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CARIBBEAN RENEWABLE ENERGY DEVELOPMENT PROGRAMME

giz
German International Cooperation

Wind Power in the Caribbean - On-going and Planned Projects

May 2011

CREDP/GIZ Project c/o
Caribbean Environmental Health Institute (CEHI)
P.O. Box 1111
The Morne Fortune
Castries

St. Lucia, W.I.

Tel (direct) ++ 1 758 458 1425
or -1423
Fax ++ 1 758 453 2721

internet: http://www.credp-giz.org
e-mail: info@credp-giz.org

GIZ Principal Advisor:

Thomas M. Scheutzlich

CREDP/GIZ
c/o
Caribbean Environmental Health Institute (CEHI)
P.O. Box 1111
The Morne Fortune
Castries,
St. Lucia, W.I.
Tel ++ 1 758 458 1425 (direct)
Fax ++ 1 758 453 2721
e-mail: thomas.scheutzlich@projekt-consult.de

Project Background

CREDP/GIZ is a joint Project of the Caricom Secretariat and the German International Cooperation. It is implemented by the Consortium of Projekt-Consult GmbH, Germany and Entec AG/Switzerland on behalf of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH Germany, financed by the Federal German Ministry of Economic Cooperation and Development (BMZ).

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On-going and Planned Projects 2011

May 2011

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

Factor 4 Energy Projects GmbH

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List of Abbreviations

AC	alternating current
APUA	Antigua Public Utilities Authority
ASG	asynchronous generator (induction generator)
ASR	Active Stall Regulation
AVEC	Advanced Vocational Education Centre
BEI	British Electricity International
BLPC	Barbados Light & Power Co Ltd
BWPU	Barbados Wind Power Unit
CARICOM	Caribbean Community
CARILEC	Association of Caribbean Utilities
CAWEI	Caribbean Wind Energy Initiative
CREDP	Caribbean Renewable Energy Development Programme
DC	direct current
DOE	Department Of Energy
DOMLEC	Dominica Electric Services Ltd
DSEC	Dominica Sustainable energy Corporation
EE	energy efficiency
EIA	environmental impact assessment
Eng.	engineer
EPC	Engineering Procurement Construct
EUEI	European Energy Initiative
FAPE	Fundashon Antiyano Pa Energia
FIDIC	Fédération Internationale des Ingénieurs-Conseils
GEF	Global Environmental Facility
GIGO	Garbage in – Garbage out
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GTZ GmbH
GRENLEC	Grenada Electricity Services Ltd
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit GTZ GmbH
HP	haute puissance (high power)
IEC	International Electrotechnical Commission
IGBT	Insulated-Gate Bipolar Transistor
IPP	Independent Power Producer
JPS	Jamaica Public Service Company
LUCELEC	St. Lucia Electricity Services Ltd
MAN	Maschinenfabrik Augsburg - Nürnberg
MEEA	Ministry of Energy and Energy Affairs
MoU	Memorandum of Understanding
MP	moyenne puissance (medium power)
MSM	master synchronous machine
NCB	National Commercial Bank of Jamaica
NEG	Nordtank Energy Group
NEP	National Energy Plan
NEVLEC	Nevis Electricity Co. Ltd.
NREL	National Renewable Energy Laboratory
OAS	Organization of American States
OECS	Organisation of Eastern Caribbean States
PCJ	Petroleum Corporation of Jamaica
PDF	Partnership Dialogue Facility

PPA	power purchase agreement
RE	renewable energy
RES	Renewable Energy Systems
RFP	Request for Proposal
SCADA	System Control and Data Acquisition
SG	synchronous generator
SOC	state of charge
SWP	Siemens Wind Power
TERNA	Technical Expertise for Renewable Energy Application
UNDP	United Nations Development Programme
US	United States of America
USD	United States Dollar ($)
VINLEC	St. Vincent Electricity Services Ltd
VRLA	Valve Regulated Lead Acid
WC	wind class
WEB	Water en Energie Bedrijf Bonaire
WWF	Wigton Windfarm Ltd

Summary of Findings

This evaluation of wind energy projects in the Caribbean covered 12 projects in 11 CARICOM countries and the three non-CARICOM countries Aruba, Curaçao and Bonaire, due to their strong involvement in wind power.

These 14 countries were visited by the consultant of the Caribbean Renewable Energy Development Programme CREDP in February and May 2011.

This report is meant also as a self-evaluation of CREDP's activities in the field of wind energy. As such, these activities and their effect are documented.

Wind Resources

During the past six years wind measurements have been carried out in practically all Caribbean islands. They demonstrate the outstanding wind energy potential of the region, with annual average wind speeds in 50 m height between 7.5 m/s and in excess of 9 m/s. With such wind speeds, a utility wind turbine in the MW class produces between 50 and 100 % more here in the Caribbean than it would under typical European wind conditions.

Key Results

In general, the results of this evaluation are not encouraging: in consideration of the extremely high generation costs from (typically) diesel generators in the Caribbean region and the proven excellent wind resources of the region, progress with wind energy based electricity generation is slow.

Only two CARICOM-countries – Jamaica and Nevis – feature wind parks in operation. While several others are in different stages of project development, only one country – Barbados – seems close to implementation.

On a first glance, the principal reasons for this retarded development seems to lie primarily in the high competition for the space needed for wind parks – mainly from actual or expected tourist development projects.

Electricity Supply Acts – Fuel Surcharge

On closer inspection, however, this hypothesis cannot be maintained: it is rather the lack of an economic incentive for the utilities which is responsible. The most important constraint to wind development in the Caribbean seems to be the combination of (a lack of) energy policy and existing electricity supply acts which guarantee the utilities a rate of return on investment. Or, in other words, the fuel surcharge, which caused the region to generate some of the highest electricity tariffs in the world.

Also, and paradoxically so, the fuel surcharge simultaneously caused the utilities not to look for (cheaper) alternatives to diesel-based electricity generation – as they would get their revenues independently from the oil price anyhow.

One also could argue: knowing that for each kWh the utilities themselves generate from a non-fossil energy source they will not receive the fuel surcharge (which is, at times, several times the base rate) utilities have no economic stimulus to do something new, i.e. wind instead of diesel.

As a consequence, utilities expect the same "revenue safety net" for wind energy as for diesel power generation – and this, of course, is politically out of question.

Outlook

Unless the legal framework conditions are changed – in particular the guarantee for utilities to earn their revenue independently from the oil price – the Caribbean region is not likely to see an accelerated wind power development.

In any case, this evaluation could not identify the lack of knowledge or information being in any way responsible for a lack of wind power development.

1. Introduction

1.1 Caribbean Renewable Energy Development Project CREDP

1.1.1 General Information

The objectives of the Caribbean Renewable Energy Development Project (CREDP) are to assess barriers to the exploitation of the Caribbean's substantial renewable energy resources and to design project components to remove them.

Figure 1-1:
CREDP's Project Region

Source: Thomas Scheutzlich, "Renewable Energies in the Caribbean, especially Wind", paper presented at the wind energy seminar in Paramaribo, 16th of February 2011, see http://adekus.uvs.edu

The 16 Caribbean Countries involved in this project are:

- Antigua & Barbuda
- Bahamas
- Barbados
- Belize
- Dominica
- Dominican Republic
- Grenada
- Guyana
- Haiti
- Jamaica
- St. Lucia
- St. Kitts & Nevis
- St. Vincent & the Grenadines
- Suriname
- Trinidad & Tobago

CREDP is financed by GEF/ UNDP, the German Government through Deutsche Gesellschaft für Internationale Zusammenarbeit GIZ GmbH and by the Austrian Government through Austrian Development Agency ADA.

Counterpart of CREDP is the Energy Unit of the CARICOM secretariat in Guyana.[1] CREDP supports only proven renewable energy (RE) technologies, such as wind energy, hydro power, geothermal, solar and biomass energies.

Consequently, projects with a high degree of research and development activities cannot be supported.

Apart from that, there are not many limitations to CREDP's support, i.e. the project can cooperate with public and private utilities in the same way as with private investors. Also the field of work is not limited to grid-connected electricity – however, this is a major focus of CREDP. Consequently, also projects with solar-thermal applications or off-grid electricity can be carried out.

CREDP has started its activities in the Caribbean in 2004 and is currently scheduled to run until 2012.[2]

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1) see http://www.caricom.org/

2) http://www.caricom.org/jsp/projects/credp/about_credp.jsp?menu=projects and http://www.credp-gtz.org/

1.1.2 Energy Situation in the Caribbean

Even though the project countries differ in several aspects – overall size, language, currency etc. – some common traits can be identified for the energy situation of the Caribbean countries. These are first and foremost a high dependency on imported fossil fuels (more than 90 % of electricity production) and generally less than 5 % of electricity from RE sources.

In addition, most Caribbean territories feature a universal monopoly for the (national) utilities in typically small markets (< 150 MW installed power).

As a result, most Caribbean countries have high electricity tariffs of up to US$ 0.37/kWh (at an oil price of 70 US$ per barrel).[3]

In the order of importance, the countries' major consumers are in (1) the hospitality (tourist) sector, (2) domestic households, (3) commercial sector and (4) industrial sector.

Main policy issues in the 1970s and 1980s concerned the privatization of utilities, however, without properly setting the rules of the game for the buyers. At that time, energy forecasting and the formulation of energy policy were left in the hand of the utilities.

Consequently, most of the countries have no incentives for utilities to use RE sources of energy or to foster energy efficiency (EE). What is more, electricity supply acts in many Caribbean countries guarantee a rate of return on investment of 15 % for electric utilities. This is generally reached through charging the electricity customer a so-called fuel surcharge.

Currently, many Caribbean countries have no accepted national energy policy, no long-term energy strategy and/or no energy action plans.

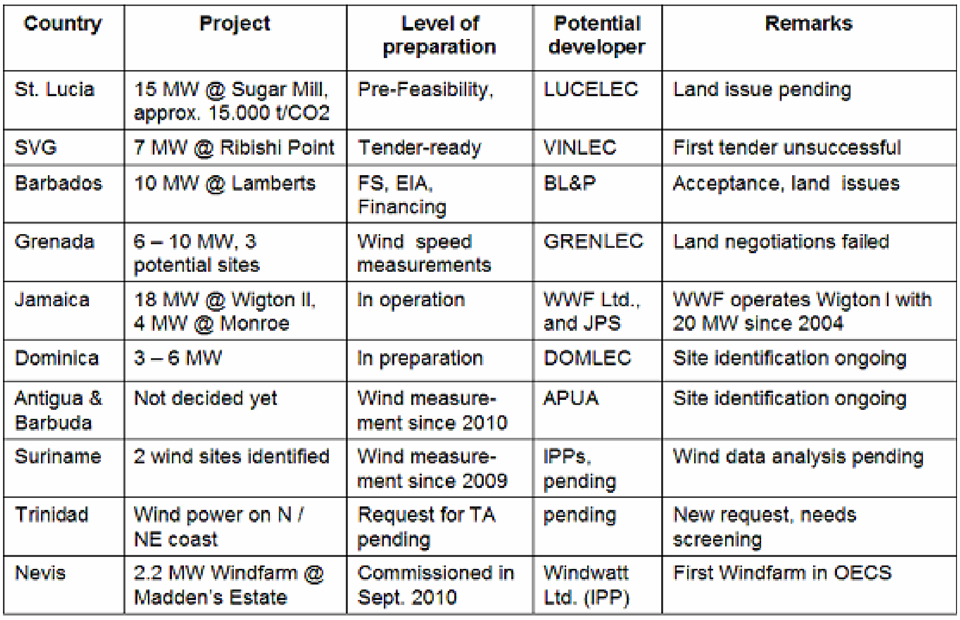
In general, one can observe relative inefficient energy policy decision procedures due to split energy portfolios in energy ministries and public utilities. This is mainly the result of the lack of specific RE and EE expertise in the concerned organisations.[4]

1.1.3 Activities in the Field of Wind Energy

CREDP's activities in the field of wind energy were carried out in all CREDP project countries with the exception of Bahamas, Belize, Dominican Republic and Guyana.

Typically, they concerned planning activities for wind parks, such as site selection and wind measurements, feasibility studies etc. **Figure 1-2** gives an overview of existing and planned wind energy projects in the CREDP countries.

Figure 1-2:
Existing and Planned Wind Energy Project in the Caribbean



Country	Project	Level of preparation	Potential developer	Remarks
St. Lucia	15 MW @ Sugar Mill, approx. 15.000 t/CO2	Pre-Feasibility,	LUCELEC	Land issue pending
SVG	7 MW @ Ribishi Point	Tender-ready	VINLEC	First tender unsuccessful
Barbados	10 MW @ Lamberts	FS, EIA, Financing	BL&P	Acceptance, land issues
Grenada	6 – 10 MW, 3 potential sites	Wind speed measurements	GRENLEC	Land negotiations failed
Jamaica	18 MW @ Wigton II, 4 MW @ Monroe	In operation	WWF Ltd., and JPS	WWF operates Wigton I with 20 MW since 2004
Dominica	3 – 6 MW	In preparation	DOMLEC	Site identification ongoing
Antigua & Barbuda	Not decided yet	Wind measurement since 2010	APUA	Site identification ongoing
Suriname	2 wind sites identified	Wind measurement since 2009	IPPs, pending	Wind data analysis pending
Trinidad	Wind power on N / NE coast	Request for TA pending	pending	New request, needs screening
Nevis	2.2 MW Windfarm @ Madden's Estate	Commissioned in Sept. 2010	Windwatt Ltd. (IPP)	First Windfarm in OECS

Source: Thomas Scheutzlich, op. cit., *modified*

The current report evaluates the listed wind energy projects, based on a mission from 9th of February to 4th of March 2011.

The report is meant as a preparation of a meeting of the Caribbean Wind Energy Initiative CAWEI, which is planned for April 2011.

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[3] exceptions are Suriname and Trinidad and Tobago with considerable lower (but subsidized) electricity tariffs

[4] Thomas Scheutzlich, "Renewable Energies in the Caribbean, especially Wind", paper presented at the wind energy seminar in Paramaribo, 16th of February 2011, see http://adekus.uvs.edu

1.2 Caribbean Wind Energy Initiative - CAWEI

1.2.1 Rationale of CAWEI

CREDP has supported individual electric utilities in the Caribbean during site selection and wind measurements. During the final project de-sign phase, and after a market review among wind turbine manufacturers, it became clear that such small projects between 6 and 15 MW would likely not attract major wind turbine manufacturers, and that an individual project implementation on each is-land independently would be too costly a venture.

To support the final planning of wind park projects, the Caribbean Wind Energy Initiative CAWEI has been founded in 2007 under the umbrella of CARILEC, the association of electric utilities in the Caribbean region.[5]

CAWEI's main focus is to facilitate a 'pooling' of individual wind energy projects.

Apart from spreading knowledge about wind energy through training courses etc. – organized by CREDP – the Caribbean Wind Energy Initiative aims at reducing the project implementation risks being specific to wind parks in the Caribbean, such as

- *transportation and erection:* all interested island states pose similar constraints with regard to site preparation, transport and installation of equipment. Apart from the obvious problem of crane availabilities, the topography of the islands – generally steep ridges and gorges – pose special problems for the transport of equipment (lacking road network, existing roads with sharp bends etc.);
- *operation and maintenance (after sales service):* Through pooling of smaller projects, it is estimated that between 30 and 40 MW can be implemented during the next years. A reliable operation and maintenance strategy would require the manufacturer to establish a permanent service post in the region, details of which are to be discussed through a dialogue between the concerned utilities and manufactures;
- *hurricane risks:* the wind resources in the Caribbean are excellent (7 to 9 m/s annual average in hub height), but the risk of hurricanes has to be accounted for by adequate measures. While tilting towers are regarded as a valid option only for smaller, non-utility type turbines, several other measures, such as non-standard towers with lower hub heights, larger safety margins for the design loads, reduced rotor diameters etc. are currently being discussed with manufacturers. A particular problem arises from the fact that all utilities de-energize their grids during times of hurricane warnings to avoid damages through live wires from overhead lines. Therefore, as a minimum, stand-by generators would have to be provided for the wind parks, allowing the turbines to automatically align themselves to the rapidly changing wind directions under hurricane conditions.[6]

1.2.2 Tender Documents

CAWEI, supported by the Partnership Dialogue Facility (PDF) of the European Energy Initiative EUEI[7] has prepared a set of tender documents according to FIDIC rules, as a sample for a joint international tender procedures under the umbrella of CARILEC.

The sample tender documents consist of 10 volumes:[8]

1 Instructions to Tenderers

2 General Information

3 Conditions of Contract - Preamble

4 Conditions of Contract – Part I

General Conditions (FIDIC "Yellow Book" - not distributed)

5 Conditions of Contract – Part II

Special Conditions

6 Technical Specifications

7 Contract Forms

8 Form of Tender

9 Outline Programme

10 Schedules of Prices

The structure of the tender allows a manufacturer to offer the turbines for the 'pooled' projects as a whole, however, contracts for delivery and services are concluded with each and every individual utility/wind park operator.

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5) see http://www.carilec.com/

6) see **Annex 15 – Hurricanes in the Caribbean**

7) see http://www.euei-pdf.org/

8) see **Annex 1 – CAWEI Tender, CAWEI Flyer**

2. Wind Energy Projects in the Caribbean

2.1 Jamaica: Wigton Windfarm

2.1.1 Original Wigton Windfarm (2004)

In April 2004, 23 Wind turbines with an installed generator power of 900kW each were commissioned at Wigton, Manchester, Jamaica. Project sponsor was the Petroleum Corporation of Jamaica (PCJ).[9]

At that time, the rationale behind the project was indicated by PCJ as follows:

- the need for additional generating capacity;
- the shortage of foreign currency for fossil fuel;
- the dependence on imported fossil fuels;
- the fluctuations in international fossil fuel prices;
- the fact that wind energy is not sensitive to variations in global fuel prices;
- the interest in, and obligation to, reduce CO_2 emissions;
- the stimulation of technology transfer.[10]

The wind park with 20.7 MW total power has been financed with PCJ equity of US$ 3.2 million and a loan from the National Commercial Bank of Jamaica (NCB) US$ 16 million. PCJ could prove within the Millieu Project of the Netherlands government that the expected feed-in tariff of 5.6 US$cts per kWh offered by the national utility Jamaica Public Service Company (JPS) would render the project uneconomic without additional grant funding.

