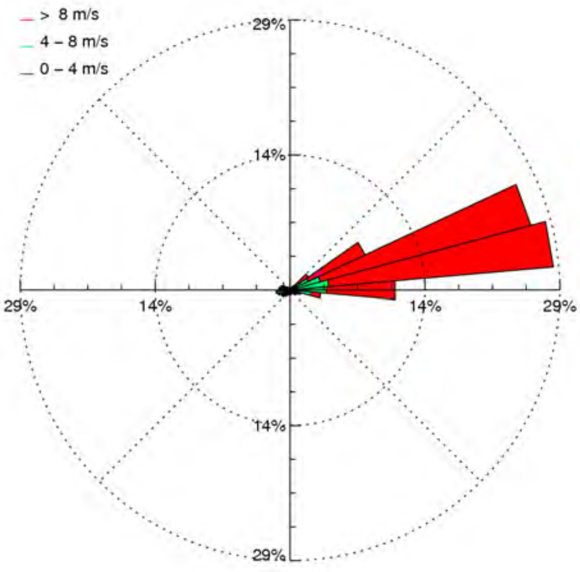

Figure 6: Wind rose recorded at the measurement site El Dante.

3.3 Wind modelling

Wind resource modelling was performed with the Computational Fluid Dynamics (CFD) software WindSim[4]. The following steps were carried out:

1. In order to include large-scale effects of topography, three-dimensional wind fields are calculated for a large area (main model) of 40 x 40 km for 12 wind direction sectors (30 ° steps).
2. The results are used as boundary conditions to calculate three-dimensional wind fields for the project area (nested model) of 15 x 16 km.
3. Subsequently, the long term wind statistics calculated are introduced into the model.

As a modelling result, long-term wind statistics are obtained for each grid point in the modelling area.

For the modelling the Shuttle Radar Topography Mission[5] (SRTM) digital elevation model with a horizontal grid resolution of approx. 90 m was converted to a regular grid with 100 m horizontal resolution.

---

[4] WindSim Version 4.8.1 http://www.windsim.com

For the main model area, roughness was based on a national land use dataset of Nicaragua. For the nested model area, land use data was digitized from orthophotos and converted to roughness.

Figure 7 shows the extension of the main model area and the nested model.

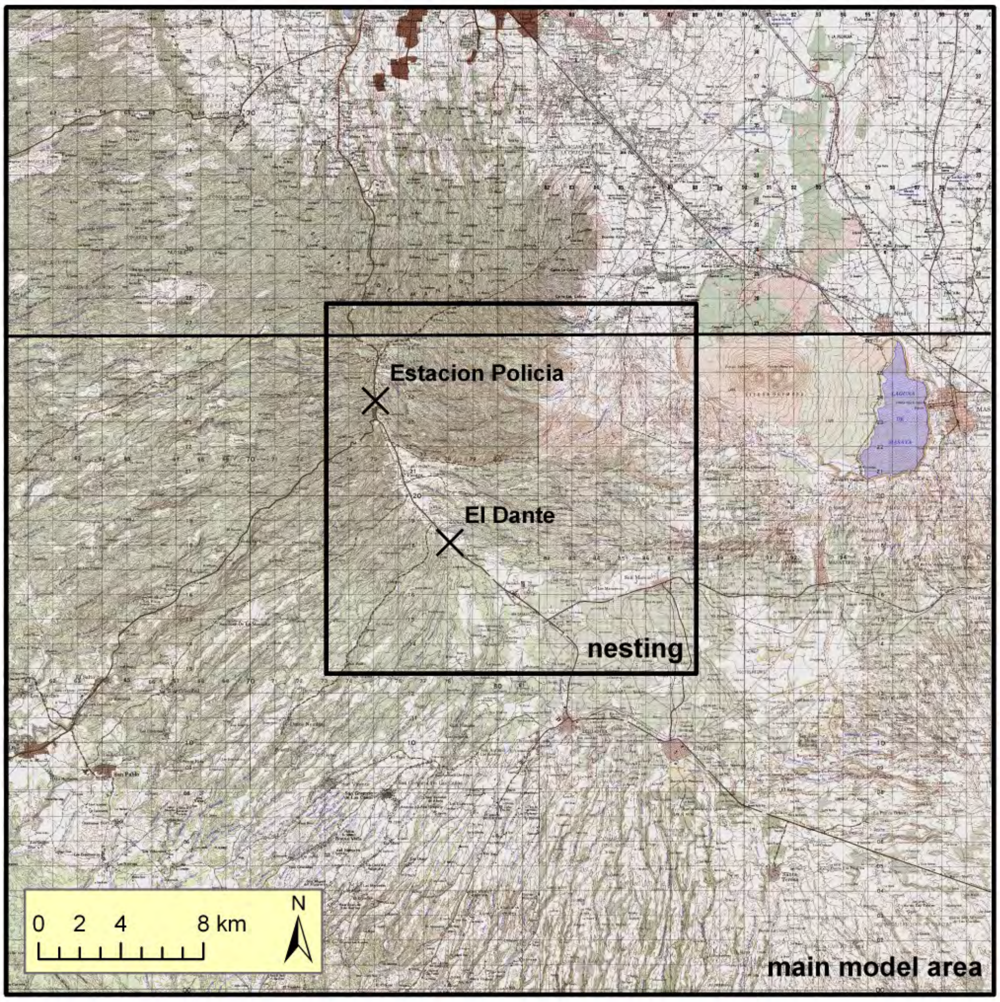

Figure 7: Overview of the two model areas.

3.4 Validation of results

An overall uncertainty of roughly 12% of the modelled wind speeds was calculated from the uncertainties and errors of the mast measurements, the long term wind calculation as well as modelling uncertainty.

In order to validate the modelling results, the climatologies measured at Estacion Policia were transferred to El Dante and vice-versa based on the modelled wind

---

[5] Shuttle Radar Topography Mission: http://www2.jpl.nasa.gov/srtm/

fields. The resulting mean wind speeds deviated by between 5% and 10%, which lies within the assumed modelling uncertainty.

3.5 Energy yield

The wind turbine type chosen for the energy yield calculations is a WinWinD WWD-1 turbine with an installed capacity of 1'020 kW, a rotor length of 56 m and a hub height of 70 m which is adapted to local atmospheric conditions (see Chapter 7).

For the two determined wind park configurations (a pilot wind park of 6 MW and a wind park extension of 20 MW, see Chapter 5), energy yield calculations were performed on the basis of the modelled long term wind conditions at the hub height of each wind turbine location and the wind turbine's power curve. Mean local air density as well as park effects (influence of the turbines on each other) were taken into account.

Based on the validation of wind modelling (Chapter 3.4), uncertainties were determined for the calculated energy yield. Based on the determined uncertainty, energy yield was put in function of the probability of exceedance.

4 Local grid and power demand study

This study considers the connection of a 5 MW pilot wind farm, and the planned extension of a 20 MW wind farm to the grid and the new grid infrastructure needed.

In calculations for this study, the WinWinD WWD-1 MW turbine with 56 m rotor diameter (IEC II) has been used. It is considered suitable for weak electricity grids.

Only steady state analyses, base on power flow calculation, short circuit calculation, and harmonics analysis, are conducted in this study to investigate potential system constraints on the interconnection of the proposed El Crucero wind farm. The study does not include transient and dynamic stability, detailed harmonic mitigation, electromagnetic transient program (EMTP) analysis, or other analytical calculation which normally form part of a comprehensive system study.

4.1 Local grid study concept

4.1.1 Local grid: El Crucero and Monte Fresco

The load profile in the areas of Monte Fresco and El Crucero is estimated to range between 1 MW (minimum) and 4 MW (maximum). The El Crucero 13.8 kV distribution system is connected via the Monte Fresco 5 MVA substation as shown in Figure 8.

The existing 13.8 kV distribution line between 5 MVA Monte Fresco substation and El Crucero area is equipped with AWG (1/0) cable type and the suitable PCC for wind power integration is located approximately 8.1 km from the Monte Fresco substation.

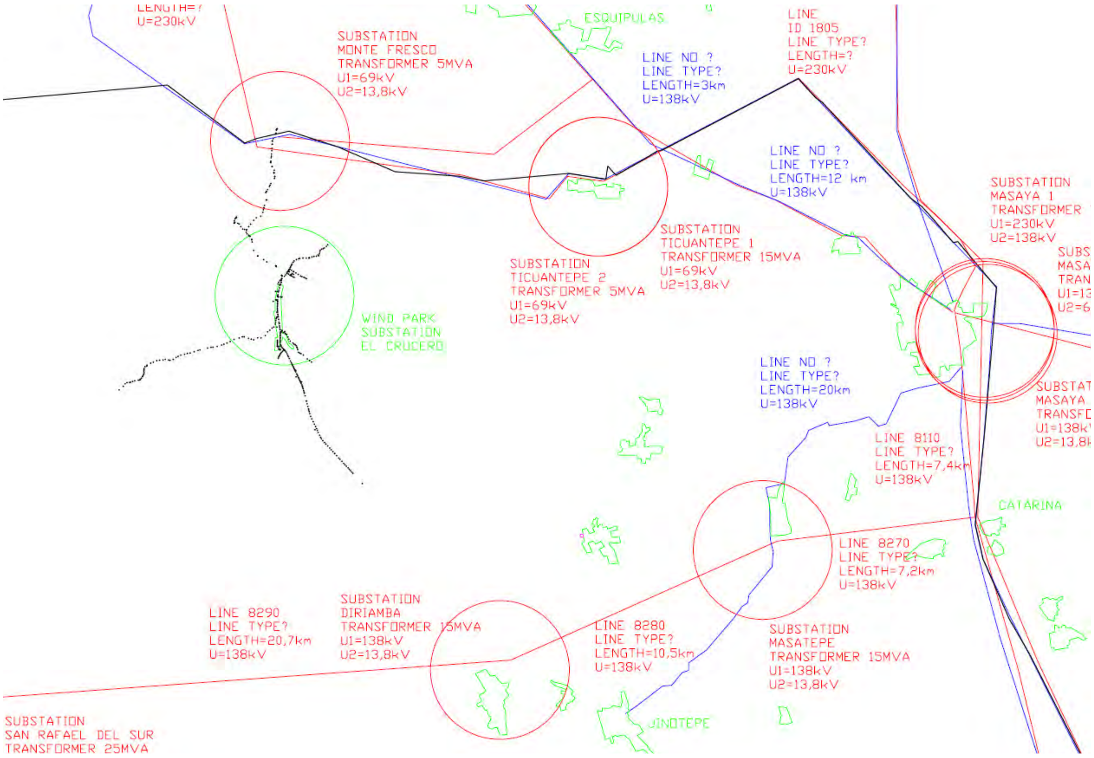

Figure 8: 13.8 kV connection between Monte Fresco substation and the El Crucero distribution system.

4.1.2 Future connection between El Crucero and Diriamba

A future connection between El Crucero and the Diriamba 15 MVA substation via a 138 kV transmission line can be foreseen. The El Crucero and Diriamba substations will be connected via a 138 kV transmission line, as shown in Figure 9.

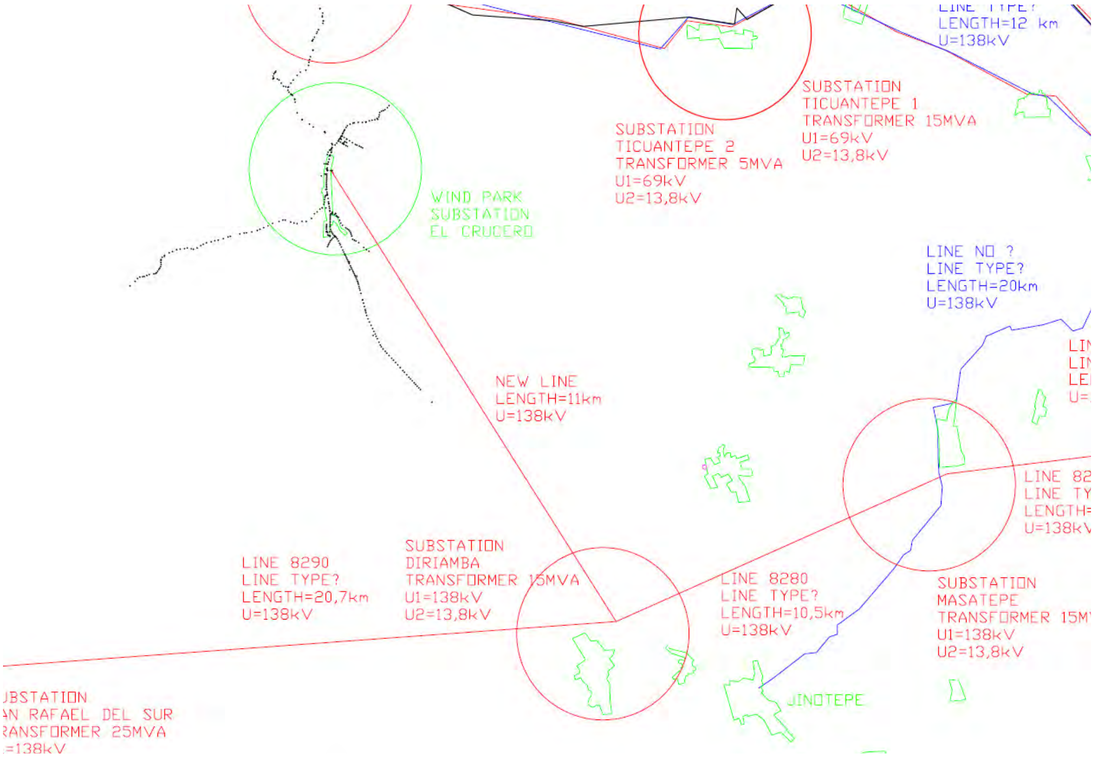

Figure 9: 138 kV Grid connection between El Crucero and Diriamba.

Load profile

The load profile in the area of El Crucero and Diriamba is estimated to range between 3 MW (minimum) and 11 MW (maximum). The upgrade of the Diriamba substation from 15 MVA to 25 MVA in 2010 is planned by ENTRESA.

El Crucero Substation

The suggested wind farm location in the El Crucero area is shown in Figure 10. A 138/13.8 kV substation with 6 MVA transformer should be installed in El Crucero for the future connection of a 138 kV transmission line between the El Crucero and Diriamba substations for a 5 MW wind farm interconnection. A 25 MVA transformer for the future substation with 138 kV transmission line is recommended for the expected increasing power demand and the integration of the expanded wind farm in the future.

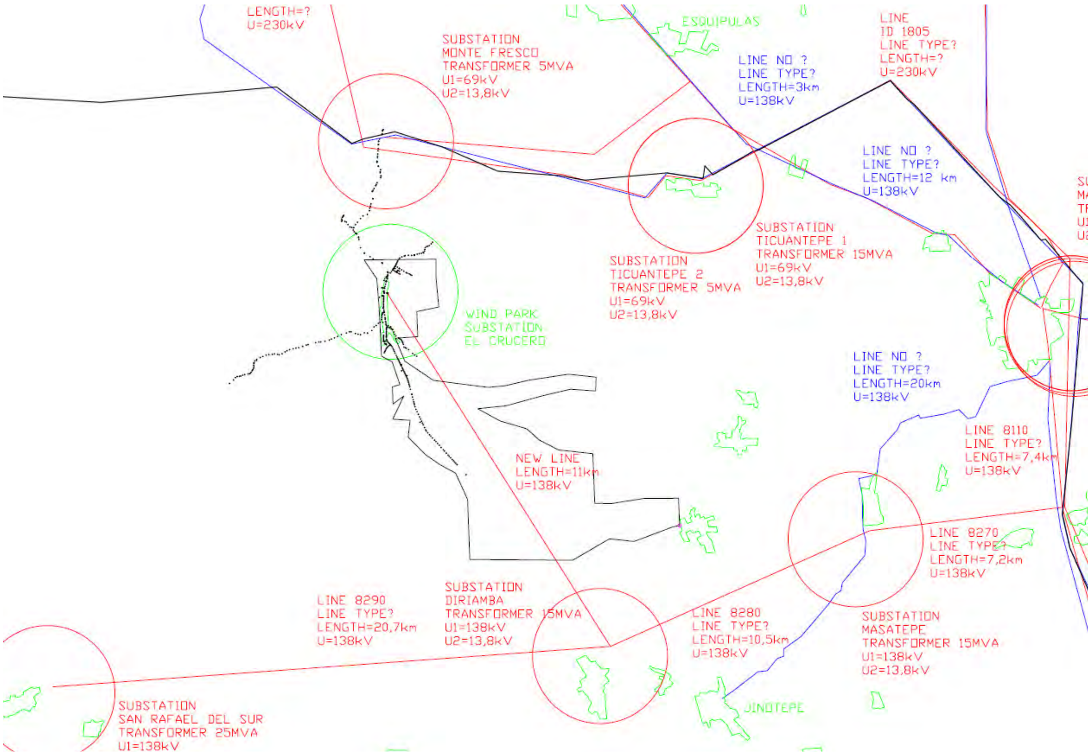

Figure 10: Wind farm connection from El Crucero to Diriamba substation and Layout for potential wind farm area (dark blue line).

4.2 Power system study

This part of the study includes load flow calculation, short circuit calculation, and harmonic analysis. The analysis is carried out based on the combination of low and high wind speed condition (i.e. zero and rated power generation from wind farm) with maximum load and minimum load conditions.

4.2.1 Assessment of local grid strength and stability in El Crucero

From the power flow calculation, the variation of voltage level is acceptable for the existing distribution system between Monte Fresco and El Crucero in maximum load conditions. However, the existing grid is too weak for the integration of a 5 MW wind farm under minimum load condition at nominal production generated from the wind farm (Figure 11).

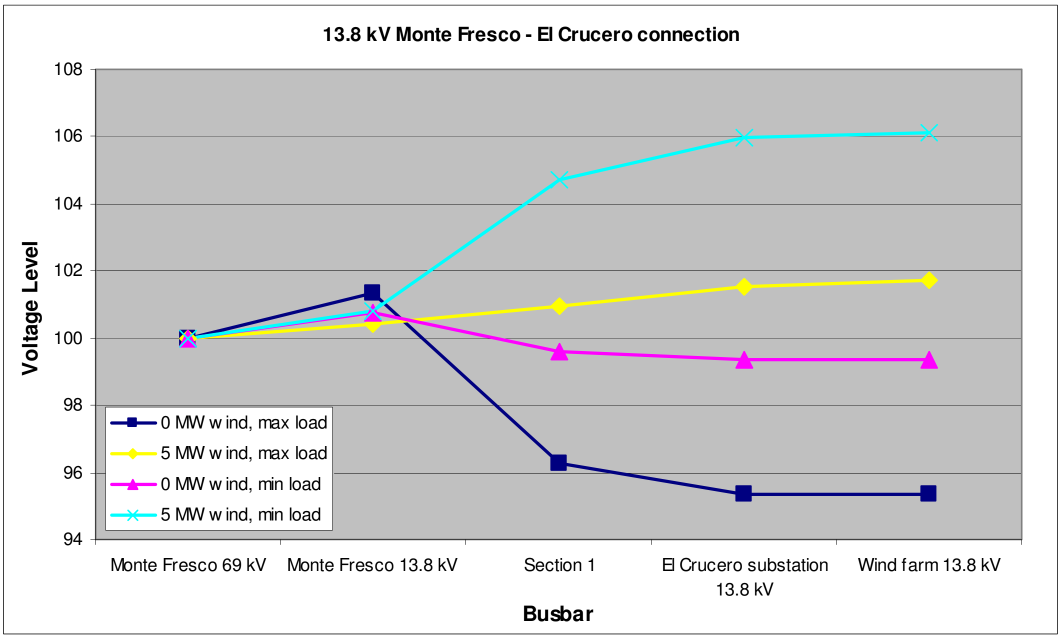

Figure 11: Voltage level on 13.8 kV El Crucero distribution system without/with 5 MW wind farm integration in maximum load and minimum load conditions.

There are several options available to increase wind energy contribution in weak grids. These include:

- Grid reinforcement
- Grid voltage controlled disconnection of wind turbines
- Grid voltage controlled wind power production
- Inclusion of energy buffer (storage)

4.2.2 Evaluation and analysis of future 138 kV line between El Crucero and Diriamba

In this analysis, a 6 MVA transformer for a future El Crucero substation with the interconnection of 138 kV transmission line is recommended for the increasing power demand and the integration of the wind farm in the future.

The assessment of voltage level in the combination of maximum/minimum load and with 5 MW wind farm is shown in Figure 12.

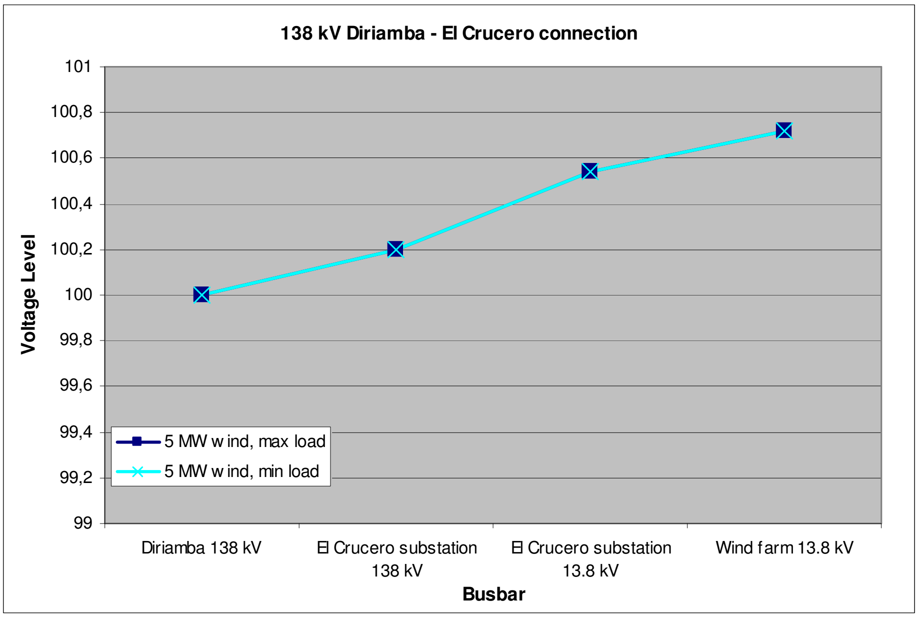

Figure 12: Voltage level on El Crucero system with the future 138 kV transmission line from El Crucero to Diriamba substation with 5 MW wind farm.