Therefore, the Netherlands Government offered a grant of US$ 7.0 million for the project,[11] a rather high grant percentage of 26.7 % of total project cost. It is estimated that this grant was given under the pre-condition, that the wind turbines be acquired in Netherlands.

With support of the English consultant and wind park developer Renewable Energy Systems RES[12] JPC signed a contract with NEG Micon, which, at that time, maintained a manufacturing plant in the Netherlands. The wind turbine (**Figure 2-1**) has a 52 m rotor and is a Wind Class I wind turbine, according to IEC (International Electrotechnical Commission).

Figure 2- 1:
NEG Micon NM52 - 900 kW Wind Turbine at Wigton, Jamaica

Photo: B. Jargstorf, February 2011

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9) http://www.pcj.com/dnn/Home/tabid/36/Default.aspx

10) Raymond M. Wright, “The Value of Wind - The Wigton Experience”, paper presented at the CREDP Seminar “Wind Power: a Feasible Energy Option for the Caribbean – Planning of Wind Parks and Case Studies” in Kingston, Jamaica, Nov 30 – Dec 2, 2004

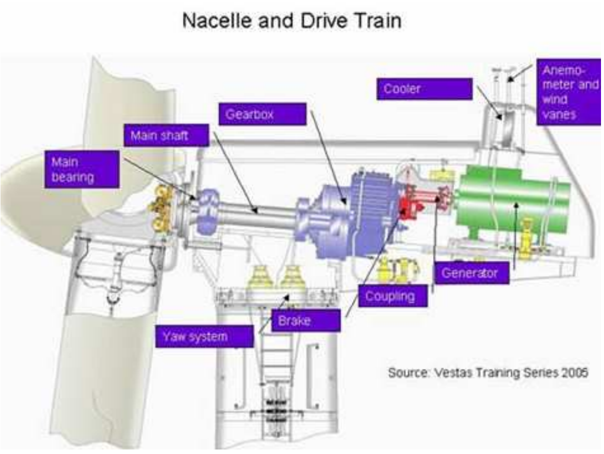
11) op. cit.

12) http://www.res-group.com/

According to the IEC design rules (IEC 61400-11), the NM52/900 kW wind turbine with a classic Danish design – stall controlled rotor, fixed rotor speed, directly coupled asynchronous generator – has a survival speed of 70 m/s or 154 mph.

This was considered a minimum requirement to reduce the hurricane risks for the project. The turbine is equipped with a water-cooled electrical generator and features a gearbox with a spur gear and a planetary stage (see **Figure 2-2**). The rotor blades have fixed pitch and are equipped with aerodynamic blade tips.

Figure 2-2:
NEG Micon NM52 - 900 kW Wind Turbine



Source: http://www.pcj.com/wigton/energy/generation.html

Wind measurements for this project started in March 1995 and had been conducted in four different potential sites, according to **Figure 2-3**.

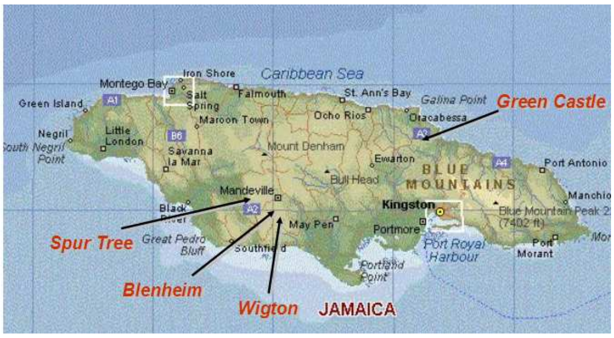
With a minimum measuring time of 12 months, the average annual wind speeds at 40 m above ground for the four candidate sites were:

- Green Castle, St. Mary: 7.2 m/s;
- Blenheim, Manchester: 7.3 m/s;
- Spur Tree, Manchester: 7.7 m/s;
- Wigton, Manchester: 8. 3 m/s (measured from January 1996 – February 2003;[13]

The wind turbines were placed with a distance of 100 m (= 1.9 rotor diameter) perpendicular to the main wind direction in two major rows, between 350 and 500 m apart (= 6.7 to 9.6 rotor diameters).

The annual net energy production had been established as 51 GWh[14] – this means a net capacity of 28.1 %. The monthly figures published by JPS for the year 2005 in **Figure 2-5** result in a total annual net production of the Wigton Wind Park of 51 GWh. Other sources indicate an annual production of 61 GWh (= capacity factor of 33.1 %).[15]

Figure 2-3:
Candidate Sites for the Wigton Windfarm



PCJ was able to get a manufacturer's warranty for an extended period of five years. During the warranty period, MEG Micon was taken over by the world's largest wind turbine manufacturer, Vestas of Denmark. Because Vestas had a wind turbine with identical rotor diameter (V52), but with a technically advanced concept (pitch control, variable speed, double-fed induction generator), the manufacture of the NM52/900 kW was discontinued.

The Wigton wind park is connected via a 24/69 kV substation and a 11 km long 69 kV transmission line to the next JPS 138 kV substation.

On account of this dedicated connection to the 138 kV transmission, the directly coupled induction generators of the NM52/900 kW turbines did not cause grid stability problems. But the high consumption of reactive power of ~ 8,000 kVAr (**Figure 2-4**) cost the Wigton wind park operator dearly, as JPS charged Wigton standard rates as industrial consumers.

Subsequently, a study[16] was conducted to propose additional power factor correction facilities for the wind park. Capacitor banks were installed directly at the 24/69 kV substation and the reactive power consumption of the wind park was reduced.

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13) Raymond M. Wright, op. cit.

14) http://www.thewindpower.net/wind-farm-4143.php?PHPSESSID=03a13e1809055d2365c684a98c9e1c2e

15) Ricardo Case, "Integration of Wind into the Mixed Grid of Jamaica – The JPS/WWF Relationship" – CARICOM, 04-10-2006

16) Francois A. Lee, PE Leecorp Ltd, "Wigton Windfarm Ltd, Power factor and VAR Control Experience – Problems and Solutions", see http://www.leecorpweb.com/?page_id=55 and www.caricom.org/.../Francois%20Lee%20Wigton%20Presentation.ppt -

Figure 2-4:
Wigton Windfarm - P – Q Characteristic[17]

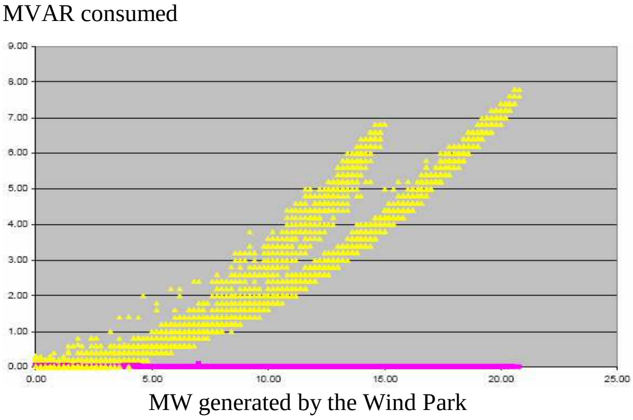
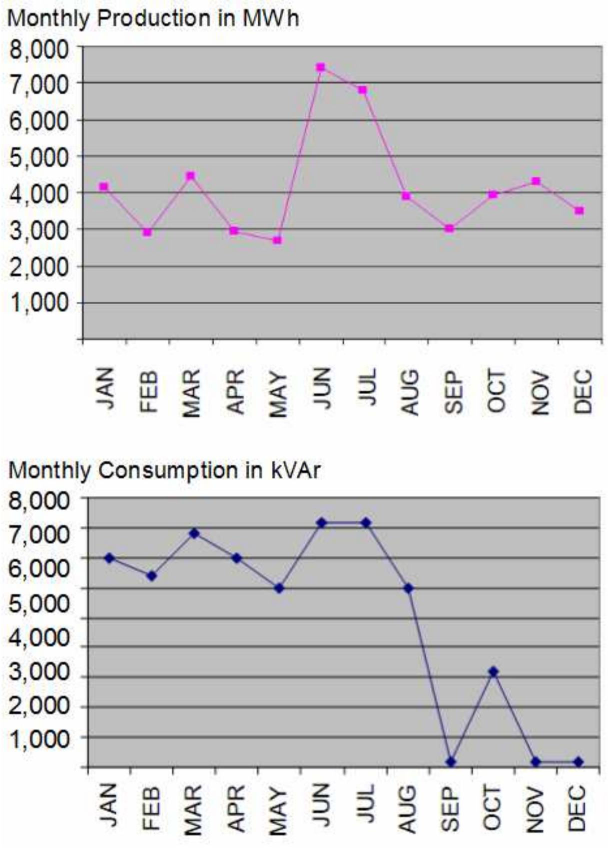


Figure 2-5:
Wigton Windfarm – Production/Consumption Active/Reactive Power in 2005



Source: Ricardo Case, op. cit. (modified)

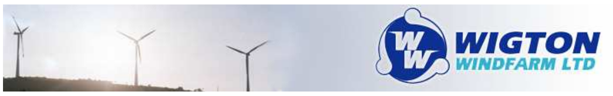
The effect of the installation of the capacitor banks in September 2005 can be seen in the monthly consumption of reactive power by the wind park in **Figure 2-5**, which was reduced from typically 5,000 to 7,000 kVAR to below 3,000 kVAR. In the same figure one can see that the reactive power consumption of the wind park – before compensation, had been, to a certain degree, independent of the level of production. This is a typical behaviour of non-optimized (not optimally compensated) wind parks with induction generators.

Figure 2-6:
Wigton I – Reactive Power Compensation

Photo: B. Jargstorf, February 2011

According to information given by Mr. Raymond Wright in 2004, PCJ negotiated a Power Purchase Agreement (PPA) with JPS, according to which for the first 5 years of operation US$ 5.6 cts/kWh would have to be paid. For the remaining period, a feed-in tariff of US$ 5.05 cts/kWh had been agreed upon.[18]

In the meantime, the PPA with JPS has been renegotiated, also under the influence of the extension to the original Wigton Windfarm with 9 x 2 MW Vestas turbines.



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[17] Francois A. Lee, PE Leecorp Ltd, “, op. cit.

[18] Raymond M. Wright 2004, op. cit.

2.1.2 Wigton Windfarm Extension (2010)

During 2009 and 2010 the existing wind park of the Wigton Windfarm Ltd. (WWF) was extended by 9 units of Vestas V80-2 MW with funding of the PetroCaribe Development Fund.

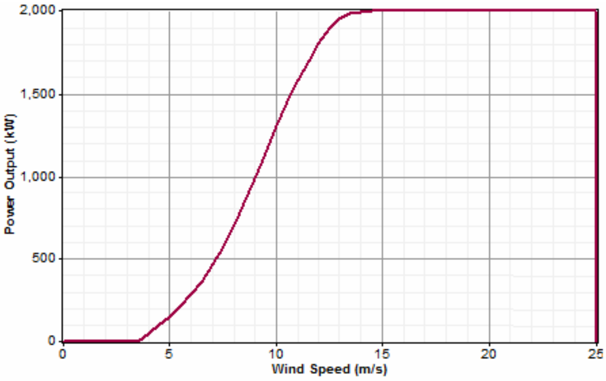
The new micro-locations were identified in immediate vicinity of the existing Wigton I wind park, relatively close to existing houses (**Figure 2-9**).

In preparation of this extension, CREDP was consulted on 25th of February, 2008 and discussions about potential wind park sites and the reduction of hurricane risk were held.[19]

Figure 2-7:
Wigton II - Construction of Foundation for Vestas V80 – 2 MW

Source: http://www.pcj.com/wigton/news.html

Figure 2-8:
Vestas V80-2 MW – Power Curve



Source: Windographer, www.mistaya.ca

The Vestas turbine features a 80 m rotor which operates with variable speed, the rated power is reached at 13.5 m/s (see **Figure 2-8**). In contrast to the turbines of Wigton I, the power factor of the Vestas V80 can be varied dynamically, i.e. the problems with the high reactive power consumption are avoided.

Figure 2-9:
Wigton II – Vicinity of Human Dwellings

Figure 2-10:
Wigton II – Instantaneous Active and Reactive Power – 10-02-2011, 10:23 h

Photos: B. Jargstorf, February 2011

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[19] see **Annex 2** for a Summary of Results

Figure 2-11:
Grid Connection Concept – Wigton I[12]

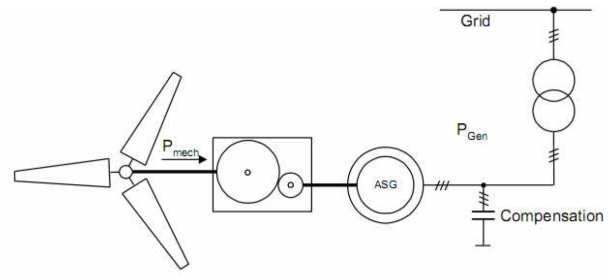
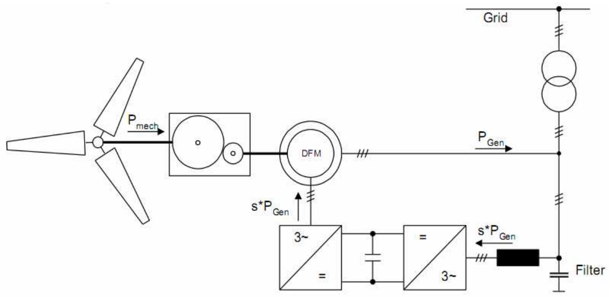


Figure 2-12:
Grid Connection Concept – Wigton II[20]

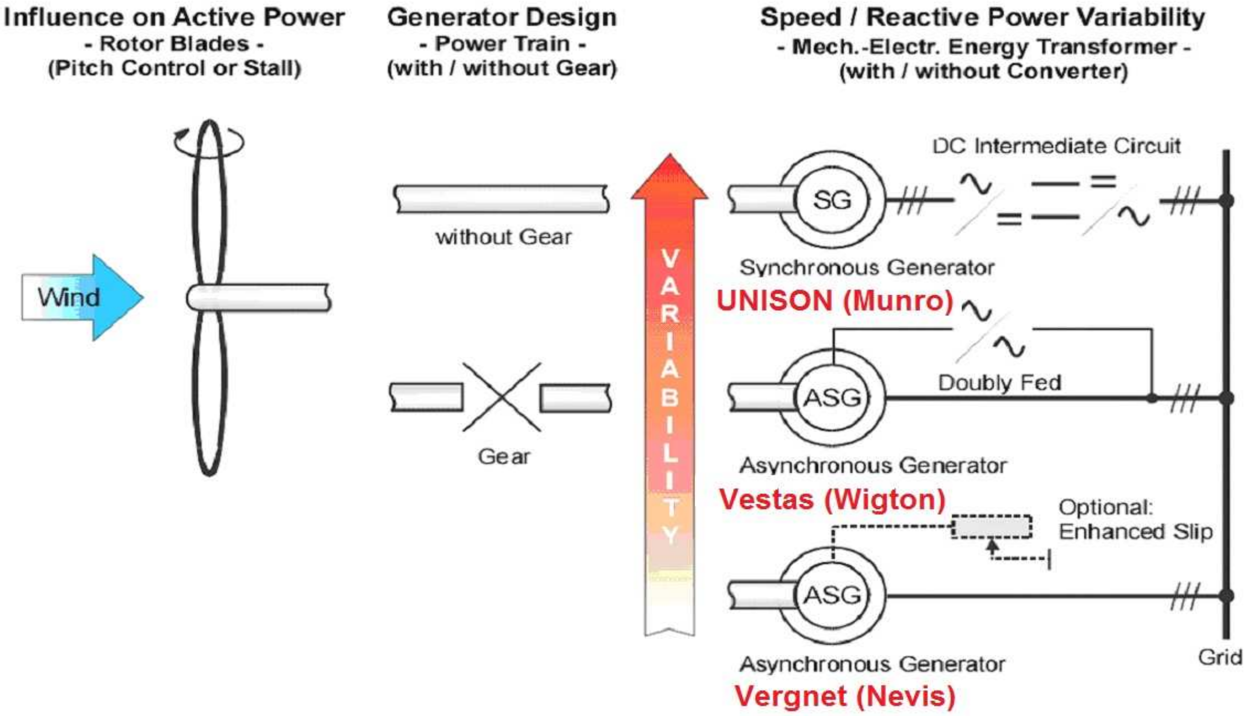


During the time of visit – 10th February 2011 - both Wigton I and II experienced excellent wind conditions with hub height wind speeds between 10 and 15 m/s. At the grid control interface for the wind turbines of the Wigton II wind park, readings between 16 and 18 MW were shown with very little variation – the wind park was practically producing at rated power.

As can be seen in **Figure 2-10** the Wigton II wind park practically does not consume any reactive power – the doubly-fed induction generators of the Vestas V80 offers such an operation, while the standard asynchronous generators of the Wigton I turbines do not. The different grid connection concepts of both phases of Wigton are shown in **Figure 2-11** and **2-12**, and compared with the grid connection concept of the wind parks in Munro (UNISON, **Section 2.2**) and in Nevis (Vergnet, **Section 2.10**) in **Figure 2-13**.

Finally, on 10th of February 2011 it was observed that all 32 wind turbines of Wigton I and II were in operation, so the wind park's technical availability on that day was 100 %.[21]

Figure 2-13:
Three Generator Concepts and their Variability ("Grid Friendliness")



Source: Cornel Ensslin, „Integration hoher Windenergieanteile in elektrische Versorgungsnetze", ISET University of Kassel, *modified*, see www.iset.uni-kassel.de/abt/FB-I/.../01-05-01_wind_integration.pdf

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20) S. Müller, M. Deicke, Rik W. De Doncker, "Adjustable Speed Generators for Wind Turbines based on Doubly-fed Induction Machines and 4-Quadrant IGBT Converters Linked to the Rotor"

21) Maybe this was a direct result of the technician from Vestas being at Wigton for routine maintenance – anyhow, it resulted in a very good impression and gave a good image of the installation.