On the future 138 kV transmission line between the Diriamba and El Crucero substations, it can be seen that the variation of voltage level is also acceptable in both maximum load and minimum load conditions.

4.2.3 Evaluation and analysis of 20 MW wind farm

Evaluation of 20 MW wind farm – current load condition

For a 20 MW wind farm, a 25 MVA transformer for the future El Crucero substation with 138 kV transmission line is recommended for the increasing power demand and the integration of the wind farm in the future. The variation of voltage level is acceptable in both maximum and minimum load conditions, either with or without the integration of a 20 MW wind farm.

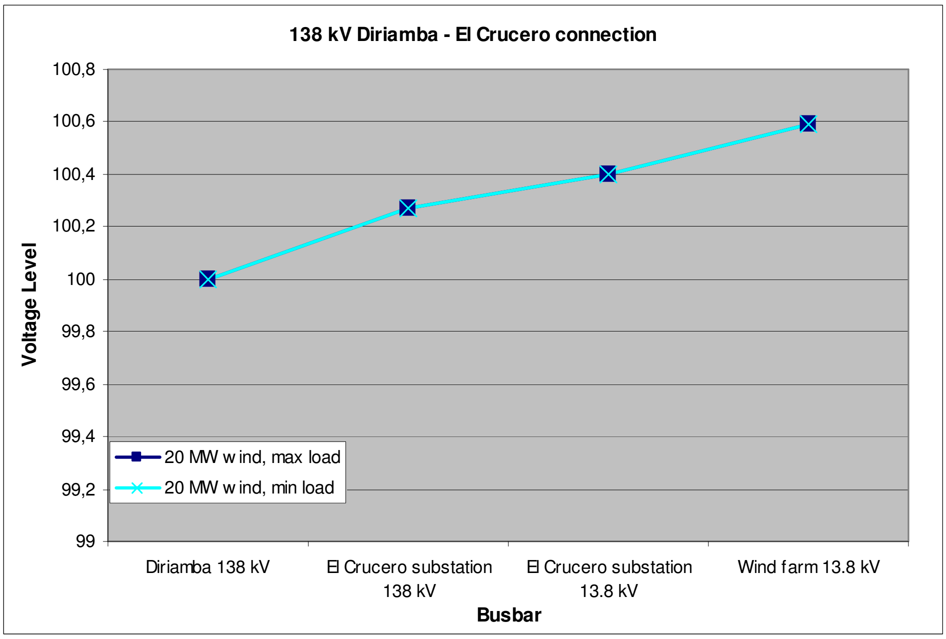

Figure 13: Voltage level on El Crucero system with 138 kV transmission to Diriamba substation with 20 MW wind farm.

The voltage level, current, cable voltage drop, active and reactive power balance, and loading percentage of main components are considered acceptable. The analysis indicates that under normal system conditions, the upgraded system is capable of delivering the wind farm maximum output based on the steady state consideration for all scenarios.

4.2.4 Short circuit calculation

The assessments of fault current for the connections from El Crucero with the 13.8 kV distribution line to Monte Fresco and from El Crucero with the 138 kV transmission line to Diriamba were carried out and three-phase fault current studies are conducted. The results of the fault current study based on maximum load condition of each scenario show acceptable fault levels at all concerned busbars. The integration of the wind farm will result in increasing of the system fault level.

4.2.5 Harmonics analysis

The power electronic converters of wind turbines cause harmonic disturbance to the grid. The modern wind turbine has IGBT rectifier converters in the turbine main circuit and the grid side current is typically filtered on the turbine low voltage side.

Simulations of El Crucero wind farm show that when using the existing connection from Monte Fresco, the voltage THD level is quite high at the wind farm connection point. The level is about 10–12% on the13.8 kV side with the 5 MW wind farm and with the minimum grid side loading.

In simulations with the new El Crucero substation (25 MVA) and a 20 MW wind farm, the voltage THD level is much lower, about 1.3–2.0% on the wind farm 13.8 kV side. The IEEE 519 gives a 5% limit for the voltage THD. The wind farm with the strong grid connection can fulfil this requirement.

4.2.6 Recommendations on local grid expansion for 50 MW wind farm

In order to accommodate the interconnection of a large scale wind farm in El Crucero, a major network upgrade is required. The grid expansion is recommended for the interconnection of a wind farm with the capacity larger than 20 MW at a later stage. The expansion of a large scale wind farm needs a strong grid connection, and it is recommended to be directly connected to the 138 kV grid.

4.3 Conclusions and recommendations

From the assessment of the existing 13.8 kV distribution system with power flow calculations, the variation of voltage level is acceptable for the existing distribution system between Monte Fresco and El Crucero in maximum load conditions. However, the existing grid is too weak for the integration of a 5 MW wind farm with minimum load condition at nominal production generated from wind farm.

Therefore, “grid reinforcement” and “grid voltage controlled wind power production” can be recommended to integrate a wind energy contribution in the existing grid. Grid reinforcement increases the capacity of the grid by increasing the cross section of the lines and cables or by upgrading the transformer size. This is usually done by erecting a new line parallel to the existing line for some part of the distance.

Another solution would be a new 138 kV transmission line from El Crucero to Diriamba and a new 138/13.8 kV substation. In order to accommodate the interconnection of a 20 MW wind farm in El Crucero, the major network upgrade is required.

On the future 138 kV transmission line between Diriamba and El Crucero substations, the variation of voltage level is acceptable in both maximum load and minimum load conditions, either with or without the integration of a 20 MW wind farm. A 25 MVA transformer for the future substation is recommended.

Based on the short circuit calculations, the results of the fault current study based on peak load condition of each scenario show acceptable fault levels at all concerned busbars. A cursory investigation of the increased fault level due to the integration of a 20 MW wind farm does not indicate that equipment rating on the system will be exceeded.

Simulations of the El Crucero wind farm show that when using the existing connection from Monte Fresco, the voltage THD level is quite high at the wind farm connection point. The level is about 10–12% on 13.8 kV side. This is a typical phenomenon in weak grids. In simulations with the new El Crucero substation (25 MVA) and with a 20 MW wind farm, the voltage THD level is much lower, under the IEEE limit of 5%.

For larger scale wind power integration up to 50 MW, local grid expansion is recommended. It can be foreseen that the upgrade for the transformer and the 138 kV transmission cable between El Crucero and Diriamba substations are necessary for the expansion of the large scale wind farm.

5 Installation possibilities and restraints

5.1 Transport and Logistics

The turbine components and towers that are being considered for this study, the WinWinD WWD-1 with a rotor diameter of 56 m and a hub height of 70 m, are manufactured in Finland. Their transport to Nicaragua will involve two principal segments: a maritime segment for the Finland to Nicaragua segment, and land borne for the port to wind park segment. Possible restrictions or limitations in the transportation infrastructure in Nicaragua are analysed in this section of the report.

Large wind turbines have components that are much larger than the dimensions of standardised containers used in sea and land transport, and so have to be shipped as project cargo on specialised ships - equipped with their own cranes.

A favourable precedent exists for the transportation and logistics of wind turbines in Nicaragua. In 2008 and early 2009, a total of nineteen 2.1 MW Suzlon S88 turbines were installed in the Rivas region of southern Nicaragua. They were unloaded at Nicaragua's Pacific Coast port of Corinto and transported along the main coastal highway passing the site being proposed for the current project in El Crucero.

The component sizes and dimensions of the WinWinD WWD-1 turbine are significantly less than those of the S88 turbine. The fact that the Amayo project has successfully transported its turbines and towers from Corinto to the project site in Rivas, signifies that the WinWinD turbines should not present any particular problems in being transported along the same route as far as El Crucero (Figure 14).

Nonetheless, for the sake of completeness a detailed analysis of the transport infrastructure and possible obstacles was carried out.

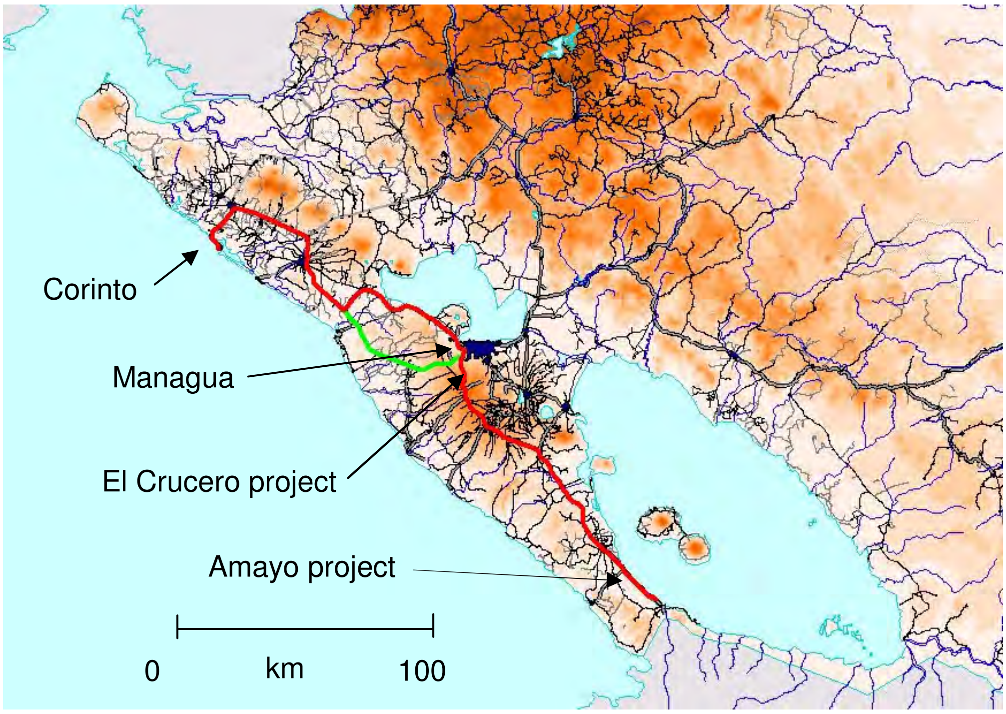

Figure 14: Land transportation route from Corinto port to project site.

5.1.1 Port facilities

Nicaragua's principal port is located at Corinto on its Pacific Coast. The port has a 45 ton portal container crane, that can handle container ships of up 2'400 TEU capacity approximately. The port does not have general cargo cranes of any significant size, but these could be hired locally. Ideally therefore, a project cargo ship with its own cranes should be used to discharge the turbine and tower components.

5.1.2 Road Transport

General

The port is linked to the capital Managua, by a 146 km two-lane asphalted road (expanded to four lanes in places) which was rebuilt to a high standard following hurricane Mitch in 1998 and has been maintained to this standard since. The distance from Managua to the wind farm sites is an additional 20 to 30 km. This section of highway has also been rebuilt and maintained to a high standard.

Two possible routes may be used to reach the project sites from Corinto. The main asphalted highway follows the red route in figure 2. However, an alternate route known as the old León highway, between the location known as Izapa to Managua (the green section in Figure 14) may be used in case overhead obstacles prove problematic near the capital Managua over the main route, although the road surface on this section is badly deteriorated.

The blades of large wind turbines have to be transported on specialised extendable flat-bed trailers, often having steerable axles to facilitate the manoeuvring (Figure 15). The nacelle and tower sections are transported on flat-bed trailers (Figure 16).

The land transport routes must have sufficient road width and the appropriate curvature such that these trailers can pass without major difficulty.

Figure 15: Extendable flat-bed trailer used to transport wind turbine blades.

Figure 16: Three-axle trailer of the type used to transport the nacelle and hub of a wind turbine.

Road width and curvature

Between the 1st and 5th October 2009, the entire route along the main highway from Corinto to the project site (red route in Fig.1) was verified for possible obstacles regarding road width, road curvature and overhead clearance, using data supplied by WinWinD specifying the minimum clearance parameters.

No road width limitations exist between Corinto port and the project sites.

Regarding road curvature, the visual inspections were supplemented with inspections of aerial photography of the Corinto port area and Google Earth imagery of the coastal highway between Corinto and the project sites.

In the case of port access, the extra-long vehicles required to transport the blades and tower segments can be manoeuvred satisfactorily both within the port area and outside it, through the main street of Corinto town and beyond to the coastal highway.

Between Corinto and Managua there are no critical points where road curvature may present problems.

There are however two tight curves that need to be considered carefully on the following section from Managua to El Crucero.

The first is close to the US Embassy in Managua, where the main highway to the west of the country and Corinto, joins a main urban artery at a busy road junction. On inspection of this junction, it is probable that by using the opposite road lane and removal of a small road sign, passage can be achieved.

The other critical point is a curve on the highway climbing up to El Crucero out of Managua, where the outside curvature could be close to the specified limit. In Google Earth this point is partially obscured by cloud and so more precise measurements could not be made. However, a visual inspection made on 1st Oct 2009, determined that this curve is no sharper than others on this stretch of road, and which have been evaluated favourably with Google Earth imagery.

Finally, the entrance from the highway to the pilot wind park site that has been identified in Chapter 5, represents a sharp right-angled turn and will require widening. There is an empty lot adjacent to the access road here, and so widening should not represent a major problem, although a post supporting overhead power distribution lines will have to be moved.

Overhead Clearance

Permanent overhead obstacles along the main highway route such as footbridges and road signs were identified and measured between the 1st and 5th October 2009. None of these will present any problems for the turbine or tower transport.

The minimum vertical clearance requirements for medium voltage lines of 13.8 or 24 kV that cross highways, or urban streets, in Nicaragua are not exceeded by the WinWinD logistics specifications. High voltage lines have much higher vertical clearance requirements, and so do not represent a problem either.

In practice, the clearances for distribution lines are not always respected and some lines – especially low tension lines of 110/220 V, are occasionally found below the WinWinD thresholds.

Telephone lines are also frequently strung at lower levels than recommended.

Tree branches can also present obstacles to tall traffic on highways. The passage of standard traffic and trucks tends to keep these "pruned" to about a metre more than the height of the tallest vehicle in general use (Figure 17). These are the so-called "high cube" containers that are similar in structure to standard containers, but taller. Standard containers, have a maximum height of 2.591 m, while high-cube containers are 2.896 m tall.

When mounted aboard a trailer, the high-cube container and trailer together typically have an overall height of 4.1 to 4.26 m.

Figure 17: Tree branches can present obstacles in the range of 5–5.5 m (the white truck is approx. 4 m high).

5.1.3 Summary

There are no port limitations for delivering the turbines to Nicaragua, although a self-geared ship is recommended.

There are no road width limitations between the port and project sites.

Road curvature also presents no serious obstacle for the transportation of the turbine components from the port of Corinto to the wind park sites. The access point to the pilot wind park site from the main highway will have to be improved however, to achieve the curvature required.

As far as overhead clearance is concerned, there are no permanent structures that limit the transport of the wind turbines and tower components between the port of Corinto and the wind park sites.

However, many cables – particularly telephone, cable TV and some low tension (120/240 V) cables appear to be slung below the recommended levels – especially in urbanised areas. Many of these can be temporarily raised using long poles, and/or a longitudinal "skid bar" installed over the highest point of the cargo to prevent snagging of the cable, although in the case of electricity cables these may require temporary disconnection.

Tree branches overhanging the highway may also present obstacles at certain points, although careful manoeuvring (using the opposite road lane for example) can most probably avoid many of these potential obstacles. In the worst case, branches will have to be cut where avoidance is not possible.

The green route in Figure 14 between Izapa and Managua, passing through fewer settled areas or towns has far fewer overhead cables, and as such might offer an alternative. The road surface on this section though is very poor, with many potholes and a total lack of an asphalt surface in many places.

It is recommended that a more detailed analysis be made of the "temporary" overhead obstacles such as cables of tree branches, using laser range-finding equipment, to determine the most convenient and economic routing option.

5.2 Telecommunications interference

Being located on an extinct volcanic mountain ridge some 900 m above the Nicaraguan capital Managua, the El Crucero municipality is host to more than 75 telecommunications towers. All the main television and radio stations serving the Pacific coastal region, and the country's two cellular phone operators – Enitel and Movilstar – as well as a number of radio communications providers and institutions such as the police, army and civil aviation authorities, all have transmission towers located within the municipality. These are almost exclusively located to the north of the municipality in the area known as Las Nubes.

Figure 18: Concentration of telecommunications towers in the El Crucero municipality (Las Nubes).

Telecommunications are carried out across a range of the electromagnetic spectrum, the use of a particular wavelength, or frequency, depending on the application (see Table 1).

Table 1: Typical telecommunications frequencies, bands and use.

Frequency	Communications Band	Use
3 kHz to 30 kHz	VLF	Maritime navigation
30 kHz to 300 kHz	LF	Navigation aids(e.g. Loran)
300 kHz to 3 MHz	MF	Medium wave AM radio
3 MHz to 30 MHz	HF	Short wave radio
30 MHz to 300 MHz	VHF	FM radio, VHF television
300 MHz to 3 GHz	UHF	UHF television, cell phones, GPS
3 GHz to 30 GHz	SHF	Microwave and satellite links
30 GHz to 300 GHz	EHF	Radio astronomy

According to Telcor, the telecommunications regulatory and licensing body in Nicaragua, there were in 2006 (the latest data available) 52 AM radio stations, 228 FM radio stations, 16 VHF and UHF TV stations and three (now two in 2009) cellular phone service providers.

All the principal TV and radio stations serving Managua and the Pacific region, and the two cellular phone service providers (Enitel and Movilstar), have telecommunications towers located in the El Crucero vicinity, most of them located in the northern part of the area in the locality known as Las Nubes.

5.2.1 The field study

A field study was carried out on April 24th 2009, to 1) identify all towers in the El Crucero area with directional antennas, 2) to note the geographical co-ordinates of each of these towers with a hand-held GPS unit, and 3) to measure the direction – or line-of-sight – in which each antenna is pointing with a compass, taking care to avoid possible magnetic interference effects of the towers themselves.

The point-to-point links of the cellular phone networks, and similar links used by TV and radio stations to transmit their signals from studios (usually located in urban centres) to their main multi-directional transmitters (usually placed on high terrain such as at El Crucero) are those that are of principal concern in this study, to avoid that any future wind park will interfere with these "trunk" communications. These point-to-point links can be easily identified by the type of antenna mounted on the tower and are usually Yagi or parabolic dishes.

The geo-referenced points of the towers on which the directional antenna are mounted, and the compass bearings of the lines-of-sight of the antennae, were entered into a data base and plotted within a geographic information system. In this way all the point-to-point links within the area have been identified and plotted, and have been used to avoid siting wind parks where electromagnetic interference (EMI) might occur.

5.2.2 Wind turbine interference with point-to-point telecommunications

It is generally recognised that wind turbines can create EMI and interfere with telecommunications in one of three ways: Near field effect, diffraction and reflection or scattering. Exclusion or clearance zones can be calculated to avoid EMI for each type of effect by the wind park.

Industry formulae were used to calculate the exclusion zones for each of these effects and these have been used to avoid siting the two wind parks in this study in such a way that they might generate EMI with point-to-point links.

5.2.3 Interference

In general terms, the main TV and radio reception areas are towards the north of the potential wind park area (the capital Managua) and to the east and west (the regional cities of Masaya, Granada, León, Chinandega etc). The proposed wind farm area itself and its "shadow" to the south-east are far less populated.

The main effect normally associated with wind turbine interference of TV reception is a combination of diffraction and scattering, that causes a "ghost" or "shadow" of the main image seen on the TV screen.

According to the International Telecommunications Union impacts beyond 5 km are unlikely. This would mean that TV interference effects would most likely be restricted to the areas around the towns of Diriamba and San Marcos, and primarily San Marcos.

This problem can usually be easily dealt with by improving the household receiver's antenna, or installing relays to transmit the signal around the wind farm. When interference is an issue, the wind project developer is typically responsible for paying for any necessary mitigation.

5.2.4 Air Traffic Control Radar

Finally, the possible effects upon an air traffic control radar (ATC) located just on the northern fringe of the potential wind park area were considered.

In general, two types of radar are used to control air traffic:

- Primary surveillance radar (PSR)
- Secondary surveillance radar (SSR)

The primary surveillance radar mode of operation consists in continuously sending pulses of signal with a 360º rotation antenna and then receiving the echo signals.

The secondary surveillance radar sends a specific frequency signal which interrogates a transponder situated in the aircraft. This type of radar is less sensitive to background noises and the received signal is stronger.

The Nicaraguan ATC authorities operate an SSR at the International Airport, located due east of the capital Managua. The approach and take-off paths lie some 15 km to the north of the PSR radar station located in Las Nubes, and well away from the wind study area.

However the PSR and any wind farm in the potential El Crucero development zone would be within the line of sight of each other, and could create Doppler-shifted radar returns from the spinning turbine blades. That said, all of the telecommunications towers in the El Crucero area and Las Nubes are within line of sight of the radar, and therefore contribute to the "clutter" level of reflected signals and noise reflected to the PSR.

Normally, the processing software of a radar can filter out this clutter from static objects.

A future wind park in the El Crucero zone would be positioned between 15 and 25 km south-west of the International Airport, and well away from the approach and take-off paths in the controlled air space above and around the airport. If a north-south cross section is taken through the terrain stretching from the airport, through the PSR station, the wind farm and south to the Pacific Ocean, it can be seen that the inverted cone of air space through which international traffic would approach the airport, would not be directly affected by the wind farm. International flight paths lie well above the zone, and so the turbine blades would not block targets, nor generate false targets in this air space (see Figure 19).

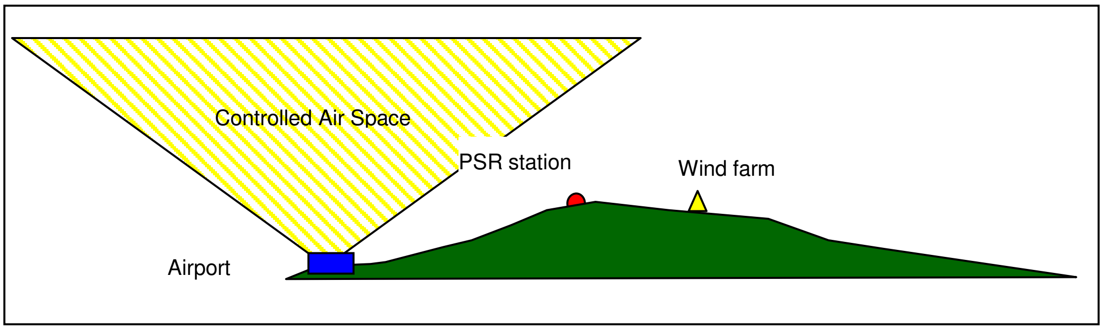

Figure 19: Schematic view of controlled air space for international traffic and relative positions of the international airport, the PSR station and wind farm (not to scale).