2.2 Jamaica: Munro Wind Park

2.2.1 Overview and Project Schedule

This wind park for the national utility of Jamaica – Jamaica Public Service Company JPS - with 4 units of the U50 turbine was the first project of the Korean manufacturer UNISON outside of Korea. UNISON has medium-term plans to deliver their mid-sized wind turbines with 750 kW to Latin America and the Caribbean. In August 2010 they also signed a contract to deliver a three unit wind park to the Galápagos islands. Both the Munro and the Galápagos wind park are EPC turn key contracts.[22]

The Munro Wind Park was visited on the 10th of February, 2011 - Richard Gordon, M.Sc. from JPS showed the consultant around the wind park and gave information about the planning procedure, the installation and commissioning of the wind park with a high degree of professionalism.

Details about the tendering of the project as well as funding and pricing were not obtained.

Consequently, this section concentrates on technical issues and stays more vague with regard to commercial issues.

The project with 4 x 750 = 3,000 MW installed capacity is expected to operate with a capacity factor of 35 %, thus, to have an annual net energy yield of 9.2 GWh. The effective annual average hub height wind speed is estimated according to these data to lie between 8.2 and 8. 6 m/s.

Figure 2-14:
JAMAICA - Munro Wind Park 4 x 750 kW – Project Schedule

JPS awarded Project by OUR	October 2008
EPC Contractor	UNISON
Contract with EPC contractor signed	December 21, 2009
Site Work Planned Commencement Date	May 3, 2010
OUR mandated Project Completion Date	December 30, 2010
Actual Completion Date	September 30, 2010

Source: Jamaica Public Service Ltd Company JPS, OUR: Office of Utility Regulation

Figure 2-15:
Grid Transformer 24/0.4 kV – 50 kW after a Fire on 15th of November 2010

The Project Schedule is shown in **Figure 2-14**. The short time between contract signature in December 2009 and actual completion date – September 2010 – is remarkable and shows that wind parks can be installed with extremely short lead times.

2.2.2 Transformer Accident

Since 15th of November 2010, the wind park has been shut down. On that day, the transformer of the

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[22] EPC: Engineering Procurement Construct

Figure 2-16:
Munro Wind Park – Control Room in the Grid Station with Telecommunication and SCADA Equipment

grid station (24/0.4 kV, 50 kW) caught fire and also damaged some neighbouring equipment in the switch cabinet (see **Figure 2-15**). This three-phased transformer has nothing to do with the wind power from the turbines being transformed to distribution level (24 kV), but is meant solely for the own consumption of the grid station, i.e. for protection, metering and communication purposes.

As can be seen in **Figure 2-16**, this grid station has only communication and metering equipment as consumers, as such, the rating of 50 kVA seems tremendously over-rated. Under consideration of this over-rating, a failure of the transformer is even more difficult to understand.

According to JPS's Project Planning & Development Analyst Richard Gordon, UNISON did the detailed design of the grid station and forwarded it to JPS for approval.

In the absence of further information about the decision to install a 50 kVA transformer the consultant assumes that UNISON had this transformer in stock, or had designed a similar grid station with larger own consumption for another project and used the same drawings to safe money.

As to the reason of the transformer failure, Richard Gordon, Project Planning & Development Analyst of JPS suspected an imbalance of load in the distribution system as one of the contributing factors. The analysis of causes is still on-going, a final verdict has not been reached.

The Munro Wind Park is directly connected to the distribution system, i.e. without a separate substation and transmission transformer. This option has been chosen as is it considerably less expensive than to construct a dedicated transmission line and a substation for such a small wind park with only 3 MW installed power. It is not an unusual procedure for wind parks of this size.

As a part of the detailed planning for the wind park connection, JPS forwarded information about the local grid situation to UNISON, i.e. voltage variations and phase imbalances at the point of connection (i.e. how much the standard grid voltage would vary when the load at the three phases of the distribution grid reached its maximum imbalance). Mr Gordon suspects that possibly they had underestimated these imbalances – thus being only one of the reasons for failure.

While phase imbalances are known to cause problems with wind turbines (normally, the turbine switches off automatically, when a certain level of imbalance has been reached) a transformer fire (i.e. an overheating) is extremely rare.

The Consultant does not think that phase imbalances are the only cause of the grid transformer failure. In particular, the wind turbines would have switched off regularly on account of phase imbalances and would have warned the operator that the grid situation was not as expected (details about the behaviour of the turbines could not be obtained).

A new transformer as well as other replacement parts for the grid station are being manufactured by UNISON's subcontractor for electrical equipment in Korea. Starting in mid-February a repair and a re-commissioning of the wind park Munro is expected. While the re-manufacture of the damaged equipment and the re-commissioning is paid for, at the time being, by UNISON, a final settlement of the additional cost of this accident has not been reached.

Figure 2-17:
Munro Wind Park – Eastern Group

Figure 2-18:
Munro Wind Park – Western Group

Despite this small accident, JPS continues to have a good working relationship with UNISON and hopes to maintain this for the future, Mr. Gordon told during the visit.

2.2.3 Micro-Siting

Apart from the damaged grid station the wind park looked very clean and visually pleasing. The turbines are placed in two groups with approx. 150 distance to each other. Between the two groups are approx. 500 m, where the topography does not permit to place turbines (see **Figures 2-17** and **2-18**).

While JPS was responsible to build the major access roads (tarmac), UNISON's task was to prepare the direct turbine access roads (gravel) and crane platforms. As can be seen from the situation of Turbine No. 4 in **Figure 2-19**, the turbine foundation has been set at approx. 1.5 m below the level of the crane platform. As a result, the wind turbine sees approx. 1.5 m less height above ground than when it would have been placed on the same level as the crane platform. This placement, however, would have required compacting of soil and, generally, a little higher effort in site preparation. It is suspected that UNISON went for the absolutely cheapest way of site preparation without thinking of the height-above-ground-issue and the higher annual energy yield a 2 m higher hub height would have given.

While the missing 1.5 m hub height might only cause 1 or 2 % less annual production, it sums up over 20 years of operation time – and it would have paid for the extra efforts in excavation and compacting.

This seems to be another indication that it is not always the best option for an operator to rely on detailed planning of the manufacturer (see **Section 2-10** for another example in Nevis), but opt for manufacturer-independent consultancy instead.

As the national utility company of Jamaica, JPS wanted to gain first hand experience with wind-generated electricity, and they wanted to gain this quickly – therefore they decided to go ahead with this relatively small wind park in Munro.

Currently, an extension with another 20 units of 750 kW is under discussion.

Figure 2-19:
Crane Platform and Foundation Level showing approx 2 m Difference in Elevation

Figure 2-20:
Munro Wind Park 50 m Measuring Tower for Expansion

2.2.4 Extension Plans

A new wind measuring campaign on a 50 m tower close to the existing wind park is already underway (**Figure 2-20**). Information about average wind speeds could not be obtained.

With a certain competition between JPS and Wigton Windfarm Limited both companies treated wind data as confidential.

Judging from the production figures of Wigton and against the general experience of the ENGINEER, the annual average wind speed at Munro is estimated to be between 8 and 9 m/s. As such, it is expected to lie in the same range as that of the Wigton Windfarm and to constitute a highly suitable wind regime for wind energy utilization in Jamaica.

2.2.5 Summary

Due to a design and/or manufacturing fault, the Munro wind park of JPS is out of order for nearly three months, after being on-grid just a little longer than 4 weeks. As the fault concerns a relatively minor component such as a standard grid transformer, the loss in production and the delay it caused in the project execution is particularly disappointing.

While an official reason for the failure of the transformer has not been established, the Consultant suspects a combination of inaccurate grid data being forwarded to UNISON for detailed design and a potential mistake in detailed design and/or manufacture of UNISON’s subcontractor in Korea. Alternatively, a serious fault condition in the distribution grid (as a result of poor design and/or maintenance?) could have caused the transformer fire.

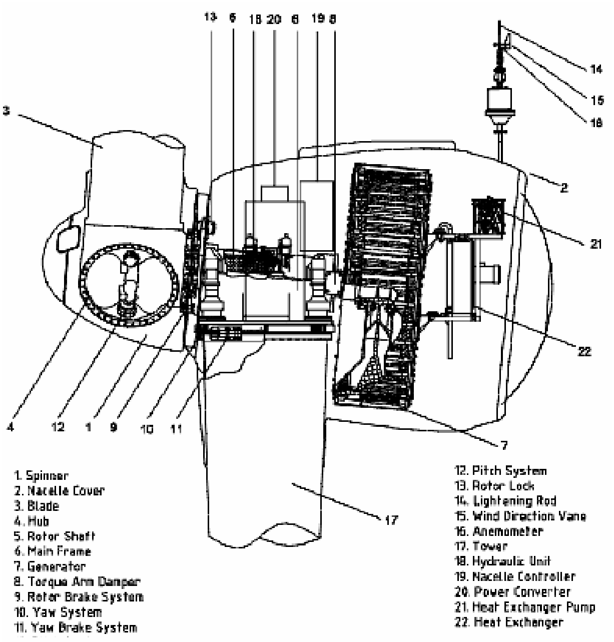
However, up to now, a plausible final explanation of the considerable over-dimensioning of the grid transformer has not been established.

If at all, the transformer accident might be an indication of the general higher complexity of a wind park feeding into the distribution system.

Box 1: Technical Specification of the UNISON U5x Wind Turbine

The 750 kW wind turbine of the Korean manufacturer UNISON has been designed in cooperation with the German wind turbine design consultant aerodyn Energiesysteme GmbH and the Pohang University of Science and Technology.[23]

Figure 2-21:
UNISON U5x – Nacelle Design



The 750 kW turbine comes with three rotor diameters of 50 m, 54 m and 57 m, matching the IEC Wind Classes I, II and III, respectively (see **Figure 2-39**). Apart from the rotor diameter and corresponding different hub heights of 50 m, 60 m and 68 m, the turbine nacelles of the U50, U54 and U57 are identical.

The U5x has a rotor with variable speed and features a direct-drive permanent magnet synchronous generator, which is connected to the grid via an inverter system with IGBT (AC-DC-AC).[24] Both PM generator and inverter system have a common water cooling system using the same heat exchanger (no. 22 in **Figure 2-21**).

The first prototype – a U50 Wind Class 1 machine – was installed in 2005 and field tested in 2006. The rotor blades have a maximum power coefficient c_p of 0.47, a length of 24.3 m and weigh 2.3 tons.

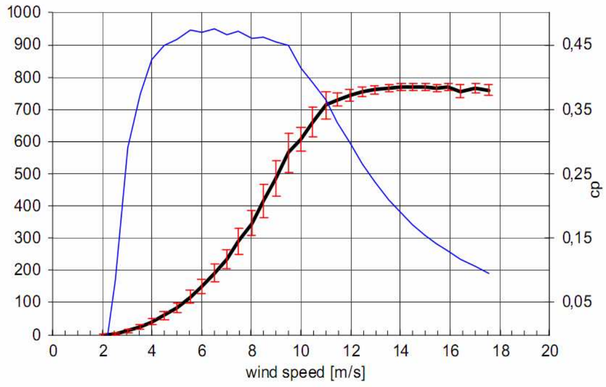
The PM exited synchronous generator has 42 pole pairs and an operating range from 6.3 Hz to 15.5 Hz. With a radius of 1.9 m it features a total weight of 22 ton. As such, it is the heaviest individual part of the turbine.

The steel losses coming from the hysteresis and eddy current is 5 kW, while the joule losses in the stator winding amount to about 32 kW. The maximum generator efficiency is 95.6 %. Neodymium (NdFeB) as the magnetic material allows continuously operating temperatures of 160° C. The water cooling system keeps the generator temperature always below 107° C.

The total power losses of the inverter system is 43 kW, it has an overall efficiency of 94.6 %.

The power curve of the wind turbine has been measured independently by WINDTEST Kaiser-Wilhelm-Koog GmbH for all three versions of the U5x turbine, **Figure 2-22** shows the measured power curve for the WC III version with 57 m rotor diameter.

Figure 2-22:
UNISON U57 – Measured Power Curve[25]



According to information from UNISON, contracts for the U5x turbine amounted to 20 MW at the end of 2009, further 60 MW were under development overseas, while another 220 MW were projected in South Korea.

Apart from the gearless U5x turbine, UNISON also manufactures a (conventional) wind turbine with a gearbox and 2 MW installed generator power.

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23) see Ji-Yune Ryu et. al. 'Development of the First Commercial 750 kW Wind Turbine in Korea', paper presented at the European Wind Energy Conference EWEC 2006

24) IGBT: Insulated-Gate Bipolar Transistor

25) WINDTEST from 23rd February 2010, measured at the prototype at Gangwon-Do, Korea

2.3 Antigua and Barbuda

2.3.1 CREDP's Technical Assistance to APUA

Upon request of the Energy Desk of the Prime Minister's Office – Ambassador Joane Underwood – CREDP's wind energy expert discussed a wind measuring campaign for site selection in May 2010. An engineer from APUA - Antigua Public Utilities Authority - had just completed his M.Sc. at a Great Britain university with a thesis on wind energy – he was the ideal partner for planning measures for the implementation of wind power projects at Antigua and Barbuda.

This situation was the starting point for the development of a wind energy development plan for Antigua and Barbuda, dealing with the following aspects

(a) determination of the suitable size of a wind park,
(b) discussion of site selection aspects for Antigua and Barbuda,
(c) development of a wind resource assessment plan,
(d) discussion of practical implementation possibilities, and
(e) a summary with proposals for the Government of Antigua and Barbuda and recommendations for the electric utility APUA.[26]

It was decided to engage in a systematic evaluation of the wind regime in Antigua and Barbuda, through the installation of four wind measuring stations, three in Antigua and one in Barbuda.

To save wind measuring costs, the determination of the inland wind resources – generally on top of the hills in the Western and Southern parts of Antigua – was to be effected through using existing telecommunication towers.

These towers are generally installed at well exposed sites to achieve a wide-area coverage of their signal(s). As such, they are often representative for potential wind park sites in their vicinity. The aerial photo in **Figure 2-24** shows the 60 m tower at McNish Mountain and two suitable wind park areas close-by, for which the measured wind data could be taken for a first energy assessment.

Figure 2-25, as an example, shows two installed anemometers at 30 and 60 m above ground and the wind shear calculated with the measuring results (Guinea Bush).

The main target for the design of the wind measuring campaign was to find out whether the higher wind resources to be expected on top of the (inland) hills would be sufficient to pay for the extra costs for the wind park infrastructure (i.e. for access roads, grid connection etc.)

Figure 2-23:
Example of Anemometer being Mounted to an existing Telecommunication Tower

Therefore, an easy accessible potential wind park site, in close distance to APUA's main thermal power plant, and directly at sea level (150 m distance to the shore) was selected as a reference site. For this site – Crabbs - a long-term correlation of wind speeds with the wind data from the neighbouring airport had established an annual average wind speed at 50 m above ground of 7.6 m/s.

On this potential wind park site on the peninsula of Crabbs a 60 m guy-wired wind measuring tower was installed by APUA under the supervision of CREDP in June 2010 (**Figure 2-28**).

2.3.2 Preliminary Results of Wind Measuring

The first wind data from Antigua show a marked diurnal variation with a peak at about 11 o'clock (**Figure 2-26**). As such, the midday load peak experienced by APUA from **Figure 2-27** is partly served.

As the measuring campaign has not been finished, a final decision about the further project development cannot be taken. The results obtained so far indicate about 10 % higher wind resources in the mountain sites, which gives about 15 to 20 % higher annual average production.

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[26] see **Annex 3** – Summary of Results – April 2010

Figure 2-24:
Telecommunication Tower at Antigua (McNish Mountain) indicating two adjacent potential Wind Park Sites

Photo: B. Jargstorf, February 2011

Figure 2-25:
Telecommunication Tower at Guinea Bush and Vertical Wind Shear obtained from Wind Data