However, radar signals of light aircraft approaching at low altitude from the south and the Pacific Ocean coastline, could possibly be temporarily blocked by the wind farm, or alternatively false images due to the Doppler Effect, could be generated in this zone.

From various studies made in the United States and Europe, where the rapid expansion of wind energy and the aviation industry have produced conflicts of interest, a number of mitigation measures have been suggested as guidelines for wind farm developers and could be applied in this case.

It is possible to establish conservative estimates on minimum separation between wind farms and ATC radar based on nominal assumptions about the wind turbine radar cross section, radar transmitting power and sensitivity to interference, and propagation conditions. It is not within the scope of this study to go into this level of detail, but to point out where problems might lie and to indicate where further analysis and study is required.

From the foregoing analysis it can be said that it is improbable that a wind farm in the El Crucero vicinity will have detrimental effects on air traffic control of aircraft entering or departing on established and controlled international air routes into Nicaragua, and its main international airport at Managua. Possible interference may occur however, with the tracking of light aircraft approaching at low altitude from the south of the PSR radar at Las Nubes, and false signals from this direction and at low altitude might also be generated by the wind farm.

5.2.5 Conclusion

The conclusion of this part of the wind park feasibility study, is that the high concentration of telecommunications towers in the El Crucero area, does not represent a serious obstacle to the development of wind energy projects in the zone. Practically all of the point-to-point VHF, UHF and SHF links (radio, TV and microwave links) do not cross the area of interest for wind park development, and by calculating appropriate exclusion zones we have ensured that the chosen wind park sites do not interfere with these few cases.

Possible TV reception interference could occur principally in the towns of San Marcos and Diriamba, but relatively low-cost mitigation measures can be implemented to overcome any likely problems.

The tracking of light aircraft in uncontrolled airspace approaching from the south of the wind park and at low altitude, could possibly be affected, but a future wind farm in the El Crucero area is unlikely to affect Air Traffic Control of international traffic flying on pre-established flight paths and routes.

5.3 Possible wind park sites

Possible wind park sites in the project perimeter were determined in a GIS analysis taking into consideration the following aspects:

- Access possibilities
- Land use
- Inhabited areas
- Acid rain zones
- Wind resources

The analysis resulted in the choice of two preliminary areas for wind parks: a pilot wind park area and a wind park extension area. Further possible areas for wind turbines were mapped according to their suitability.

6 Wind park layout

The wind park study focuses on:

- Analysing wind park layouts suggested by ENCO and Meteotest
- Suggesting alternative locations for turbines situated in less optimal locations
- Calculating reference wind speeds and turbulence values for the turbines in order to determine suitable turbine types for the wind farm
- Drawing preliminary road and grid design

6.1 Pilot wind farm

The pilot wind farm consist of 6 units of 1 MW turbines. The turbines are located on a NW–SE ridge. The nearest measurement mast is Policia. This data has been used to analyse wind conditions at the pilot wind farm.

Based on the modelled wind resources the turbine locations were analyzed. The array efficiencies are in general very high, in average 99.5 %. This basically means that turbines in the pilot wind farm do not influence one another. In case beneficial, even more turbines could be located at the pilot wind farm site within the presented area, or turbines could be placed closer to one another.

6.2 Wind farm extension

The wind farm extension consists of 20 units of 1 MW turbines. The turbines are located on three rows heading NW–SE. The nearest measurement mast is Dante. This data has been used to analyse the wind conditions at the wind farm extension.

The array efficiencies are in general in a good level, in average 96.5%. The lowest array efficiencies are slightly above 90% which can be considered suitable. Some turbines suffer from relatively high wake losses. Even though the wake effects do not exceed the typical recommended values, it might be advisable to try to relocate those turbines as the complex terrain will most likely cause additional loads for wind turbines.

Based on the analysis of reference wind speeds and turbulence intensity, IEC class I B (or C) would be suitable for the pilot wind farm site. IEC class II B (or C) would be suitable for the extension site. However, as the terrain is complex and the maintenance probably more difficult to organize than in typical wind farm sites, it may be advisable to make a conservative selection for the turbines, and to select IEC Class I turbine also for the wind farm extension.

6.3 Preliminary road and grid design

Preliminary layout drawings including road and grid design were produced.

The road design for the pilot wind farm follows the existing road that goes through the wind farm. The internal grid of the pilot wind farm follows the road design and is designed considered using underground 13.8 kV cables. There are two options for grid connection:

1. To connect the wind farm to a new substation in the south (wind farm extension)
2. To connect the wind farm to the Monte Fresco substation in north.

The road design on the wind park extension is based on one connection road from the main road, in which roads to the turbines are branched out.

The 20 MW wind farm in the south shall be connected to the grid with a new 138/13.8 kV substation and with a new 138 kV overhead line. The internal grid of the wind farm consists of six turbine groups which are connected to substation with their own underground cables and feeders. Four turbines at the maximum are connected to one cable and in the worst case a cable defect will cause the stopping of four turbines. The underground cable routes are recommended to follow the road lines as far as possible. The cable trenches are easiest to dig at the same time with the road construction.

More details about the grid connection can be found in Chapter 4.

6.4 Conclusions

The layout for the pilot wind farm is very clear in terms of turbine locations, road design and grid connection. It is recommended to use IEC Class I B turbines for the site.

The layout for wind farm extension is acceptable, but not as certain as the layout for the pilot wind farm. After the pilot wind farm is constructed and in operation, the lessons learnt can be used to optimize the wind farm extension.

In the wind farm extension some locations of the turbines could be shifted in order to reduce the loads caused by other turbines without losing production. These issues could be considered when land lease contracts are being negotiated.

In case the layout is optimized and there is more experience on the wind conditions at the site, and the turbines in the pilot wind farm do not seem to face problems, it might be possible considering IEC Class II B turbines at the wind farm extension, in order to improve the production.

7 Technical wind turbine solutions

7.1 Air pollution and acid fallout

The Masaya volcano is a massive source of SO_2 and HCl flux, producing approximately 1'000 tons of different types of acid particles per day. SO_2 is the dominant type, and HCl is produced in an approximate mass ratio of SO_2:HCl = 3:1. Most of this pollution is dispersed to the western area of the volcano by a predominant easterly wind. Figure 20 describes the situation.

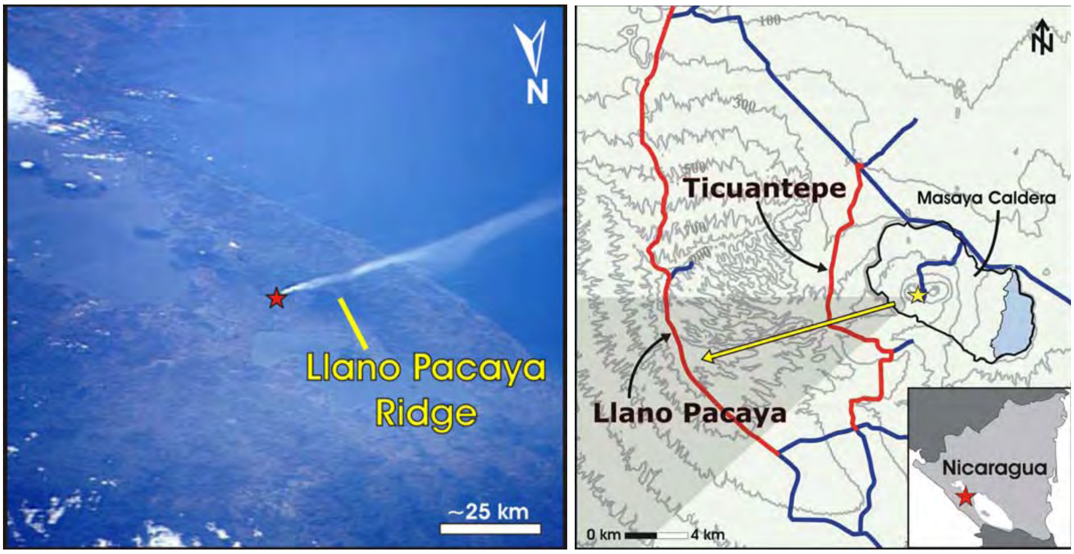

Figure 20: Satellite picture and map showing the plume of the Masaya volcano (source: Bull Volcanol (2009) 71:389–400).

According to international research carried out between 2002 and 2008, and published in Bull Volcanol, the SO_2 level is close to 50 ppbv in the atmosphere around El Crucero during the dry season. Another study showed SO_2 levels of up to 100 ppbv near El Crucero (Figure 21).

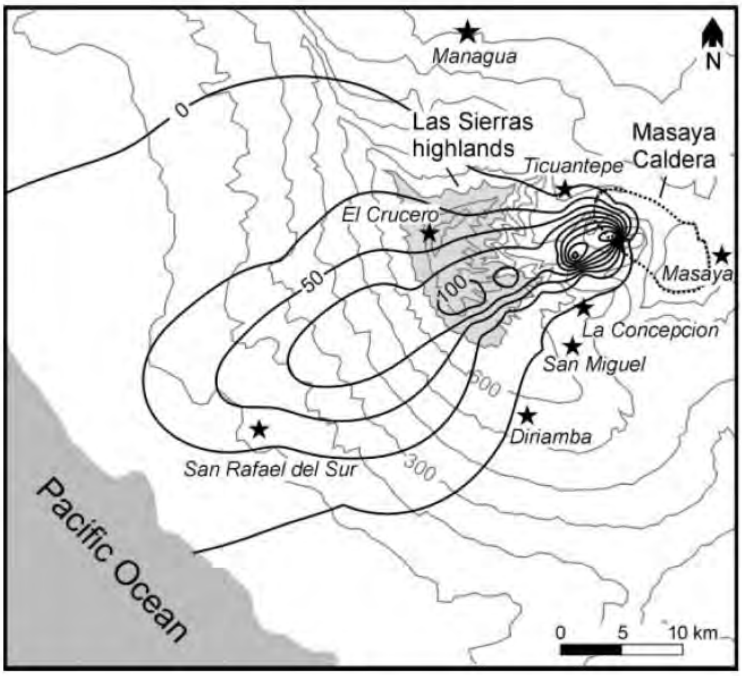

Figure 21: Atmospheric SO_2 concentration (ppbv) contour map based on measurements in 1999 (source: Bull Volcanol (2002) 64:423–434).

7.2 Corrosion

An environment with high moisture level added to acid contamination causes remarkable corrosion problems. Acid rain is the most common and well-known problem, which can be produced in two ways. In the first case small acid particles, produced by the volcano, come in contact directly with humidity or water in the atmosphere, producing H_2SO_4. In the second case acid falls directly to the ground and only after moisturisation or rain, is the sulphuric acid produced.

The first case mainly occurs during the rainy season, while the second case occurs when high temperature variations are combined with extreme air humidity levels which causes water condensation on surfaces.

ISO 12944 defines six grades of corrosivity categories for an atmospheric environment, from C1 to C5. C5 is divided into two sub-categories, C5-I (industrial) and C5-M (marine). To define corrosion class, ISO 9223 defines methods to evaluate the correct corrosivity category. According to these methods the corrosion environment in El Crucero is classified as C5-I.

7.3 Technical solutions

The technical solutions proposed in order to adapt the wind turbines to the conditions at El Crucero are described in the following section and are illustrated in Figure 22.

Internal climate control, pressurization and air filtering

The outer atmosphere contains several acid particle types and probably a variable amount of dust. Coarse air filtration can be carried out by a cyclone air cleaner unit while smaller sized dust particles and chemicals can be filtered by an activated carbon unit and/or an activated Alumina unit. These units must be renewed after the maintenance time period has elapsed.

Cooling system

Coolers are needed for inverter and gearbox cooling. To cope with the heavy corrosion levels we consider two options:

- One is to use heavy-duty models with better corrosion resistance, but maintenance is not so easy in these types and in the case of leaks, these radiators must be replaced.
- The second option is to use industrial type air coolers, commonly used in building technology. The total radiator size will increase by 70–100% and weight by approx. 50%. In case of a major break-down, the unit can be repaired quickly with a minimum number of spare parts, which is very important to minimize lost time in energy production.

Better air and dust sealing on nacelle

Dust can be kept out by improved air-sealing in the nacelle cover. The hub has a special dust-ring, wire-brush type sealing ring around it to keep the dirt and dust out.

Epoxy and polyurethane resins

Both blades and nacelle cover are surface-coated with suitable epoxy or vinyl ester coating to keep the moisture (which can contain acid) out of the structure. These coatings are used successfully in the marine industry to prevent seawater seeping into polyurethane structures in boats.

Running surfaces on radial sealings

Sealing surfaces which are exposed to the outer atmosphere are equipped with Inconel bushings to avoid excessive wear and corrosion. Inconel metal alloys are well-known and used in corrosive environments, especially in high temperatures. Shaft seals are maintained regularly by adding suitable grease.

Painting system and coating

The painting system is based on a multilayer system, provided by one of the world's largest painting system manufacturers. This type of painting is successfully used in different types of environments, e.g. marine atmosphere. The painting system satisfies the requirements stated in EN-ISO 12944-5. The painting is basically maintenance free, but some maintenance must be done if corrosion appears.

Thermal spraying can be used in problematic areas as a primer coating, if necessary. Thermal spraying is similar to hot-dip galvanizing, but is a more suitable method for treating massive structures.

Thick vinyl ester or epoxy coating can be used in problematic areas, if necessary. These types of coatings are commonly used in water or acid reservoirs, to separate metallic areas from fluid. The thick film resists abrasion well. Damaged areas can be repaired under a normal maintenance procedure without special tools or high-pressure spraying units.

Good corrosion resistance on internal parts inside the windmill is achieved by normal painting and a well-controlled internal climate.

Fasteners

Bolted connections: Connections are made with coated bolts. The coating provides good corrosion resistance under wet conditions. The endurance limits are usually much higher compared to stainless steel bolts in resisting fatigue and stress corrosion failures. The coatings can be of two different types, metallic or organic.

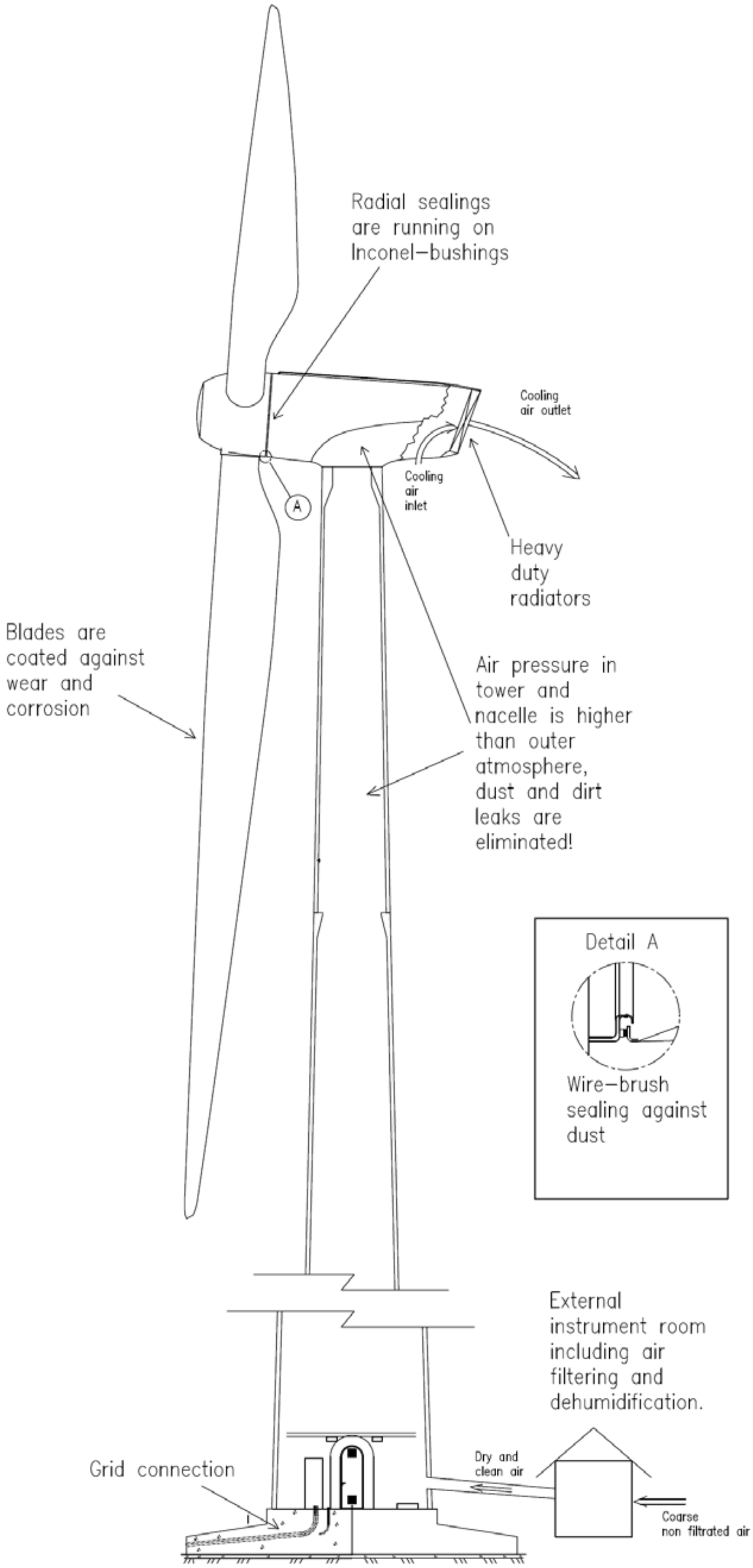

Figure 22: Technical solutions against corrosion.

8 Financial modelling and wind park financing

8.1 The Financial Model

The financial model is based on a model developed by ENCO Centroamérica S.A. as an analytical tool for evaluating the financial viability of new wind farm projects in Nicaragua. It allows the user to adjust more than 20 different variables, in various inter-linked modules, in order to quickly analyse their impact upon two principal financial variables: the Net Present Value (NPV) and Internal Rate of Return (IRR) of a project. These variables are the most frequently used by financial analysts to evaluate projects and investments.

The model is particularly useful for carrying out sensitivity analyses rapidly, by seeing how shifts in turbine annual output, interest rates, tax rates, financial leverage, for example, can change the profitability of a project. Tax incentives made available under Law 532 have been built into the cash flow analysis of the model.

8.1.1 Input Variables

The input variables shown in Table 2 can be adjusted within the indicated ranges.

Table 2: Input variable ranges, ranges and default values.

Variable	Range	Default value
1. Debt/Equity ratio	0 to 1	0.75
2. Interest rate debt	0 to 30%	12%
3. No years principal	0 to 40	12
4. Grace period	0 to 3	0
5. Inflation	0 to 30%	0%
6. Tax Rate	0 to 70%	30%
7. Discount Rate	0 to 100%	10%
8. Const. Cost factor	-50% to +50%	0%
9. Tariff US$/MWh	30 to 200	90
10. No. of turbines	1 to 30	According to site (5,6,15 or 20)
11. MWh/yr/turbine	1 to 4000	Calculated power output
12. CO_2 cert $/ton	1 to 20	10
13. O&M US$/kWh	0.008 to 0.050	0.015
14. Subsidy %	0 to 100	0
15. Auxiliary Machinery $000	0 to 5000	200 for 5 MW project
16. Downtime %	0 to 100	5

8.1.2 Output variables

1. NPV: This is the Net Present Value of the project. It is calculated as the present value of the free cash flows produced over a 25 year period. The design life of most turbines is a minimum of 20 years, although manufacturers claim useful operational lives of up to 30 years.

2. Interest Cover: This is the number of times that the interest payment is covered by the gross income of the income of the project.

3. IRR: This is the Internal Rate of Return of the project and is defined as the discount rate at which the free cash flow of the project is discounted and that produces a Net Present Value of zero.

8.1.3 Weighted Average Cost of Capital

This part of the model allows the user to calculate the most appropriate discount rate to use for discounting the project's cash flow, taking into account market loan rates, "risk-free" rates (e.g. US government bonds), market risk premiums, and specific project risk factors.

The seven variables in this module, their range and default values are given in Table 3.

Table 3: Input variable ranges and default values. The range and default values of the variables used to calculate the discount rate

Variable	Range	Default
Power sector Beta	0.5 to 1.5	0.7
Fixed costs proportion of project	0 to 1	0.75
Fixed costs proportion of market	0 to 1	0.25
Risk-free rate (10 year US Treasury)	0 to 10%	2%
Market premium rate	0 to 30%	9.5%
Gearing	0 to 1	75%
Tax rate	0 to 30%	30%

The Weighted Average Cost of Capital (WACC) is automatically adjusted as the variables are changed. The value obtained once the variables in this module are set, is the value that is entered into the first module as the discount rate for the project, used to calculate its NPV.

8.1.4 Cashflow

In this part all the cash flow calculations are carried out and give rise to the model output values of NPV, Interest Cover and IRR. Cash flows are calculated and discounted over a period of 25 years.

Tax incentives available for the renewable energy sector have been built into this section of the model.

Additional sheets in the model allow figures to be entered for the cost of substations, the cost and number of turbines to be installed, road and grid access, wind park cabling, the number of turbines used, and the probabilities of achieving targeted production levels.

8.2 Model results

Average overall installation costs are in the range of US$ 2 million to US$ 2.2 million per MW capacity, including the grid connection, for the two project sites. This is an acceptable level and typical of many land-based wind farm projects in different parts of the world, and very close to the US $2 million per MW installed cost of the 40 MW Amayo project in southern Nicaragua.

The US$ 90 per MWh feed-in tariff that is currently paid for the energy produced by this project (the only existing wind farm project in Nicaragua at present), can produce positive or negative financial returns for either of the El Crucero project sites, depending upon the choice of values for the different model variables.

A sensitivity analysis was carried out using two sets of scenarios – a negative one in which each variable is changed successively to produce a less favourable result compared to the default values, and to identify which factors are more critical in varying the financial results. A positive set of scenarios was then tested in which each variable is again changed successively to produce a more favourable result, and to again identify those factors that exert most influence on financial performance.

The value of the variables for the two different sets of scenarios is shown in Table 4.

Table 4: Low and high scenarios values for sensitivity analysis.