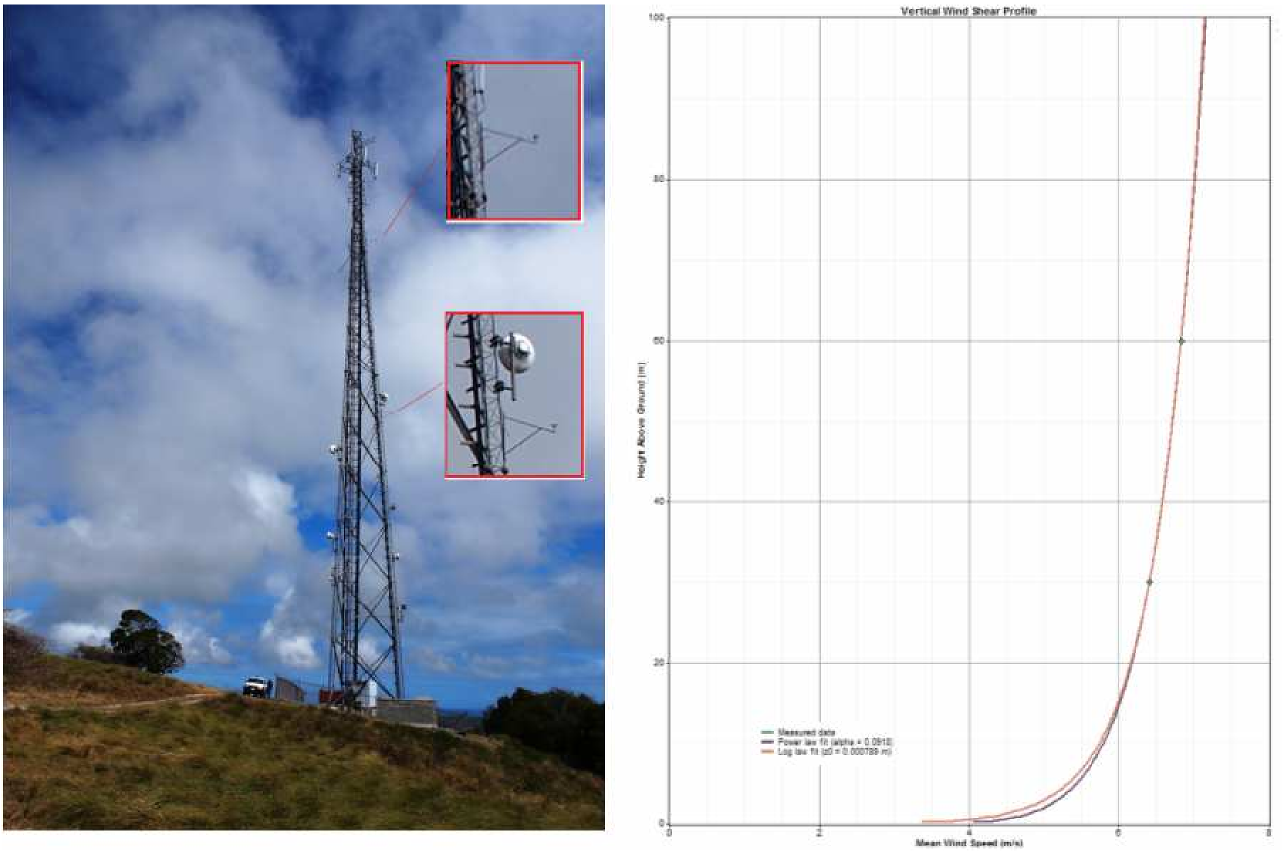


Photo: B. Jargstorf, February 2011

Figure 2-26:
Crabbs Peninsula - Antigua
Average Diurnal Variation

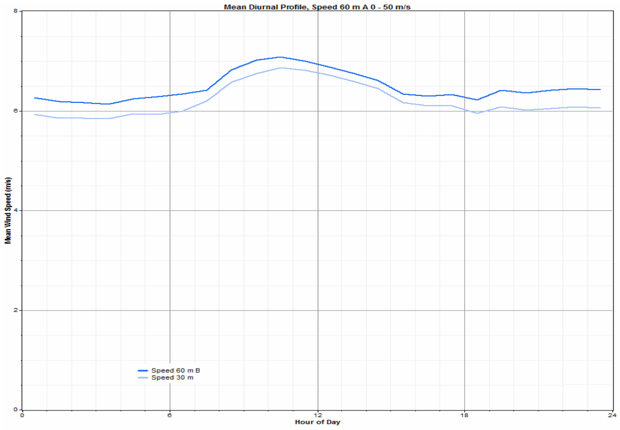
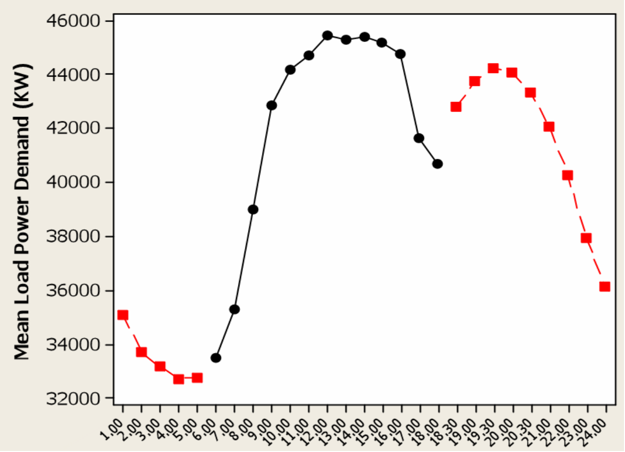


Figure 2-27:
APUA – Antigua – Typical Daily Load Curve



2.3.3 Barbuda

As the load situation in Barbuda is completely different from that at Antigua, a joint project implementation using the same type of wind turbines seems highly unlikely.

With a peak load below 200 kW, Barbuda can be considered as a potential site for a wind/diesel system – similar to the situation in Grenada and Carriacou.

The special problems with wind/diesel systems, - where the installed wind power has the same magnitude as the diesel power – as opposed to a grid-parallel operation of wind parks in isolated networks, where the wind power installation is much smaller than the diesel power plants, are discussed in detail in **Section 2.7.3** (Carriacou). Unfortunately, the power requirements in Carriacou are considerably higher than in Barbuda – therefore, no common project approach is possible.

Figure 2-28:
Hoisting of the 60 m Wind Measuring Tower at Crabbs – 18th of June, 2010

Photo: B. Jargstorf, June 2010

Box 2: Capacity Factor of Wind and other Power Plants

On 16th of April, 2010 an article was published by the ANTIGUA SUN, entitled "**Navigating the Murky Waters of 'Clean Energy'**".[27] Obviously, when putting the term Clean Energy in inverted commas, the writer has his doubts about its usefulness. This is definitely the case with this article.

One can interpret the whole article as a warning to the general public, not to expect too much from renewable energy, in particular from wind energy. The usual disadvantage of wind energy are discussed at length:

- the lack of predictability (i.e. not to know when the wind is blowing and how much it contributes to the grid);
- the need for back-up thermal capacity, in case the wind production suddenly drops;
- a non-concurrence of wind speed peaks and demand peaks;[28]

Basically, wind energy is described as an non-dispatchable form of energy. In addition, but without indicating hard evidence it is assumed that RE is not cost-competitive to fossil fuels.

"*Let us face the facts, wind and solar systems are neither free not cheap and in all analyses one has to take into consideration the true cost of integrating them into the grid. Can we therefore say off hand that their introduction will lead to an immediate and rapid decrease in the retail price of energy to the consumer? Your answer will now be as good as mine. It is primarily for these reasons that wind and solar systems have always had to be highly subsidized.*"

The writer is openly warning the public: if you insist on the introduction of renewable energy in Antigua, you will have to face higher retail prices.

However, there is no evidence for such an automatism – in the case of Bonaire, the introduction of large amounts of wind energy lead to a reduction in retail prices of 10 - 20 %.[29] The calculations undertaken with wind measurements in Saint Lucia and Saint Vincent indicate average specific energy cost below 8 US$cts per kWh and show that electricity from wind is cheaper than electricity from diesel power plants, as long as the oil price stays below ~ 50 US$ per barrel.[30]

One of the reasons – according to the ANTIGUA SUN article – why wind power is so expensive, is the low capacity factor. You install 1 MW, but only get 250 kW on average from it.

In the article it is assumed that something uneconomic as that, never happens with thermal power plant – here you install 1 MW and get 1MW of power.

Against this situation, let us look at the capacity factors of Antigua. Here is the definition:

*The **Capacity Factor** (also known as Load Factor) is the percentage of power production as a fraction of the nameplate capacity of the wind energy conversion system. This can be the instantaneous value, but often will be the yearly mean. The latter can also be expressed as Full Load Hours via a multiplication with 8,760, i.e. the number of hours of one year.*[31]

When looking at the seven different diesel power stations of Antigua totalling 122 MW installed power with the actual production data from 2009, we calculate the following capacity factors:

	Installed Power	**Generation in MWh**	**Capacity Factor**
Friars Hill	13 MW	7,598	6.7 %
Crabbs	5.1 MW	6,610	14.8 %
West Indies Oil	5 MW	5,461	12.5 %
Aggreko Friars	10.2 MW	23,707	26.5 %
Aggreko Crabbs	10.2 MW	3,455	3.9 %
APC 1 Black Pine	28 MW	128,226	52.3 %
APC 2 (17+33 MW)	50 MW	148,614	33.9 %
Total 2009	**122 MW**	**323,670**	
Average			**21.5 %**
APUA (Chinese)*	30 MW	108,000	41.1 %

*) currently under construction, production figures as planned for 2011

This average 21.5 % capacity factor compares with capacity factors of wind parks indicated in Jamaica between 30 – 35 %, in Suriname between 28 – 34 % and in Bonaire of ~ 40 %.[32]

Author of the article is Eng. George I. Pigott, Deputy Chairman, APUA Board of Commissioners.

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27) see **Annex 4 – ANTIGUA SUN article from 16-04-2010**

28) well, for Antigua, first measurements indicate that the peak load is congruent with the daily wind speed peak (see **Figure 2-26** and **2-27**)

29) see **Section 2.13 - Bonaire**

30) see **Section 2.11** and Section **2.12**

31) see also **Box 3 – Capacity Credit**

32) see **Section 2.1**, **Section 2.4** and **Section 2.13**

2.4 Suriname

2.4.1 CREDP Wind Measuring

In April 2008, the Fundashon Antiyano Pa Energia from Curaço was charged by CREDP to conduct a wind energy mission in Suriname. This mission, undertaken by Ms. Margo Guda, had three principal tasks:

1. provide a preliminary assessment of potential wind park sites, already pre-selected by the Suriname side;
2. propose a measurement campaign; and
3. provide support for capacity building in the field of wind measurement and data evaluation.

From a total of five proposed sites – Nieuw Nickerie, Coronie, Paramaribo, Nieuw Amsterdam, and Galibi – two sites were chosen for the installation of wind measurement towers. All sites are located at the coastal strip of Suriname (**Figure 2-29**). After discussions with the Faculty of Technology of the Anton de Kom Universiteit van Suriname – Cornel Wijngaarde and Anand Kalpoe – two sites were selected for a wind measurement campaign: Nieuw Nickerie on the border to Guyana in the West and Galibi at the border to French Guiana in the East. The measurement were conducted in 2009 by those persons of the University under the CREDP program “Wind Speed Measurement in Suriname at Nw. Nickerie and Galibi”.

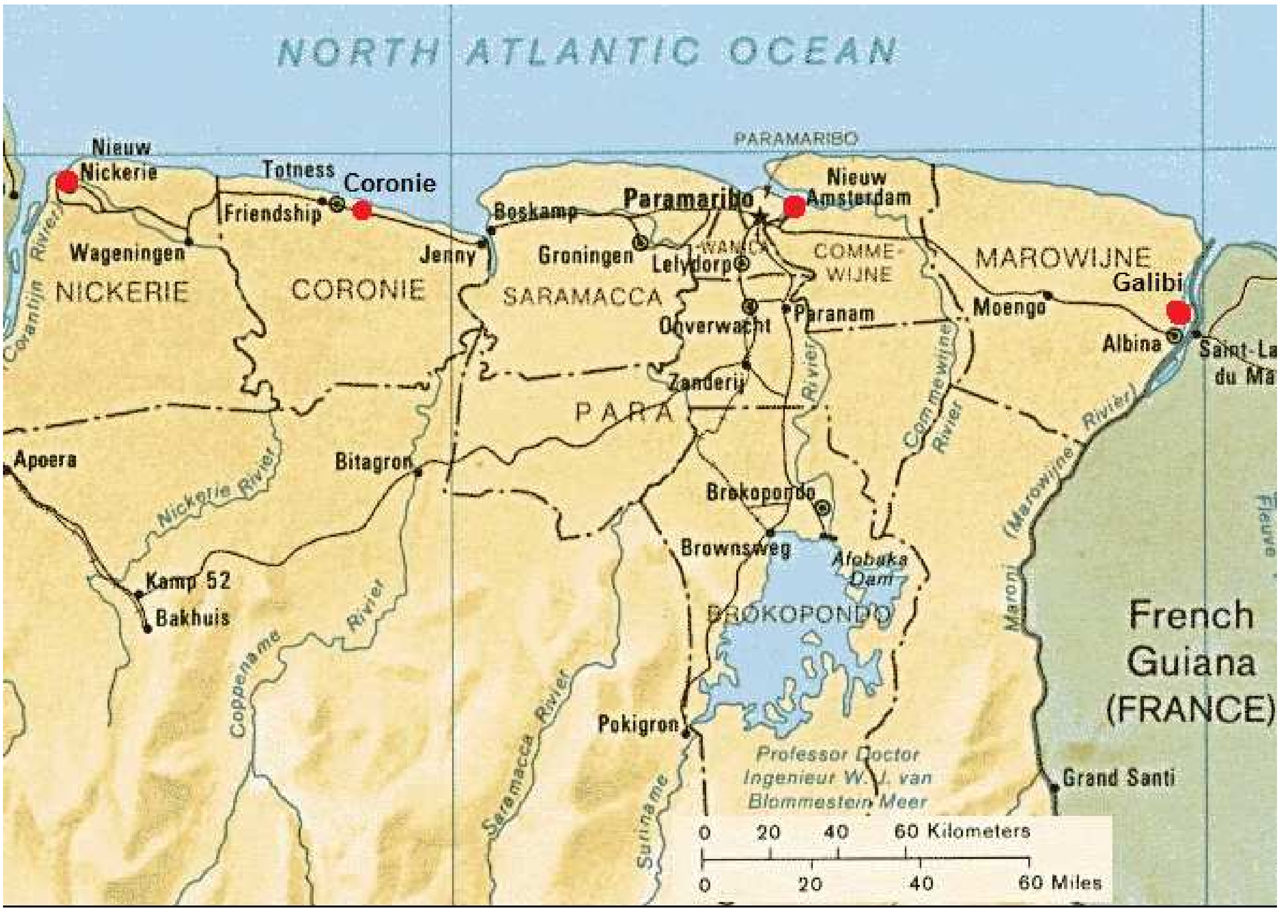
Both sites are not connected to the interconnected grid of Suriname. Nieuw Nickerie in the principal rice-growing area of Suriname has an isolated electric grid based on a diesel power plant with 16.3 MW installed power. Galibi is a thriving fishing village with only a few kW electricity demand.

The results of the wind measurements from a one-year measurement campaign are discussed in the following sections, along with proposals for an implementation of wind power projects.

2.4.2 Nieuw Nickerie

Data were available from 8th November 2009 to 18th November 2010. At 30 m above ground, the Nieuw Nickerie site features an annual average wind speed of 5.47 m/s. However, due to the micro-location of the measurement station higher wind speeds nearby might be found.

Figure 2-29:
Location of Pre-Selected Wind Measuring Sites – Northern Suriname



Source: Google map, *modified*

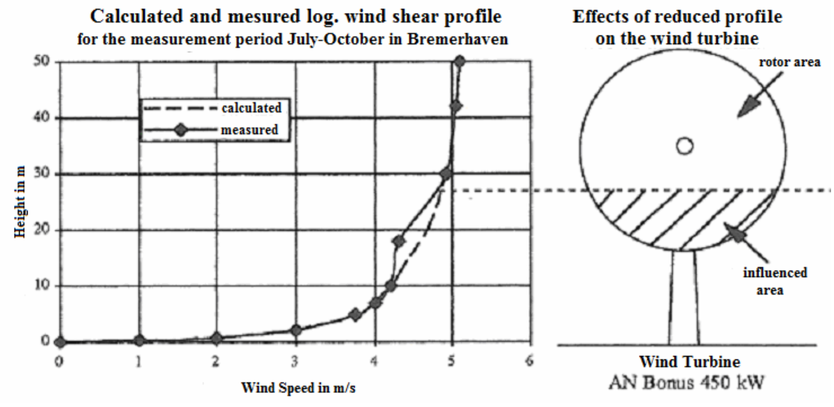
The 30 m NRG Systems guy-wired tower has been installed approx. 100 m behind the dyke, between a two-storey building (the meteorological station of the airport) and an aircraft hangar (see **Figure 2-30**).

Figure 2-30:
Micro-Location of the 30 m Wind Measuring Tower – Nieuw Nickerie

Photo: B. Jargstorf, February 2011

But not only the adjacent buildings are expected to have a negative influence on the measured wind speeds, but, even more so, the relative position of the meteorological tower to the dyke. Detailed measurement undertaken within the scope of a MSc thesis in Germany showed the influence of the dyke on the vertical wind shear. After a few years of operation it was observed that the wind turbines of the wind park Luneort (Bremerhaven) were producing about 10 – 15 less energy than predicted, even though the measured wind speeds were according to plan.

Figure 2-31:
Influence of Dyke on a Wind Turbine



Source: Oliver Bunk, "Deichnähe vermindert Ertrag und Lebensdauer" (Closeness to Dyke reduces Energy Output and shortens Life Time), **in:** WindEnergie Aktuell 11/96, p. 30 – 31, *modified*

Through measuring with several anemometers in the rotor area, a detailed wind speed profile could be established (see **Figure 2-31**). Output calculations could prove that this irregularity in the vertical wind shear profile was responsible for the 10 – 15 % reduced energy yield.

Figure 2-32:
Wind Turbines behind Dyke (Bremerhaven)

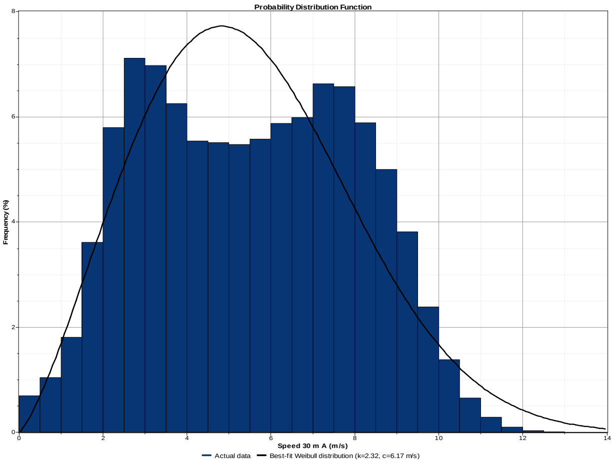
Photo: B. Jargstorf, June 1994

The wind turbines were installed close to an airport (similar situation as in Nieuw Nickerie) – therefore a re-location or a higher hub height was not possible (height limitation – see red warning spinners in **Figure 2-32**). On account of the unwanted dyke-influences on the rotor area, the project had to live with 10 – 15 % less energy output for the project lifetime (20 years). As a result, the (private) investor did not receive his targeted return of investment.

To avoid situations like this, it is proposed that a wind park site closer to the dyke but at the same elevation of the dyke is identified. This site will render quite higher annual average wind speeds than measured at the current station. Suitable candidate sites have been identified in close distance to the measuring site of Nieuw Nickerie – a bit further to the West.

The measured annual frequency distribution at Nieuw Nickerie shows a particular characteristic with two relative maxima (**Figure 2-33**). This relative rare phenomenon occurs, when a site is under the influence of two distinctive wind regimes during the year, one with marked frequency distribution at the lower wind speed range, and another at the higher wind speed range – the resulting frequency distribution then refuses to have a best-fit with a Weibull function (see **black line** in **Figure 2-33**).

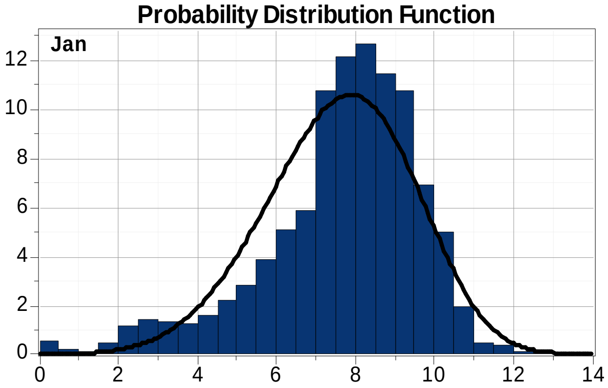
Figure 2-33:
Nieuw Nickerie – Annual Frequency Distribution



Source: Cornel Wijngaarde and Anand Kalpoe, „Wind Speed Measurements in Suriname“ paper presented at the “The Future of Wind Energy in Suriname”, 16-02-11

The two distinct wind regimes at the Suriname coast correspond to the strong wind season from December to April (dry season, see **Figure 2-34**) and to the low-wind season (rainy season, see **Figure 2-35**).

Figure 2-34:
N. Nickerie – Frequency Distribution January



Wind data from the Brazilian coast, at about 2,500 km further to East of Nieuw Nickerie, shows a similar frequency distribution, however, with considerable higher annual average wind speeds of ~ 9 m/s at 10 m above ground (**Figure 2-36**).

Figure 2-35:
N. Nickerie – Frequency Distribution August

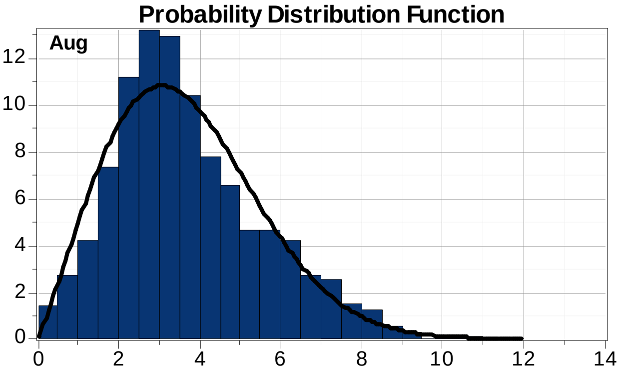
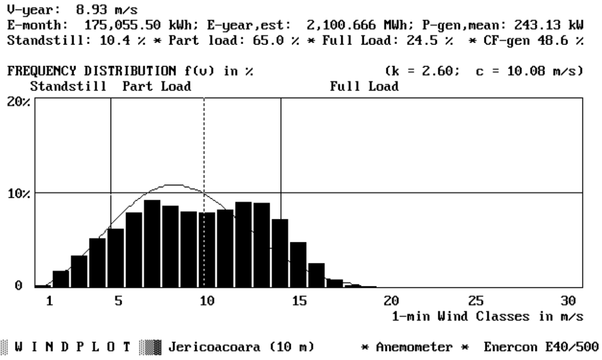


Figure 2-36:
Annual Frequency Distribution – Jericoacara (Cearà, Brazil)



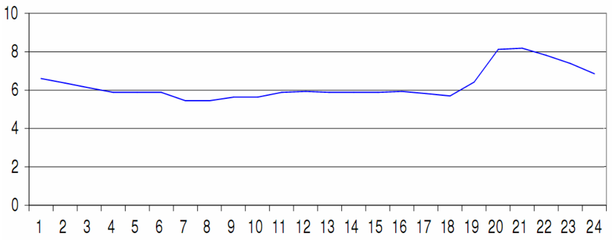
Source: GTZ, Tandem GmbH (B. Jargstorf, T. Könemund), “Windenergieprogramm TERNA Brasilien, Demonstrationswindpark 3 MW”, April 1993

To be on a conservative side for an energy output estimation, we use the measured data from Nieuw Nickerie and not the higher wind speeds which can be expected on the dyke. Also, we employ a projection of the vertical wind shear from measured wind speeds to hub heights > 60 m, where an annual wind speed of more than 6 m/s can be reached (see **Figure 2-38**). Thus, the negative influence of the dyke can be avoided.

The relative moderate wind speeds require wind turbines with a low specific installed generator power, preferably with values below 300 W/m^2. These are normally wind turbines designed according to the IEC Wind Class III or IV (see **Figure 2-39**).

With absolute minimum loads in the diesel power station of Nieuw Nickerie in the range of 6 MW (**Figure 2-37**), a grid-parallel wind park could have a maximum installed power of 3 MW – the same size as the wind park Munro in Jamaica (see **Section 2.2**).

Figure 2-37:
Typical Daily Load Curve in MW
Clara Power Station, Nieuw Nickerie



Source: Samuel Mehairjan et al, “Wind Energy Interconnection in Nickerie”, paper presented at the “The Future of Wind Energy in Suriname”, 16-02-11, *modified*

However, for the considerable lower average wind speeds in Suriname we chose the Wind Class III version of the UNISON wind turbine, featuring a rotor diameter of 57 m and a tower height of 68 m – with otherwise identical technical specifications (see **Figure 2-40**).

Calculating the annual energy output with this WC III turbine (UNISON U57), we arrive at 1,817 MWh/a and a capacity factor of 27.6 %. The WC I turbine with 50 m rotor diameter and 50 m tower (as in Munro, Jamaica) would have only produced 1,217 MWh/a with a capacity factor of 18.5 %.[33]

This higher output is the result of the lower specific generator power of the WC III turbine: it features a value of 293 W/m^2, while that of the WC I turbine is 382 W/m^2. Currently, more and more turbines specifically designed for low and moderate wind regimes become available, with specific generator powers between 200 and 300 W/m^2. In doing so, the wind turbine manufacturers considerably broaden the wind speed range where their turbines can operate economically.[34]

Thus, a 3 MW wind park at Nieuw Nickerie could yield an annual production of 7.3 GWh and reduce the fuel consumption in the diesel power plant by approx. 9 %. Proposals for grid connection had already been presented by the technical director of the Clara Diesel Power Plant in Nieuw Nickerie.[35]

Figure 2-38:
Nieuw Nickerie - Vertical Wind Shear

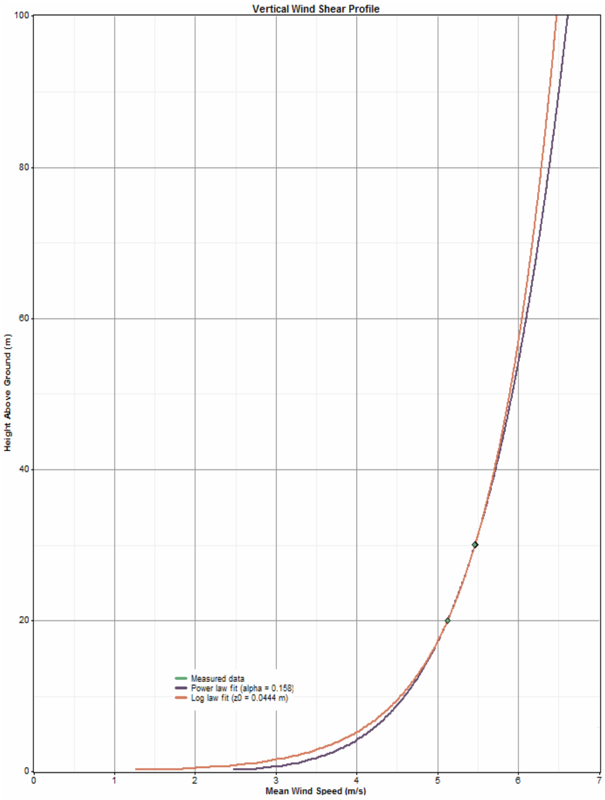


Figure 2-39:
IEC Wind Classes for Wind Turbines

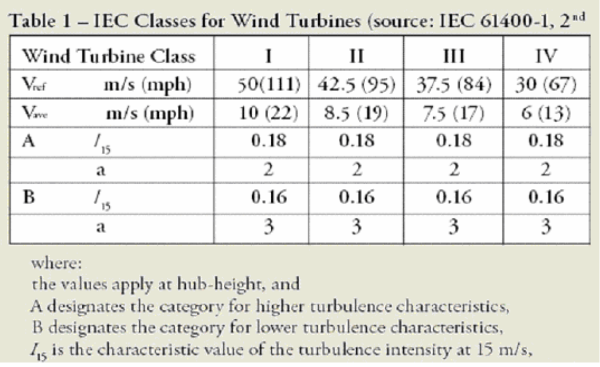
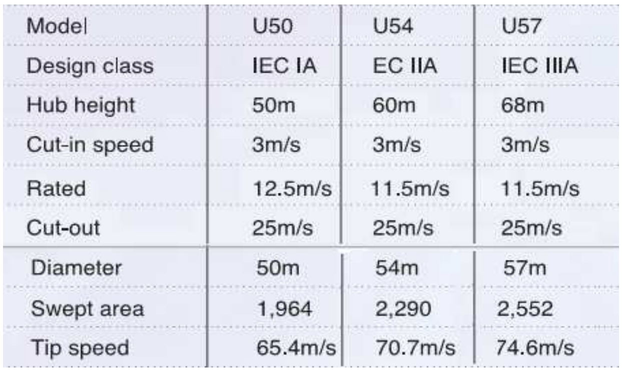


Table 1 – IEC Classes for Wind Turbines (source: IEC 61400-1, 2nd

Wind Turbine Class		I	II	III	IV
V_{ref}	m/s (mph)	50(111)	42.5 (95)	37.5 (84)	30 (67)
V_{ave}	m/s (mph)	10 (22)	8.5 (19)	7.5 (17)	6 (13)
A	I_{15}	0.18	0.18	0.18	0.18
	a	2	2	2	2
B	I_{15}	0.16	0.16	0.16	0.16
	a	3	3	3	3

where:
the values apply at hub-height, and
A designates the category for higher turbulence characteristics,
B designates the category for lower turbulence characteristics,
I_{15} is the characteristic value of the turbulence intensity at 15 m/s,

Figure 2-40:
UNISON U5x - One Turbine – Three Designs



Model	U50	U54	U57
Design class	IEC IA	EC IIA	IEC IIIA
Hub height	50m	60m	68m
Cut-in speed	3m/s	3m/s	3m/s
Rated	12.5m/s	11.5m/s	11.5m/s
Cut-out	25m/s	25m/s	25m/s
Diameter	50m	54m	57m
Swept area	1,964	2,290	2,552
Tip speed	65.4m/s	70.7m/s	74.6m/s

Source: company brochure UNISON, *modified*

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[33] as a rule of thumb, wind turbines should operate with more than 20 % capacity factor to allow economic operation

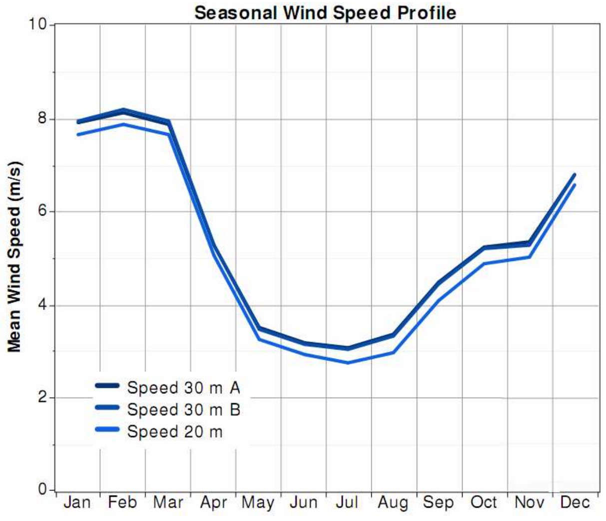
[34] recently, SIEMENS Wind Power (SWP) developed a wind turbine with an extremely low specific generator power of 230 W/m^2 – see http://www.windpowermonthly.com/news/1059670/Close---Siemens-revamps-23MW-turbine-direct-drive-new-rotor

[35] Samuel Mehairjan et al, “Wind Energy Interconnection in Nickerie”, paper presented at the “The Future of Wind Energy in Suriname”, 16-02-11

2.4.3 Galibi

The wind data from Galibi show a similar extreme seasonal variation as in Nieuw Nickerie (see **Figure 2-41**).

Figure 2-41:
Galibi - Monthly Wind Speeds in m/s



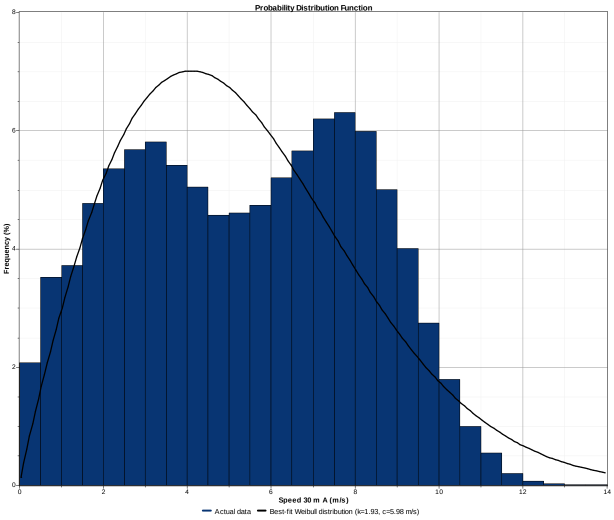
Source: Cornel Wijngaarde and Anand Kalpoe, „Wind Speed Measurements in Suriname“ paper presented at the “The Future of Wind Energy in Suriname”, 16-02-11

The measured annual average wind speed at 30 m in Galibi is with 5.33 m/s slightly below that of Nieuw Nickerie with 5.47 m/s. However, also Galibi features a relatively unfavourable micro-location, due to the nearby houses and vegetation (see **Figure 2-42**).

Figure 2-42:
Galibi – Surroundings of 30 m Mast[36]

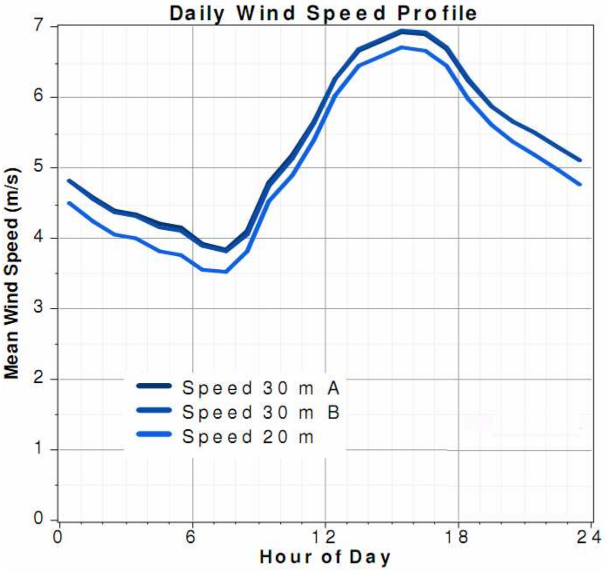
The frequency distribution in Galibi features a slightly higher maximum at around 8 m/s than Nieuw Nickerie – therefore, one can expect higher specific energy outputs there, even with lower average wind speeds (**Figure 2-43**).

Figure 2-43:
Galibi – Annual Frequency Distribution[26]



Favourable for the implementation of wind energy at Galibi is the diurnal variation of the wind speed, which features a marked maximum at 16 to 17 o’clock (**Figure 2-44**). Therefore, a stand-alone wind energy system needs only about 2 to 3 hours of battery storage to cover the peak load, expected to be experienced after sunset.

Figure 2-44:
Galibi – Diurnal Variation of Wind Speeds[26]



The (fishing and tourist) village of Galibi does not feature a 24 h electricity supply system. Currently, small diesel power generator(s) supply electricity in the evening hours or when needed. Details about peak demand and operation hours are not known.

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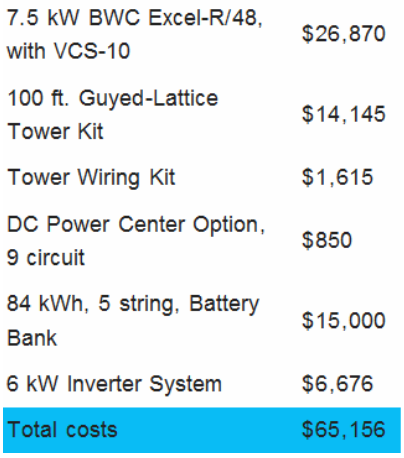
36) Cornel Wijngaarde and Anand Kalpoe, op. cit.

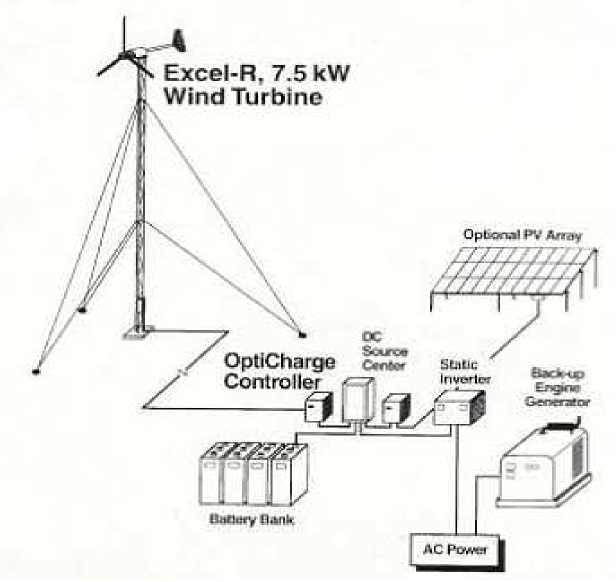
In this situation it is proposed to install a small wind turbine either as a grid-parallel or part of a battery system in Galibi – without further design studies. Such proven small wind turbines – for example a 7.5 kW Bergey turbine from the US[37] – cost about 27,000 US$ and have a very long and good track record with high reliability (gearless design).