Variable	Low scenario	High scenario
1. Debt/Equity ratio	0.5	0.9
2. Interest rate debt	10%	15%
3. No. years principal	20	8
4. Inflation	5%	0%
5. Tax Rate	35%	25%
6. Discount Rate	13%	7%
7. Const. Cost factor	+10%	-10%
8. CO2 cert $/ton	5	15
9. O&M US$/kWh	0.02	0.008
10. Auxiliary Machinery $000	500	200
11. Downtime %	10	2

It was found that for both sites, inflation, discount rate, construction cost, O&M costs, and downtime are the factors that have the greatest effect on financial performance. These were then discussed separately and optimum performance parameters were identified.

8.3 Summary

The financial analysis has shown that the current US$ 90 per MWh being paid for wind energy in the Nicaraguan market, can produce either good or poor financial performance for a wind energy project in the El Crucero area, and indeed in any area in Nicaragua with similar good wind resources as at El Crucero, depending upon the values used for key input variables.

The choice of key financial factors in the analysis such as the discount rate used to discount the project cash flow, and the inflation rate and whether this can be transferred to the feed-in tariff over the project lifetime, has a very major impact on financial performance. Much attention should therefore be paid to these two factors in evaluating the project, and in the negotiation of an energy supply contract.

On the operational level, key factors are the operating and maintenance costs and downtime. The WinWinD 1 MW turbine is designed as a robust machine, and the modifications proposed by WinWinD for use in the acid rain environment are aimed at keeping O&M costs within acceptable limits. If optimum performance is obtained under these conditions, and an efficient and proficient O&M programme is carried out by the wind farm owner, then a profitable wind farm project should be possible at both sites.

One possible business alternative for the pilot project was analysed, to sell electricity directly to large consumers, and thereby obtain a higher feed-in tariff than that currently being paid in the wholesale electricity market for wind energy. This was found to produce favourable results.

Under optimum performance parameters, and a feed-in tariff of US$ 90 per MWh, it was found that financial returns were very favourable with an NPV value in excess of US$ 10 million for the pilot wind park site, and in excess of US$ 20 million for the wind park extension site. Corresponding IRR values were around 14% and 12% respectively, and average interest cover values being close to 3.5 and 3.0 respectively. Positive financial results were even obtained at 95% production probability exceedance levels (in other words at the lowest energy production levels expected).

It is stressed however that careful consideration must be given in selecting the appropriate discount rate and inflation rate applied in the model. Different financing sources and financial analysts can assess risk differently, and adjust these key parameters accordingly. The variables and parameters used in this model however are based on standard financial industry models, and the ranges used are within acceptable limits.

Also, as in any wind project, close attention needs to be paid to minimising O&M costs and downtime, which can be achieved by good design, care in component manufacture and assembly, and an efficient and proficient O&M programme throughout the project lifetime.

9 Environmental studies

9.1 Photomontages

Professional photomontages were produced for the pilot wind park as well as the wind park extension in order to visualize the project. The photomontages take into account the wind park layouts and turbine sizes. Perspective due to focal length and distance is taken into account.

Figure 23 shows a photomontage sample.

Figure 23: Sample photomontage for the pilot wind park.

9.2 Noise impact

9.2.1 Introduction

Wind turbines generate sound in various ways, both mechanically and aerodynamically. The software WindPRO was used to model loudness contours for the noise emitted by the turbines and to calculate sound pressure levels experienced at the inhabited buildings around the planned turbines.

Table 5: Noise tolerance standards (in dB(A)) in selected countries.

Country	Rural		Residential		Mixed	
	Day	Night	Day	Night	Day	Night
Canada (provincial regulations)	45–50	40	45–50	40–45		
Denmark	45	45	40	40		
Germany	50	35			60	45
Switzerland	60	50	55	45	60	50

So far, no noise pollution laws are implemented in Nicaragua. 45 dB(A) is becoming the accepted noise tolerance level worldwide at private residences. In general the noise rating level at the inhabited buildings is used as the limit criterion. Table 5 lists noise tolerance limits in some selected countries. As noise is more noticeable during the quiet night times when there is less background sound, many countries apply a lower (usually 5 dB(A)) noise tolerance limit for the night time.

9.2.2 Calculation method

Below the startup speed, a wind turbine stands still and therefore does not produce any noise. If the turbine is running at maximum capacity, it emits the maximum noise. Below maximum capacity, noise emission is roughly proportional to wind speed.

The punctual sound power of a WinWinD WWD1 turbine is 104 dB at rated power. Below, a noise reduction of 1 dB(A) per 1 m/s is assumed. The effective sound power level per turbine was calculated with individual sound levels for each wind speed class of 1 m/s based on the measured wind climatologies. This resulted in an effective sound power level of 101 dB(A) per turbine.

All inhabited buildings within a distance of approximately 500 m to at least one of the planned wind turbines were identified as sound immission receptors.

At each immission area, the maximum and mean noise rating levels were calculated at a height of 5 m above ground with the software WindPRO according to the ISO standard 9613-2. No penalties for tonality and impulsivity were applied. Terrain influence was taken into consideration with a digital elevation model.

Although many of the houses are shielded by vegetation and or high walls, restraining effects by vegetations and walls were not taken into consideration.

9.2.3 Results and Conclusions

The noise tolerance limit was assumed at 45 dB(A). The calculated mean noise rating levels were within this limit at all of the inhabited buildings of the pilot wind park. However, the limit was exceeded at six buildings at the wind park extension.

Once the wind park extension is planned in detail, this should be taken into consideration by assessing the actual noise impact by including restraining effects as well as by further optimizing the wind park layout.

9.3 Shadow impact

9.3.1 Introduction

Wind turbines can cause a shadow flicker effect at surrounding buildings. Shadow flicker is the term used to describe the stroboscopic effect of shadow cast by rotating blades of wind turbines when the sun is behind them. Especially the zones westwards (morning hours) and eastwards (evening hours) of the wind turbines are affected by shadowing. This effect can create a disturbance to people exposed to it. The degree of disturbance is both dependent on the intensity of the shadow (sharp margin of the shadow) and the duration of the exposure.

The software WindPRO was used to calculate the shadow cast taking into consideration the technical dimensions of the wind turbine, the astronomical cycle, topography as well as meteorological parameters.

There are no specific regulations or guidelines that establish an acceptable degree of shadow casting impact in Nicaragua. This study discusses the results in relation with the German guidelines.

The astronomically maximum possible duration of shadowing is distinguished from the meteorologically probable duration of shadowing. The astronomically maximum possible duration of shadowing refers to the time span between sunrise and sunset when the sun is continuously shining on a cloudless sky, the rotor blades are vertically orientated to the sunbeams and the wind turbines are always operating. The meteorologically probable duration of shadowing takes into account sunshine hours, wind directions and wind speed distribution.

The German guidelines set a time limit of 30 hours per year and 30 minutes per day for the astronomically maximum possible duration of shadow casting. In case of exceedance of these values, the German guidelines recommend technical arrangements to restrain the runtime of the wind turbines if a critical effective shadow cast duration of eight hours per year is exceeded.

9.3.2 Calculation method

In a first step, the possible areas affected by shadowing were determined. All inhabited houses within this area were treated as shadow receptors. Some (generally less affected) houses were grouped in order to reduce the number of receptors. Although many of the houses are shielded by high walls and/or vegetation, shielding effects were not taken into account.

The measured wind statistics were used to determine turbine operation periods in relation to turbine orientation for the pilot wind park (Table 6) and the wind park extension.

Table 6: Turbines runtime per sector [hours/year] for the pilot wind park.

N	NNE	ENE	E	ESE	SSE	S	SSW	WSW	W	WNW	NNW
54	68	1'472	5'302	231	114	121	210	249	286	158	72

The duration of shadow casting was calculated both for the maximum possible time (with no cloud cover at all) and the meteorologically probable time with a cloud cover assumption that is derived out of monthly sunshine hours taken from the meteorological database Meteonorm[6] (Table 7). The probability of sunshine (S/S_0) is the relation of the measured mean sunshine hours per month (S) and the astronomically maximum possible sunshine hours per month (S_0).

Table 7: Probability of sunshine at El Crucero.

	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S/S_0	0.61	0.66	0.66	0.61	0.51	0.41	0.42	0.45	0.45	0.51	0.55	0.58

9.3.3 Results

The results of the shadow calculations show exceedance of the limits at one shadow receptor near the pilot wind park and several receptors near the wind park extension.

These results can be considered as worst case scenarios as shielding effects of vegetation and walls were not taken into consideration. For detailed wind park planning it is suggested to analyze the shadow receptors in more details, by taking into account shielding as well as house layouts, and, if limits are still exceeded, to optimize the wind park layout or – as a last measure – to establish technical restraints for the wind turbines based on effectively observed shadow casting periods.

---

[6] METEONORM Version 6.1, ***METEOTEST***, Switzerland. Website: www.meteonorm.com

9.4 Flora and fauna

The area of interest identified for the wind park study stretches from approximately km 20 of the southern highway out of Managua, on the outskirts of the urban area of the El Crucero township, and continues some 14 km south along the Pan American highway to the junction at Las Esquinas, and from there a further 4 km eastwards to the outskirts of the town of San Marcos (Figure 24).

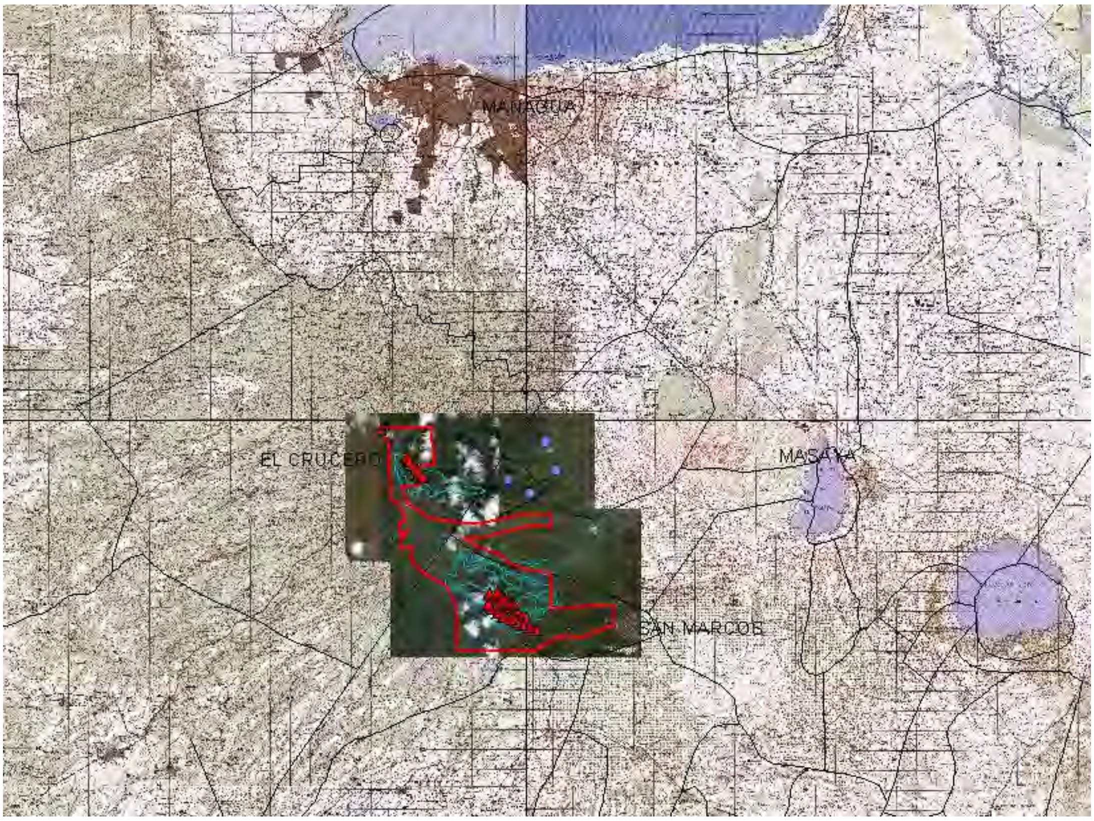

Figure 24: Area of interest (outlined in red) of wind park zone between El Crucero and San Marcos.