Figure 2-45:
Complete Battery Operated Grid System with 6 kW Inverter[16]



7.5 kW BWC Excel-R/48, with VCS-10	$26,870
100 ft. Guyed-Lattice Tower Kit	$14,145
Tower Wiring Kit	$1,615
DC Power Center Option, 9 circuit	$850
84 kWh, 5 string, Battery Bank	$15,000
6 kW Inverter System	$6,676
Total costs	$65,156

Figure 2-46:
Battery Operated Grid System with Diesel Backup and Optional PV Array



Source: Bergey Windpower, U.S.A., company brochure

A thorough design study for a wind/diesel system could cost at least twice as much as the turbine – thus, a pragmatic approach of a "test operation" of the Bergey turbine is preferred. Then, with relative low efforts, the acceptance of the wind turbine in Galibi can be researched, and possible further upgrades (with additional turbines, battery storage etc.) can be planned.

As can be seen in **Figure 2-45**, a complete battery operated grid system with a 6 kW inverter and a 83 kWh battery bank costs 65,000 US$ - it can be bought of-the-shelf from Bergey.

Given the seasonal distribution of wind speeds, where May to August have below 3.5 m/s monthly wind speeds (**Figure 3-41**), a PV generator should also be integrated, as the contribution from wind alone during this period of time will not be enough.

In **Figure 2-46** an example of a small stand-alone system on the base of wind power is given, where battery storage, a diesel generator as back-up and a photovoltaic generator to bridge over low-wind speed times are integrated.

In practice, the successful implementation of such small energy supply systems on a village level depends mainly on the availability of technical expertise in the village and a strong political will for its implementation. Projects which have been developed by universities and research institutions and "transferred" to the village at the periphery of the country were normally not successful. The initiative has to come from the village.

Also, from the beginning, people who profit from the electricity have to pay for it – otherwise, the costs for service and repair (replacement of batteries every two to three years) cannot be recovered.

One of the biggest problem often only surface when such stand-alone projects are technically successful, i.e. when they are able to bring to the village a reliable electricity supply: in that case the people in the village are buying more and more electrical appliances and soon overload the system. A such, one might say, these stand-alone systems become easily victims of their own success.

In any case, the smaller the system, the higher the specific costs of electricity generation, and also the higher the technical complexity. In the case of Galibi, only a hybrid system using both wind and solar power can be successful – the seasonal variation of wind speeds are too extreme.[38]

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37) see http://www.bergey.com/

38) as a rule, a wind only stand alone system has to be dimensioned according to the months/the season with the absolute lowest wind

2.4.4 Large Wind Parks

Larger wind parks operating in parallel with an interconnected grid are currently the dominant wind energy application – more than 99 % of all wind turbines world-wide are operating in that mode (see **Figure 2-47**).

In the case of Suriname, as an oil-producing country, there need to be substantial advantages when engaging into large-scale wind power.

The basic rationale behind such a policy should be similar to that of Trinidad and Tobago, namely to use renewable energy sources, as this leaves oil and gas unexploited today and allows it to be sold on the world market later, when considerably higher prices have been reached (see **Section 2.5.6**).

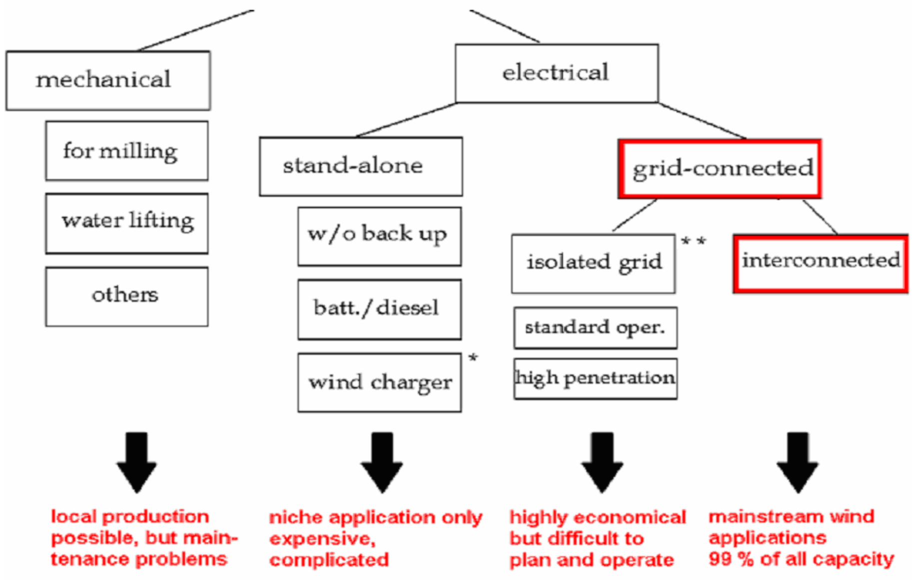
In addition, obvious advantages with regard to environmental protection, local job creation and energy supply diversification are associated with the application of wind energy.

In the case of Suriname with a large proportion of hydro power in the national interconnected grid, also another advantage derives from the use of (large) grid-parallel wind power: wind energy operates as an water saver and, thus, prolongs the use of hydro power into the dry season. Taking the water table of the Afobaka Lake as an example, the favourable combination of wind and hydro power shall be demonstrated.

Simulating a UNISON U57 turbine with the wind data from Nieuw Nickerie, we get monthly productions varying from as low as 60 MWh in July and 270 MWh in January – a variation of 1:4.5. As can been seen in **Figure 2-48**, the wind resources in Suriname are directly complementary to the availability of water in the Afobaka Lake, measured in the height of the water table above sea level.

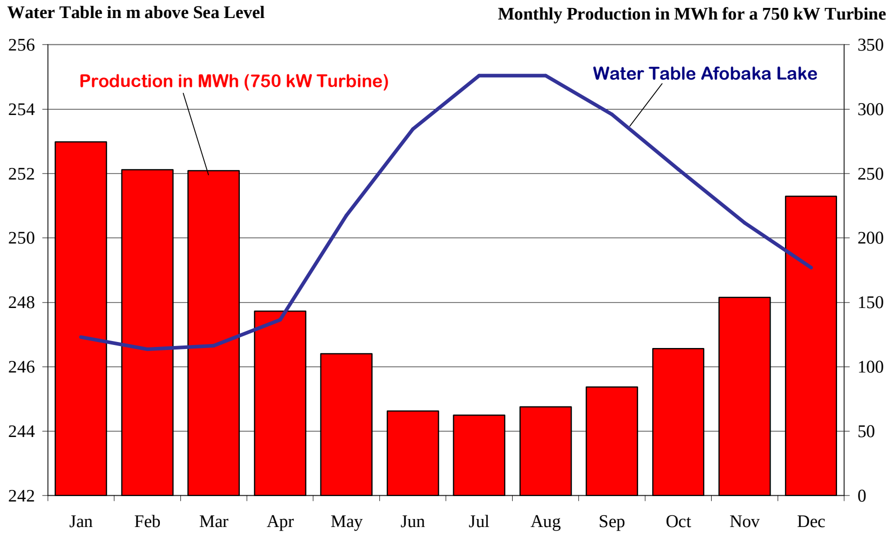
When planning a wind park operating in parallel with the interconnected grid in Suriname, however,

Figure 2-47:
Wind Energy Applications --- ‘Family Tree’



*) the case of Galibi **) the case of Nieuw Nickerie

Figure 2-48:
Wind and Hydro – Ideal Combination in Suriname



Source: B. Jargstorf (Factor 4 Energy Projects GmbH), “Wind Energy in Suriname”, paper presented at the seminar “The Future of Wind Energy in Suriname”, 16-02-11

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speeds – in Galibi May to August with less than 4 m/s. Thus, a wind only system would be extremely costly …

the turbine size calculated for Nieuw Nickerie (750 kW) will give suboptimal results. To profit from economies of scale effects, standard utility wind turbines in the MW-scale should be selected.

These turbines are available with extreme high towers for low and medium wind regimes and offer good economic results there. An 2 MW turbine (Enercon E82) with 138 m hub height would operate with the wind data from Nieuw Nickerie with a capacity factor of 32.4 % - an excellent value, considering that the average capacity factor of typical European wind parks is just about 25 %.

With this assumption, a wind park with 30 MW could yield an annual generation of 85.2 GWh and contribute considerably to the interconnected grid of Suriname.

2.4.6 Summary and Recommendations

In Suriname, with wind power being directly complementary to the hydro power, capacity credits for a wind park installation between 30 and 40 % can be expected. As such, a wind park will not only operate as a fuel saver, but also replace firm, dispatchable power in the interconnected grid.

Compared to standard wind parks, therefore, the economic analysis for a (large) grid-parallel wind park in Suriname will produce considerably better results when taking into account the economic effects of the capacity credit.

Thus, the operation of wind parks in Suriname is expected to be an economic venture, even when considering

- that Suriname is an oil producing country;
- that Suriname has a large percentage of (cheap) hydro power in its energy mix; and
- that Suriname's wind resource are only moderate.

Judging from the first results of the coastal wind measuring campaign with data from Nieuw Nickerie and Galibi, three different wind energy project types can be proposed:

1. Large Wind Parks in parallel to the interconnected Grid

Example: 15 x 2 MW for extending the full-load capacity of Afobaka Hydro Power Plant, Annual energy yield for a Enercon E82 " MW turbine with a 138 m tower: 5,682 MWh per turbine (32.4 % capacity factor), Annual generation: 85,230 MWh with an expected capacity factor between 30 and 40 %.[39]

2. Wind Parks in parallel to an isolated Grid

Example: 4 x 750 kW UNISON U57 at Nieuw Nickerie, Annual energy yield 1,817 MWh/a (27.6 % capacity factor). Annual generation: 7,268 MWh , resulting in ~ 9 % wind energy penetration.

3. Wind/Diesel or Battery System for Village Electrification

Example: 7.5 kW Bergey wind turbine in Galibi with an annual generation of 14 MWh (21.4 % capacity factor) and additional photovoltaic generator to bridge over the low wind speed months from June to August.

For all these different wind energy applications, additional studies should be undertaken, in order to prove their technical and economic viability. Given the raising world market prices for fossil fuels, however, wind energy utilisation will be an economic venture in Suriname – sooner or later.

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39) note, that a suitable location has not yet be identified for such a project – for more information, see **Annex 5** – Wind Energy in Suriname

Box 3: Capacity Credit

The capacity effects of wind power are not well-defined in the relevant literature. There is often confusion between capacity credit and capacity factor and a lack of a clear distinction between the different, but similar terms like firm capacity, displaced capacity etc.

Here we follow the definitions of Milligan,[40] as cited by Giebel from Risø National Laboratory.[41]

The easiest way to establish capacity effects of wind energy in the grid is by **firm capacity**. This is the fraction of installed wind capacity that either is online at all times or with a probability similar to the availability of conventional (i.e. non-renewable energy) power plant. Fossil fuel plant availabilities have a wide range of variability in the literature; they are given values of between 79 and 92 % by some and of 84 % by others, referring to the US national average for the forced outage rate as 12.4 % and the maintenance outage rate as 13.6 %.

Load Factor (also known as Capacity Factor) is the percentage of power production as a fraction of the nameplate capacity of the wind energy conversion system. This can be the instantaneous value, but often will be the yearly mean. The latter can also be expressed as Full Load Hours via a multiplication with 8,760, i.e. the number of hours of one year.

Typical values are 20 - 30 %, or 1,500 - 3,000 full load hours, respectively. For Nieuw Nickerie we had calculated capacity factors of 18.5 % for the UNISON U50, 27.6 % for the UNISON U57 and 32.4 % for the Enercon E82 turbine

Penetration is the percentage of wind power in the grid. This is usually defined as the amount of wind energy delivered during a year, compared to the total electrical demand during that year. Additionally, sometimes an instantaneous penetration is used, being the current (10-min or one-hour) penetration. Instantaneous penetration can reach over 100 % in a regional grid with good wind resources, for example in coastal Germany or some areas of Spain. In that case, this region exports wind-generated electricity via the transmission network to other, far away load centres.

As a general rule, however, and to avoid problems associated with grid instability, instantaneous wind energy penetration rates stay below 50 % - this rate has been assumed for the dimensioning of the proposed wind park in Nieuw Nickerie.

Finally, the **Capacity Credit** assigned to a regenerative conversion plant is the fraction of installed capacity by which the conventional power generation capacity can be reduced without affecting the loss of load probability. A proper capacity credit assessment involves long-term statistical analysis of existing power plants and can therefore only be made through a full modelling of the power system, preferably on a hour-by-hour basis and stochastically including the probabilities for each power plant to drop out. This is quite an effort, and can usually only be done by the utilities themselves, or by research groups close enough to the utility company to get access to the complete set of power grid data. Results for capacity credit calculations for wind power are extremely low for just a single (small) project (~ 2 %) and increase with the number of turbines and whether they are installed over a wide area with different micro-climates

As a rule, wind power installations in Germany (currently ~ 28 GW installed wind power) have approx. 10 to 12 % capacity credit, meaning that, statistically over a whole year, they replace only 10 to 12 % of their installed capacity from conventional, non-renewable power plants.[42]

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40) see http://www3.interscience.wiley.com/journal/85010157/abstract?CRETRY=1&SRETRY=0

41) Gregor Giebel, “Wind Power Has A Capacity Credit A Catalogue Of 50+ Supporting Studies”, EWEC 2007

42) these are typically fossil fuel and nuclear power plants, but also the relative small installed base of hydro power plants is taken into account with this calculation.

2.5 Trinidad and Tobago

2.5.1 Current Plans of the Energy Ministry

As a net exporter of petroleum products, the new government of Trinidad and Tobago realizes the importance of renewable energy (RE) and energy efficiency as critical elements for sustainable development. Consequently, the Ministry of Energy and Energy Affairs (MEEA) is currently engaging in a systematic analysis of the country's wind resources, amongst other things. To this end, MEEA has edited the draft document "Request for proposal for conduct of wind resource assessment in Trinidad and Tobago (RFP)".[43]

During CREDP's visit at MEEA on 18th of February, 2011 the experts of MEEA and CREDP discussed this RFP and its underlying approach to wind energy development at Trinidad and Tobago.

CREDP has accumulated experience with wind resource assessment and the planning of wind power projects in the CARICOM region over the past 6 years. MEEA proposed that major issues of the joint MEEA/CREDP discussion from 18th of February be summarized in a Concept Note. The following text has been taken from the Concept Note forwarded to MEEA on 4th of March, 2011.

According to the Draft RFP, the main objective of this project is the promotion of the productive use of renewable energy to reduce GHG emissions and to diversify the local energy mix for power generation. The development of wind parks in Trinidad and Tobago is one step to-wards the forming of a low carbon society.

MEEA proposes a professional approach to achieve this objective in a three-phase project:

1st phase: preliminary area identification
2nd phase: area wind resource evaluation
3rd phase: turbine selection and micro-siting

It is planned to tender the complete project to an (international) consultancy firm which will carry out the works of all three phases subsequently – possibly supported by (a) local subcontractor(s) and/or local institutions (meteorological services, universities). Estimated time for phase 1 is 1.5 months, for phase 2 one year, and for phase 3 six months. Thus, a total project execution time of below 2 years is envisaged.

It is a well thought-through project approach which is professionally designed and which will be perfectly in a position to fully reach the project objective within the given time frame. However, against the background of CREDP's practical experience with wind resource assessment and wind park planning in the Caribbean, some remarks from the discussion between MEEA and CREDP are summarized here.

2.5.2 Wind Mapping in the Caribbean

Following a systematic evaluation of meteorological data and additional wind measuring stations, wind maps have been produced on various islands which indicate the average annual wind speeds for different regions for various heights above ground (typically 30, 50 and 80 m above ground). **Figures 2-49** and **2-51** show two examples of such maps which are created using specially designed software simulating the wind flow over the island's topography.

In every-day practice of wind park planning, CREDP's experience with such wind maps, however, is not encouraging. In particular, the value of the maps in helping to identify suitable potential wind park areas on the islands has been very limited.

This is due to the following reasons:

- on closer inspection, these wind maps result practically in maps which are identical to topographic maps, with different colours for different heights above sea level. The borderlines between different annual average wind speeds generally follow the contour lines. As such, no real new information is displayed in such maps;
- the absolute value of the modelled wind speeds as indicated in the maps is not reliable enough to base a site decision upon. Even if a preliminary site decision would be based on such a map, additional wind measuring for site selection would have to be undertaken. As such, having a wind map does not free oneself from wind measuring for site selection;
- as can be seen in the two examples of wind maps for Grenada and Dominica, they depict a sort of "paradoxical" situation: the absolute highest wind speeds with more than 8 m/s (orange, red and dark red colours) are shown only on the peaks of the mountain and – surprisingly – offshore to the North and the South of the islands. Both areas, however, are normally excluded from the list of potential wind park sites, due to obvious reasons, i.e. the accessibility of the sites for large cranes and equipment;[44]

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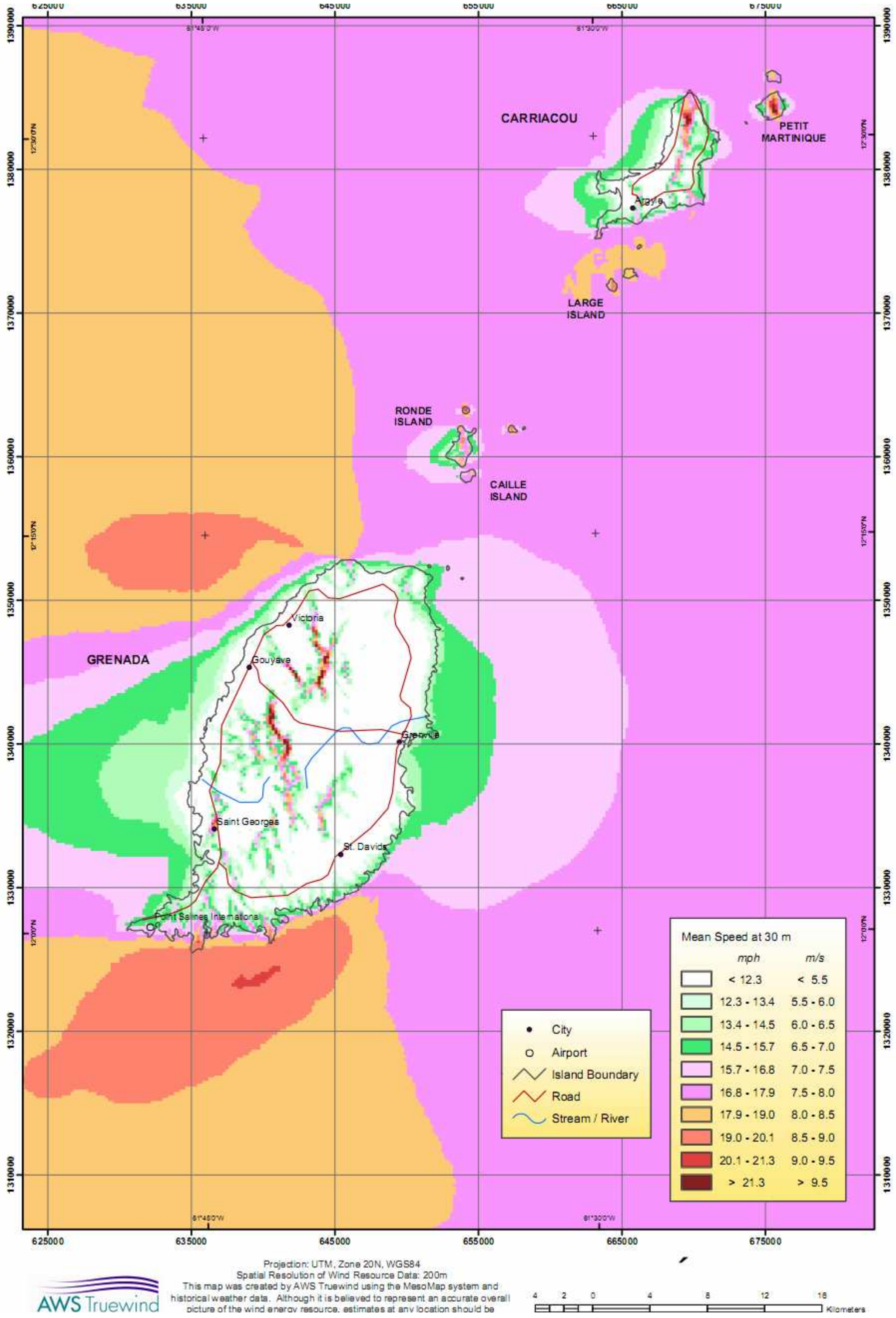
[43] see **Annex 6**

[44] the disappointing mapping result seems to come from the fact that only very limited wind data has been used as input - generally only one or two meteorological (airport) stations. As such the GIGO phenomenon holds true: Garbage In – Garbage Out.

Figure 2-49:
Wind Map for Grenada and Carriacou – with Annual Wind Speeds at 30 m above Ground



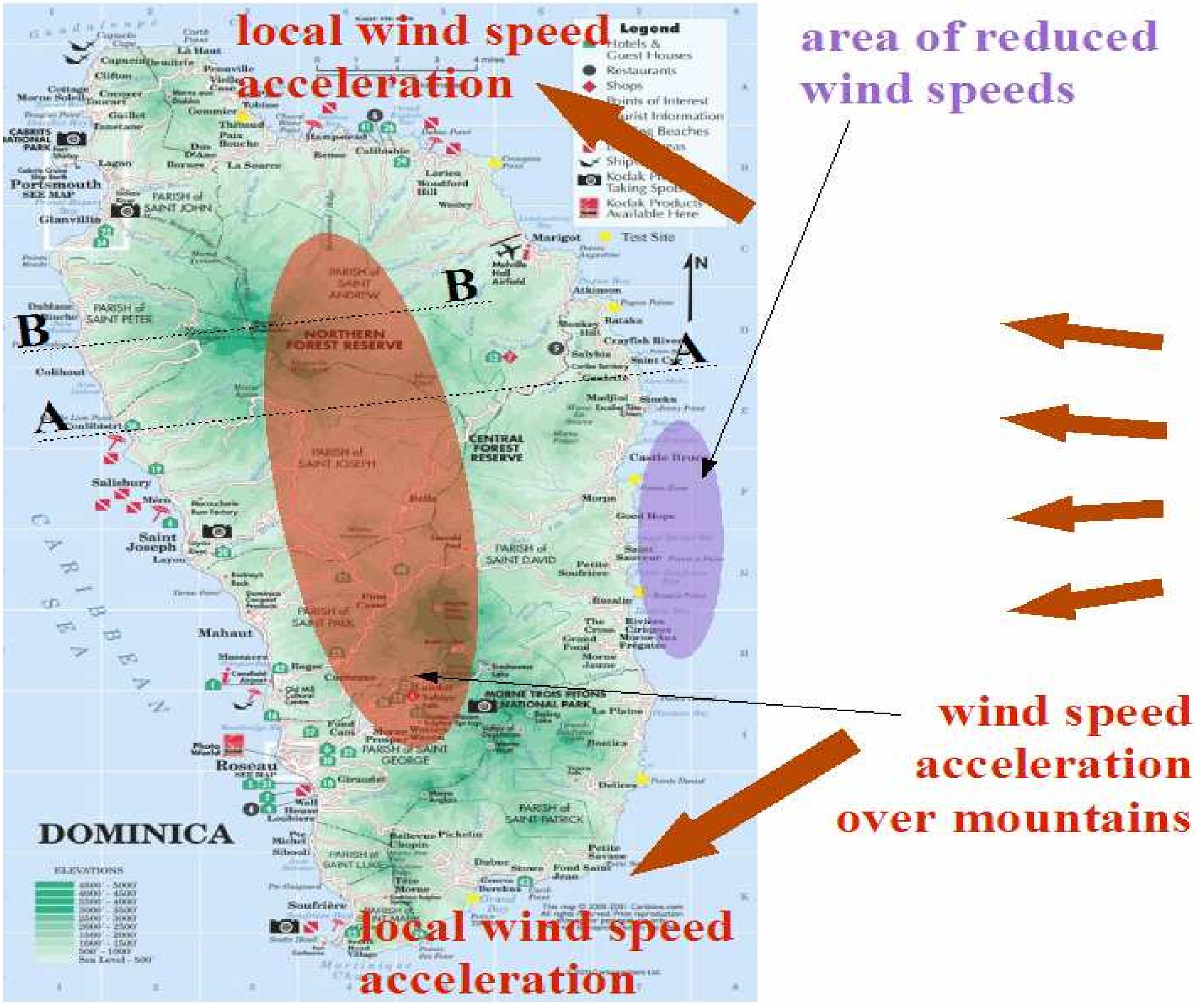
Projection: UTM, Zone 20N, WGS84
Spatial Resolution of Wind Resource Data: 200m
This map was created by AWS Truewind using the MesoMap system and historical weather data. Although it is believed to represent an accurate overall picture of the wind energy resource, estimates at any location should be

- a closer analysis also shows that the complete area of the island has to be covered by wind flow model-ling (i.e. for all grid points a wind vector has to be calculated by the wind mapping software), even though the majority of the island's surface is anyway not fit for wind turbine placements. These excluded areas are generally housing areas, towns and villages, industrial and tourist development areas, protected and military restricted areas, airports etc. On Caribbean islands, as a rule, generally less than 30 or even 20 % of the total land area would be a potential area for wind turbine placement: thus, up to 80 % of computing power is "wasted" from the beginning;
- a major disadvantage is the grid based calculation of wind flow model: with a 1,000 m grid, for example, one can have a valley of 500 m and a highly suitable ridge or hill top of 500 m. In the valley the model gives 3 m/s and on the hill 9 m/s annual average wind speed. Indicated in the map, however, are a moderate 6 m/s – thus, this highly suitable wind site is not represented in the map at all and has to be identified manually. Of course, a reduction in grid size (for example to 100 m) would show this site – but such small grid sizes are normally prohibitive as the computing power needs increase exponentially with the smallness of grid size.

When CREDP made its first detailed wind mission to Dominica in 2005 no wind map for that island existed. Just based on "engineering intuition" and previous experience with site selection on other islands under the influence of trade winds (i.e. extremely stable main wind direction), CREDP proposed areas with higher than average wind speeds for Dominica, very much in line with the wind map made later.

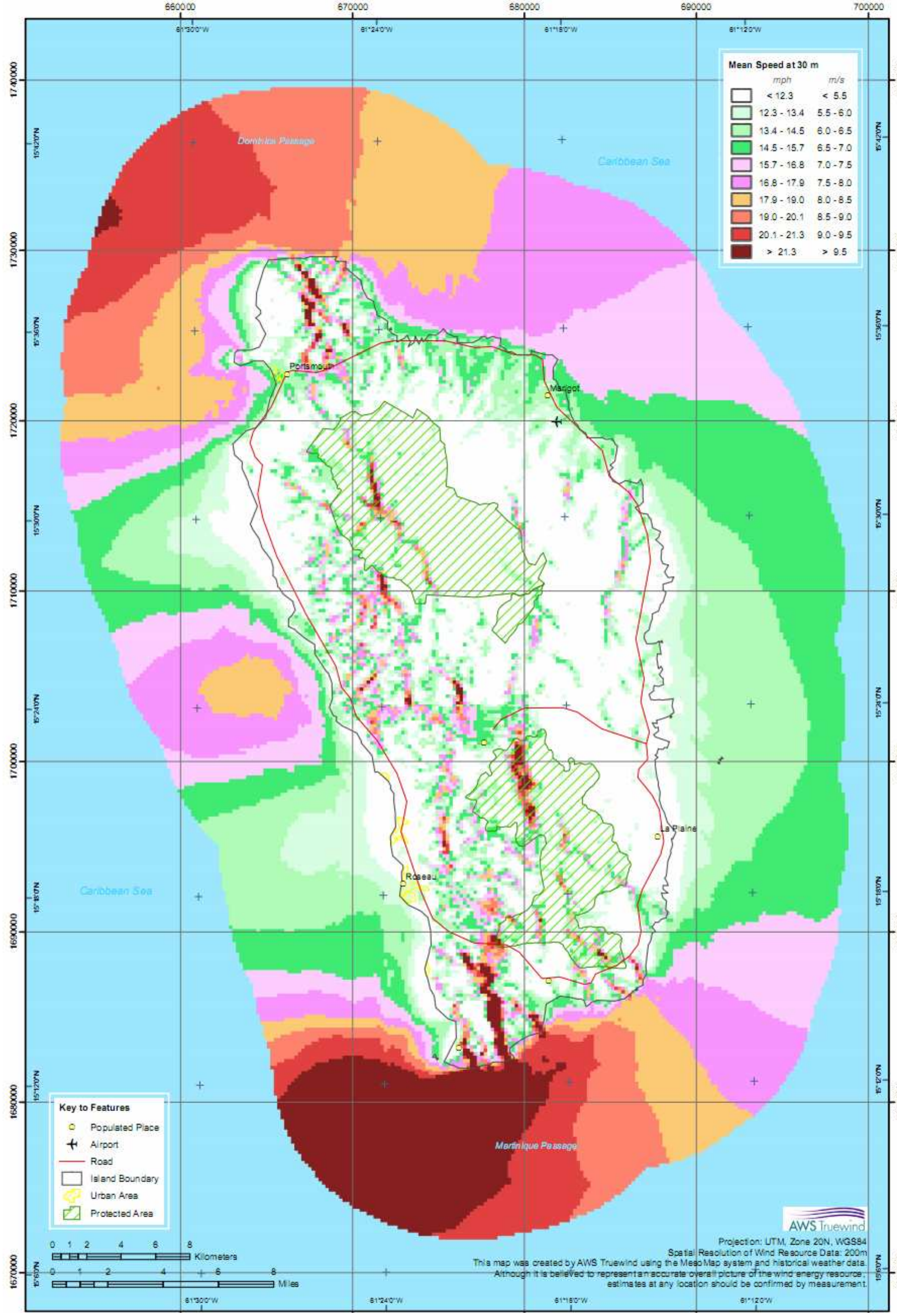
See **Figure 2-50** for CREDP's estimation of wind flow. A major input for this map has been a cross-section of the island according to **Figure 2-52**.

Figure 2-50:
CREDP's Basic Wind Flow Model for Dominica – Made before the AWS Truewind Map



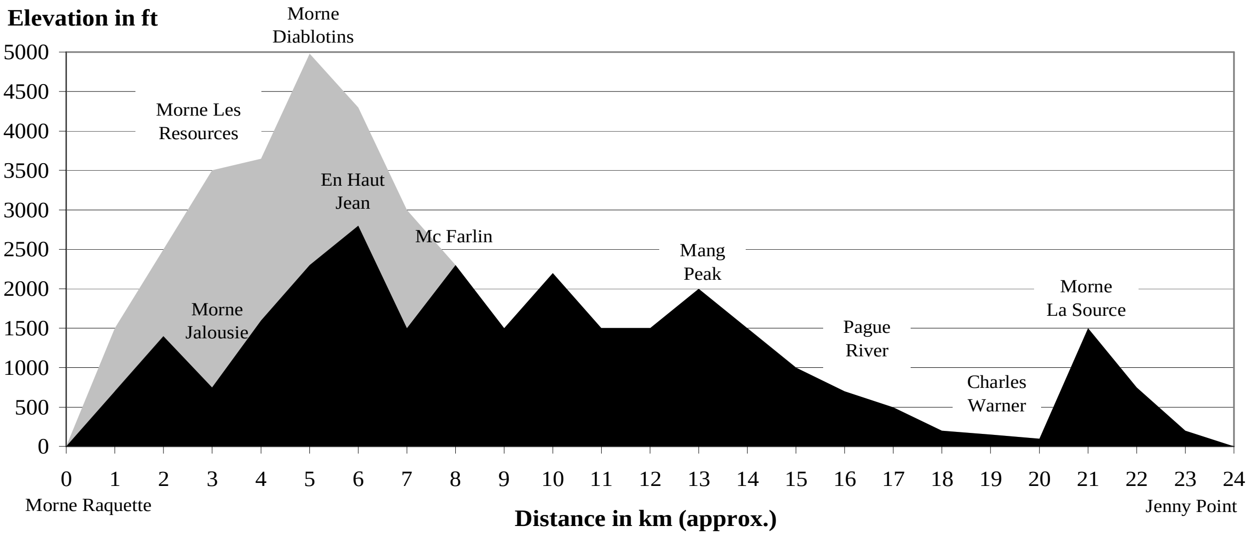
Source: CREDP/Factor 4 Energy Projects GmbH (B. Jargstorf), "Preparation of Wind Power Projects at Dominica, St. Lucia and St. Vincent", September 2005, p. 23

Figure 2-51:
Wind Map for Dominica – showing average Annual Wind Speeds at 30 m above Ground



Projection: UTM, Zone 20N, WGS84
Spatial Resolution of Wind Resource Data: 200m
This map was created by AWS Truewind using the MesoMap system and historical weather data.
Although it is believed to represent an accurate overall picture of the wind energy resource, estimates at any location should be confirmed by measurement.

Figure 2-52:
Cross-Section of Dominica in main Wind Direction from West to East



Source: CREDP/Factor 4 Energy Projects GmbH (B. Jargstorf), "Preparation of Wind Power Projects at Dominica, St. Lucia and St. Vincent", September 2005, p. 23

One can see that – based on topographic and wind direction information alone – a basic wind flow modelling can be undertaken which gives the same results as a computerized wind flow modelling.

Thus, leaving out the wind mapping exercise, one has more resources left to concentrate the search efforts for site selection measuring stations on regions/areas of the island, where the following criteria are fulfilled:

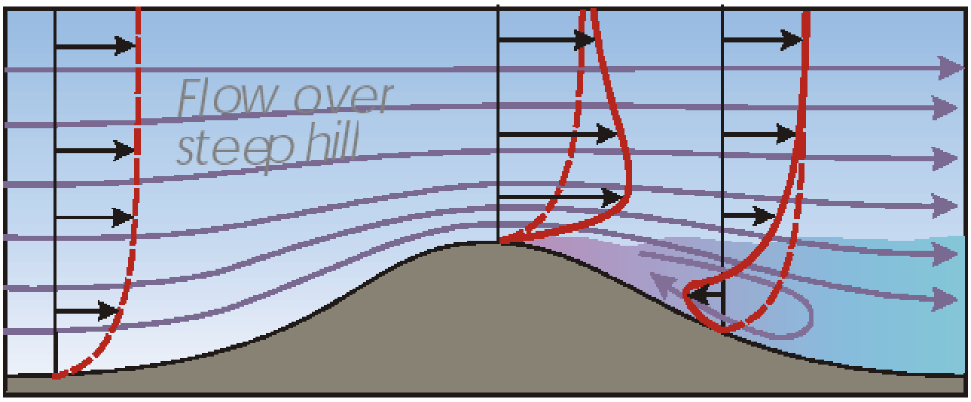
- higher than average wind speed according to the basic wind flow expectations over the island;
- close distance to the grid (transmission lines or, for larger projects, substations);
- easy road access, i.e. close distance to the existing (tarmac or gravel) road network;
- favourable property situation (often the best: government land or few private land owners as opposed to a large number of small plots which would require high efforts in negotiation for usage contracts).

In summing up, a wind map on an island with complex terrain and a single main wind direction (trade winds) is likely to not yield any more information than can be obtained from a topographic map.

Also, the grid size generally limits the usefulness of such wind maps, as it produces average wind speed in a square (often 1 x 1 km or similar), which does not take into account the local wind speed acceleration over hills and ridges.

This local wind speed amplification over hills and ridges is the most important criteria for site selection. Empirical measurements have shown that the wind resource on top of the hill can be more than double than on the bottom (see **Figure 2-53** for the principal mechanism of this acceleration effect).

Figure 2-53:
Local Wind Speed Amplification Over a Steep Hill



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

2.5.3 Site Selection Measurement Campaign

Wind maps according to **Figures 2-50** and **2-51** require the knowledge of the complete area of the island. This knowledge is normally obtained by a combination of (long-term) data from meteorological stations and (short-term) wind data measured at measuring stations, being installed for the purpose of constructing the wind map.

The standard height of meteorological stations is 10 m. While a measurement on an ex-posed location in undisturbed air flow from 10 m above ground can give good, representative results about the available wind energy potential, this is generally not the case with data from meteorological stations. Often, these stations have been established more than 100 years ago, normally at the outskirts of towns or villages. In the meantime, these towns have grown so much, that meteorological stations today are generally in the middle of towns and cities, surrounded by (high-rise) buildings and other obstacles. Thus they cannot give representative data about the wind energy potential.