The area embraces parts of three municipalities including El Crucero, San Marcos, and La Concepción, although the two areas identified in the preliminary wind park layout are situated solely within El Crucero (5 MW) and San Marcos (20 MW).

The climate is relatively fresh, with an average annual temperature of 22º C (2008/9) and rainfall ranging between 1'200 and 1'400 mm per annum. A dry season occurs between December and May.

9.4.1 General Characteristics

In general the San Marcos and El Crucero municipalities have lost much of their original forest cover, due to the expansion of human settlement and the agricultural activities over the past century. The San Marcos municipality is one of the most deforested in the country. Coffee plantations have replaced a significant part of the original forest cover.

Precious timber species were abundant in this zone in the past, but have declined due to urban development and encroachment of agricultural activities. The predominant ecosystems in this zone are classified as Closed Latifoliate Forest and Shade Coffee, and represent a significant forest and agro-forestry reserve protecting the upper watershed of the capital Managua.

Within the study area, there is a zone largely devoid of trees, and dominated by pasture and occasional bushes. This is known as the Llanos de Pacaya and where the outgassing of the Masaya volcano lying to the east has caused high levels of acidification.

9.4.2 Biodiversity in the El Crucero/San Marcos region

Ecological Zone 1

The wind farm study area lies within what is defined as Ecological Region 1 of Nicaragua, or the Pacific coastal zone, that is typified as Dry Tropical Forest, subject to a dry season when the majority of the trees lose their foliage. However at higher elevations perennial forest is present also.

The study area lies within an altitude range of 700 to 900 m above sea level and represents an important ecological niche within this Region with similar vegetation characteristics to the Mombacho volcano near Granada, and the Maderas volcano on Ometepe island in the Lake of Nicaragua, both considered to be important biological reserves.

Illegal logging, hunting, the expansion of agricultural land, and urban spread are the main threats to the integrity of the ecosystems within this zone.

9.4.3 Flora

Tree species in Ecological Region 1

A total of 47 families of tree species have been identified in Ecological Zone 1 the most representative being the Caesalpiniaceae, Fabaceae, Mimosácea, Myrtaceae, Meliaceae, Boraginaceae and Anacardiaceae.

Since June 2006, a 10-year nationwide ban has been in force forbidding the logging of Cedar, Mahogany, Pochote, Mangrove and Ceibo. Within protected areas, the ban covers all tree species. Nonetheless, illegal logging and corruption continues to deplete reserves of precious timber species.

Bush and plant species

Regarding bushes and plant species, a total of 17 families have been identified, the most representative with more than one species per family being the Apocynaceas, Bignoneaceas, Malvaceas, and Urticaceas.

Orchid and Fern Species

Regarding Orchids and Ferns, two families of orchids with a total of six species and one species of fern have been identified.

9.4.4 Fauna

The information for this section of the report has been obtained from the 2004 Management Plan of the Tiscapa Lagoon Natural Reserve, an extinct volcanic crater located in down-town Managua, but which lies at the lower end of the sub-watershed "D" and which extends up to the Las Nubes community in El Crucero and borders the wind farm study area (Figure 25).

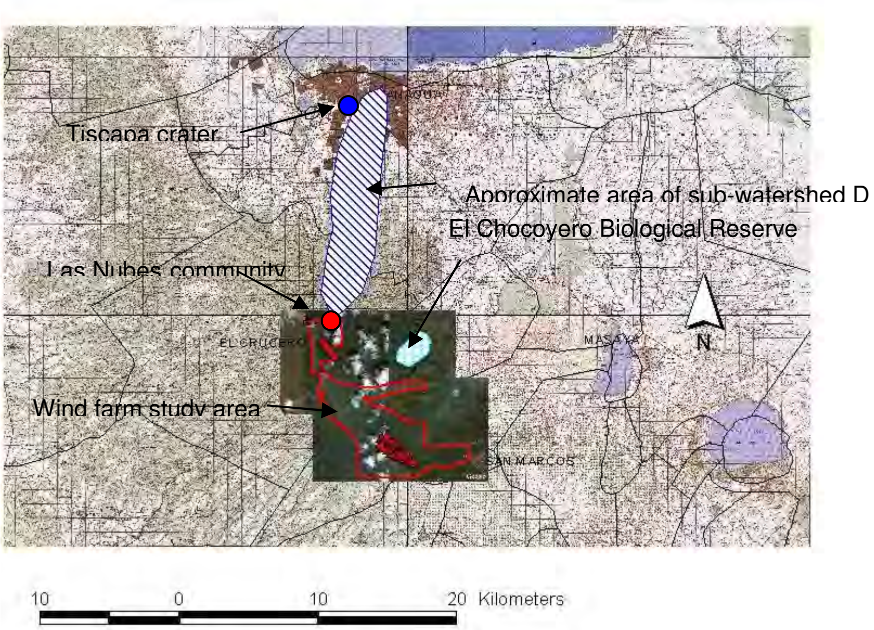

Figure 25: Map showing the wind farm study area, sub-watershed "D", and Las Nubes community in relation to the capital Managua.

Composition of the wild fauna in sub-watershed D

Mammals are represented by 7 orders, 15 families and 28 species. In the Herpetofauna (reptiles and amphibians) group 29 species are reported. 82 species of birds have been identified comprising 13 Orders, and 31 Families of which 8 are identified as migrants.

Of the migratory birds, three were identified in the middle or upper part of the watershed. 74 of the species are classified as residents in Nicaragua.

91 species, divided between mammals, herpetofauna and birds were identified in the Las Nubes community, located in the highest part of the watershed.

None of the migratory birds are considered to be endangered species and are listed under the "Least Concern" category by the International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species.

However, it is important to point out that the species presented here should not be considered conclusive. Of all the bird species possibly present in the proximity of the wind farm development area, one – the solitary eagle (Harpyhaliaetus solitarius) – is classified by the IUCN as near-threatened. There is little information on its presence in Nicaragua however. Deforestation and hunting are considered the principal threats to this species.

9.4.5 The El Chocoyero–El Brujo Biological Reserve

A 9 km^2 buffer zone surrounding the El Chocoyero-El Brujo Biological, overlaps a small part of the wind study area (see Figure 25).

The Chocoyero-El Brujo Reserve forms part of the National System of Protected Areas SINAP/MARENA, It is home to an estimated 113 bird species, 29 species of mammals and 21 types of reptiles and amphibians, including *Aratinga strenua*, an indigenous green parakeet or chocoyo, as it is known locally, after which the reserve is named. Also present are 154 species of plants.

The fauna of this reserve represents an oasis for the species that have been displaced from surrounding areas by encroaching cultivation and coffee plantations.

19 of the species of fauna found in the reserve are listed as protected by the Convention on International Trade of Endangered Species (CITES).

9.4.6 Endangered bird species in Nicaragua

65 neo-tropical migratory birds are listed on the Smithsonian Institute Migratory Bird Centre website that have a migratory range that includes Nicaragua, although up to 195 migratory birds are considered to have Nicaragua within their range.

However only ten species of birds are listed as endangered in Nicaragua by Birdlife International, based on the IUCN Red List.

Of these, the Great Curassow is known to be a resident breeding bird in twelve Important Bird Areas (IBAs) in Nicaragua including the Chocoyo reserve and surrounding landscape.

It is largely a forest bird, that makes short gliding flights at low level.

9.4.7 Wind farm impact on flora and fauna

The principal environmental impacts of a wind farm can be divided into:

A. Direct – Wind farm construction and operation:

   - Construction: This includes the impact of building access roads, power lines, and site preparation.
   - Operation: This includes the impact of visits by maintenance staff, casual visitors, and by movement of the turbine blades (bird strikes).

B. Indirect – This includes increased possible economic activity as a result of improved electricity supplies to the zone. The indirect effects of economic growth due to improved power supplies lie outside the scope of this study however.

<u>Wind farm construction</u>

Access Roads

For the pilot wind park site an existing road will have to be widened and strengthened, to allow access of the cranes and vehicles to install the turbines and foundations. For the wind park extension, access to the wind park area can be made over existing roads that will require reinforcing and improvement, but new internal roads will have to be constructed, mostly through coffee plantations.

Site clearance

To erect the turbines, clear spaces will be required at each site. In addition, and as noted above, internal access roads will be required to install and service the turbines. These areas will represent habitat and might require appropriate mitigation measures.

Power lines

Internal wind park power and communications cables will be laid in underground trenches parallel to the access road, and so do not represent a significant threat to flora or fauna, beyond that already created by the access roads.

A new three-phase 138 kV transmission line for the 20 MW wind park, will connect the south site to the Diriamba sub-station. This however can be installed alongside the Panamerican highway, along which existing medium tension distribution lines already exist.

The 5 MW wind park will connect to the existing 13.8 kV medium tension distribution line running from the Monte Fresco sub-station.

New power line installation is not therefore likely to cause a significant disturbance to flora and fauna.

Wind park operation and maintenance

There are no known unique bird species to the proposed wind farm areas and these areas are already frequented by farm labourers and hunters. Maintenance visits and occasional tourist visits to the wind farm sites are thus not considered to represent a significant threat.

The principal environmental impact is therefore considered to be the possible death or injury of birds by the turning blades of the turbine rotors.

Fortunately, wind turbine technology has improved significantly over the years, and the larger turbines considered in this study have much slower rotation speeds lessening the potential risk of collision. The siting of wind farms out of the path of known bird migratory routes, or away from important foraging or staging areas (wetlands for instance), can greatly reduce the incidence of potential bird strikes.

Many birds appear to adapt themselves quite readily to the presence of wind turbines.

However, songbirds in particular appear to be more vulnerable. Raptors such as eagles, hawks and vultures are also considered more vulnerable due to their slower, soaring flight. A focus study on these species should be considered, and possible mitigation measures taken.

Aircraft warning lights may also attract migrating birds at night. Canadian and US authorities recommend that only flashing lights should be used on towers at night, and that these should be the minimum number, have the minimum intensity, and have the minimum number of flashes per minute (i.e. longest duration between flashes) allowable.

9.4.8 Conclusion

The wind park sites are located in areas that have already been largely deforested and do not contain environmentally protected areas, and on the basis of existing information available, nor are they considered to provide critical habitats for endangered species of flora or fauna.

The one possible exception is the solitary eagle, which is listed as a near-threatened species by the IUCN, but little information exists of the presence of this species in Nicaragua.

The northern part of the wind study area of interest lies within a buffer zone around the Chocoyo Biological Reserve. Birds from this reserve, foraging in the wind park area, might be exposed to possible collisions with the turbine blades. This reserve can probably be considered to hold the widest range of bird species in the surrounding region.

The proposed wind park areas lie outside this buffer zone however.