Exceptions to this rule are meteorological stations at airports, as neither vegetation nor buildings are allowed there. In the case of Trinidad and Tobago, data from the two airports could possibly give relatively good (=representative) wind speed data, while that of other meteorological stations most likely will not.

Principally, installing 10 m measuring stations for site selection can yield good results. But often surrounding vegetation (for example, sugar cane fields) can reach a height of 2 m or more, and then drastically reduce the validity of the measured data. Thus, already for site selection, a higher measuring height is likely to result in better (= more representative) wind speed data.

CREDP has gained very good results with using existing telecommunication or (in exceptional cases) lattice towers from overhead transmission lines. These towers are generally between 30 and 80 m high and allow already for site selection a wind speed measurement in hub height.[45]

While one might not find these towers as an optimal spot for wind measurements, they are generally installed on higher mountains/hills or ridges, so that their antennae cover a wider area. As a rule, their possibly sub-optimal micro-locations is, more often than not, offset by a cost-effective measurement in direct, or close to, hub heights.

In any case, it is important to note that primarily on, or very close to, potential wind park sites measurement stations are installed. However, this does not rule out one or two stations on special landmarks (such a mountain tops or peninsulas) to be used as reference stations.

Thus, using existing telecommunication towers offers the following advantages over installing new measuring towers of 10 or 20 m for site selection:

- wind speed data from greater heights above ground (generally 30 m and more);
- the possibility of establishing the wind shear already during site selection measurements – through installing two or more anemometers at different measuring height (see example in **Figure 2-25**);
- no need to get a permission of the land owner to erect a measuring tower;
- no need to acquire a building permission for the tower from the government (or other authorities, such as the airport authority if the measurement in within the reach of the airport);
- no need to guard or protect the measuring tower and the measuring equipment (fences, etc., if needed, already exist for the telecommunication tower);
- short time for installation and commissioning of the measuring stations.

As a result of these advantages, both time and financial efforts of a measuring campaign for site selection are drastically reduced, when moving from a number of dedicated new measuring towers of 10 or 20 m to existing telecommunication towers with height between 30 and 80 m.

This advantage is still substantial, if one or two additional towers with 10 or 20 m have to be installed, because in certain interesting regions with assumed higher-than average wind speeds no suitable existing telecommunication towers can be identified.

As a rule, measurements should only be executed on or close to potential wind park sites. If no wind map is required which covers the complete area of Trinidad and Tobago, knowledge of wind resources should be gained only in areas/regions/places where concrete sites can be identified for potential wind parks.

2.5.4 Micro-Siting of Wind Turbines

While the current MEEA approach – requiring a micro-siting proposal, a pre-selection of suitable turbines and an output prediction – is a perfectly suitable way to come close to the investment stage of a (pilot) wind power project, CREDP would like

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[45] see **Section 2.4 Antigua**, especially **Figure 2-24** and **2-25**

to propose a slightly different approach which already takes into account the availability of land for lease, rent or purchase.

In order to accommodate this approach, already during the selection of wind measuring towers is it advisable to check the principal availability of sufficient large areas of land at, or near, the measurement sites. As a first measure, government land (Crown land) would have to be identified in large enough sizes to hold sufficiently large wind parks.

Only after checking the availability of the wind park areas, a micro-siting optimization procedure for standard utility wind turbines should be engaged upon. At the same time, however, also a basic check for potential grid connection concepts and access roads should be under-taken, in order to determine the basic economic parameter of the selected site(s).

It is estimated that the available resources for the Wind Resource Assessment will allow a larger number of pre-selected sites when using telecommunication towers and also a larger number of final sites, say 3 to 5 for the micro-siting.

For these sites a basic pre-feasibility study should be made to determine the principal economic parameters of the site. This includes a preliminary micro-siting, as well as preliminary access road and grid connection designs.[46]

With such pre-feasibility studies, at the end of the project, a sort of public project tendering could be made (especially when only wind parks at Crown land have been identified), where potential Independent Power Producers (IPP) can bid for the selected wind park sites. In a first estimate, a minimum size of ca. 20 MW and an maximum size of ca. 60 MW (such as 10 x 2 MW and up to 20 x 3 MW unit size) could be envisaged as optimal project sizes for such a tender procedure.

Also, preferential treatment in this tendering procedure for the Power Generation Company of Trinidad & Tobago Ltd could be given, in a way that they might freely choose from the sites before the remaining sites are tendered to IPPs.

Of course, also other approaches for the micro-siting can be developed, however, an availability of land check should be required before continuing with the project planning. Judging from experiences elsewhere in the Caribbean, the land issue can cause substantial delays or even be the killing assumption of a wind park project with excellent proven wind resources.

It is proposed that the Wind Resource Assessment ends with a pre-feasibility study for each final wind park site. Further project planning, such as the detailed technical planning and the environmental impact study etc. should be done by the winning bidder(s).

Also, in parallel to the Wind Resource Assessment it is proposed that a discussion is held with the concerned government and regulatory bodies about the potential feed-in tariff a wind park operator could be offered. As a minimum, this tariff should take into account the current generation costs in the existing power plants (assuming world market prices for oil and gas) and the external costs, caused by environmental damages (CO_2 emission etc.). Taking just the avoided fuel cost would, most likely, result in such low feed-in tariffs for wind park operators that even excellent identified wind resources will not allow an economic operation of wind parks in Trinidad and Tobago.

2.5.5 Selection of Consultants

It is estimated that the complete works according to the Terms of Reference of MEEA can only be offered by an international consultant, most likely in cooperation with a local consultant from Trinidad and Tobago. However, (larger) international consultants will, most likely, not have extended practical experiences with wind resource estimation and project planning in the Caribbean con-text.

Against this background it is proposed to only tender the services of a local Consultant for the acquisition and installation of the measuring equipment and accept CREDP’s offer for consultancy services, at least for the first phase of the project. CREDP is ready and in a position to work closely with the local consultant and university institutes, and has a special focus on capacity building and on-the-job training of counterparts.

Depending on the result of the cooperation during phase one of the project, the tendering of additional consultancy services can be undertaken at a later date. When following the proposals of this section, no international consultant would be needed, at least not for the first phase of the project and considerable funding can be spared.

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46) Pre-Feasibility Studies have been undertaken by CREDP for sites in St. Vincent and Saint Lucia, they can be made available upon request

2.5.6 Summary and Recommendations

The Wind Resource Assessment project of MEEA makes a lot of sense against the current price developments on the world fossil fuel market. With the ever-rising oil prices, one can rightfully argue that using renewable energy sources in Trinidad and Tobago makes economic sense, as this leaves oil and gas unexploited today and allows it to be sold on the world market later, when considerably higher prices have been reached (such as 200 US$ and more per barrel).

The proposed three-phased approach with preliminary area identification, area wind resource evaluation and turbine selection and micro-siting constitutes a professional project design. Judging from previous experience with wind resource assessments in the Caribbean since 2004, CREDP proposes some changes, primarily, the employment of existing telecommunication towers for site selection.

A wind map of the complete area of Trinidad and Tobago is not considered necessary for the site identification process of potential wind park sites. Instead, CREDP proposes to concentrate on potential wind park sites, measure the wind speed only there and prepare several of these sites for tender.

This preparation for tender includes the originally not planned elaboration of (sample) Pre-Feasibility Studies for suitable wind park sites. Funds earmarked for the wind mapping exercise are expected to cover these extra costs – thus the modified project implementation will most likely not require additional funding.

The changes proposed in the current approach of MEEA are expected to bring several projects closer to realization using the same resources in a shorter timeframe.

Thus, overall project planning time could be substantially shortened.

2.6 Barbados

2.6.1 Wind Park Lamberts – Project History

Already in December 2002 Barbados Light & Power Co Ltd (BLPC) commenced with the preparations of the wind park Lamberts East. A contract about a Feasibility Study was agreed upon with the British consultancy firm Renewable Energy Systems (RES).[47]

Already before this date, several studies about the wind potential on Barbados had been made. However, despite wide ranging measurement programmes by varied organisations, detailed knowledge about the wind resources of Barbados was still scant after several measuring campaigns.

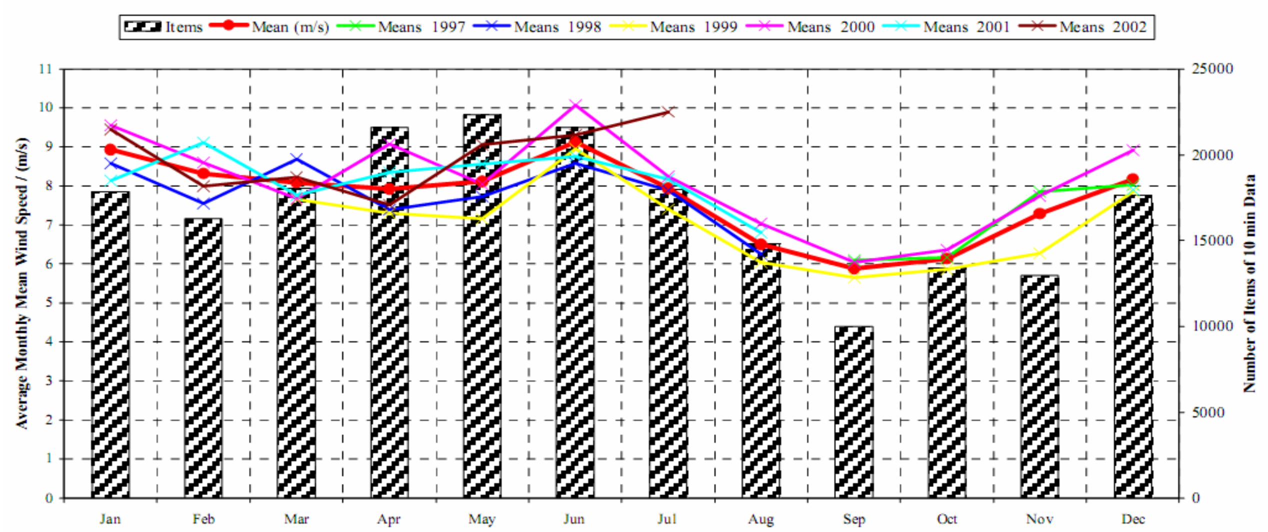
In the 1980s, the Barbados Wind Power Unit (BWPU), in association of British Electricity International (BEI) and Sir William Halcrow & Partners provided one of the more comprehensive reports covering a preliminary site investigation phase and the installation phase of a Howden 200 kW wind turbine, at that time one of the largest serial production machines on the market.

This turbine operated only from 1984 to 1988 with a lot of reliability problems and has been abandoned since. The project was funded by the Caribbean Development Bank and the Government of Barbados. For more than 20 years this turbine at Lamberts stood there as a project ruin (**Figure 2-54**) – it id not improve the reputation of wind energy in Barbados or, for that matter, in the Caribbean. In the meantime, it has been dismantled.

Figure 2-54:
Defunct 200 kW Howden Wind Turbine in 2007

Photo: B. Jargstorf, February 2007

Figure 2-55:
Lamberts East – Monhtly Wind Speeds in m/s at 40 m above Ground (1997-2002)



Source: RES Feasibility Study (footnote 21), "Predicted Long Term Wind Climate for Lambert's East, Barbados", *modified*

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[47] see http://www.res-group.com/

2.6.2 Wind Resources

Between 1984 and 1988 several wind measurement campaign at 20 m, 25 m and even 100 m above ground were carried out.[48]

The conclusion for these studies was that the North Eastern region of Barbados features annual average wind speeds in excess of 8 m/s at 30 m above ground, and that between 30 and 100 m only about 1 m/s wind speed increase could be expected.

Between 1997 and 2002 RES carried out another set of measurements at 40 m above ground. The results of this measurement campaign (**Figure 3-55**) was used for an energy output assessment of the current project at Lamberts East.

It was based on a long-term annual average wind speed of 7.7 m/s in 40 m above ground and predicted an net annual production of a 12 unit wind park with Vestas V52-850 kW turbines (10.2 MW) of 32.8 GWh/a. Thus, the turbines would operate with a capacity factor of 36.6 %.

According to the seasonal variation of wind speeds the period between August and November features around 1 to 1.5 GWh/month, while the rest of the year monthly productions between 3 and 4.5 GWh can be expected (**Figure 2-56**).

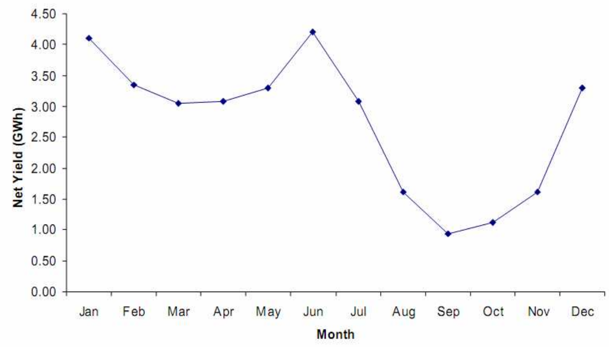
2.6.3 Environmental Impact Assessment

Between 2005 and 2007 the consultancy firm AMEC[49] executed a thorough environmental impact assessment (EIA). The project had been optimized in a wind park consisting of 11 turbines of the ~ 1 MW class with a micro-siting according to **Figure 2-57** (photo montage in **Figure 2-58**).

In February 2007 the first public hearing was held and the positive results of the EIA were presented. At that time, major questions of the concerned neighbours focussed on noise emissions, low frequency noise, visual impact, shadow flicker and the effects of the wind park on the avifauna.

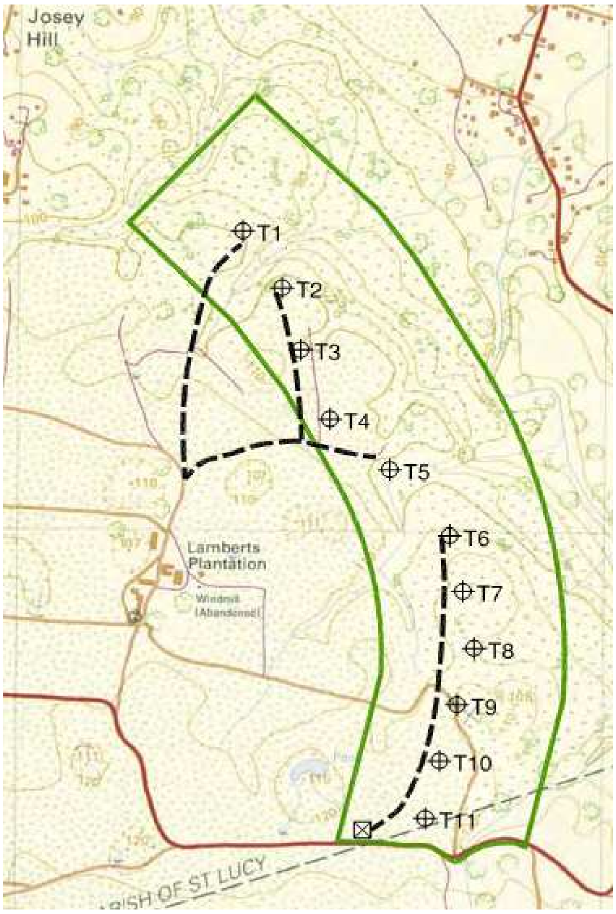
A lengthy licensing process started, during which the property owner of the proposed wind park changes and several applications from nearby neighbours had to be dealt with. Originally the commissioning of the wind park was envisaged for 2009[50] - the final permission to construct was granted only in December 2010.[51]

Figure 2-56:
Predicted Monthly Net Energy Yield



Source: RES, "Feasibility Study, Annex 10, p.23, op. cit.

Figure 2-57:
Proposed Micro-Siting from EIA



Source: AMEC Earth & Environmental, "Environmental Impact Assessment – Lamberts East Wind Farm", p.10

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[48] Renewable Energy Systems Ltd RES (R. Lord), "Feasibility Study for a Wind Farm on Barbados", March 2004, p. 3

[49] see http://www.amec.com/

[50] Roger Blackman (BLPC), "Lamberts Windfarm Project", presentation at the Town Hall Meeting of EIA, public hearing, 24-02-2007

[51] see **Annex 7 – Planning Permission Lamberts Wind Park**

Figure 2-58:
Photo Montage of Lamberts Wind Park (2007)

Source: Roger Blackman (BLPC),

2.6.4 Outlook

Currently, BPLC is negotiating a land lease agreement with the new property owner. In parallel, the financing of the project is updated – project finance had been granted through a loan of the European Development Bank.

According to the current implementation plan of BPLC, an international tender procedure could be carried out in the second half of 2011.

As such, the Lamberts East Wind Park is – as originally planned – a candidate for the joint tender procedure of CAWEI.

2.7 Grenada

2.7.1 Technical Assistance of CREDP

In March and October 2007 the wind energy consultant of CREDP visited Grenada and discussed possible approaches to the implementation of wind energy projects.

At that time, a private land owner had installed a 30 m tower at his property at Lake Antoine, but wind data were not yet available (**Figure 2-60**).

With regard to site selection, CREPD proposed an pragmatic approach, which can be called a "reductive" approach, it reduces, through the successive application of different selection criteria, the area which is actually evaluated for wind measuring.[52]

This approach has been discussed in more detail in **Section 2.5.3** for Trinidad and Tobago. For Grenada, a it was proposed that GRENLEC – Grenada Electric Services Ltd – follows a two-stage approach to site identification, i.e. using 10 m towers in the first step and hub height measurement in the second. For the first stage, at least three different sites are proposed for measurement, one of which should be a site directly as the shore line and two other in hilly terrain. Through the comparison of these measurements, the local wind speed amplification effects can be verified and other parameter of the wind regime compared (for instance the turbulence levels at mountain and coastal sites).

GRENLEC, however, had already contacted a consultant[53] who used the "standard" approach through ordering a wind map first (see **Figures 2-49** and 2-61).

During the second mission to Grenada, the site Lake Antoine could be visited. Through discovering vines at the guy wires (and evaluating the first wind data recorded at 30 m) it became clear that this site features below-average wind speeds, estimated to be around 5.5 m/s (**Figure 2-59**).

GRENLEC wanted to install another 50 m tower at Lake Antoine, something which was not recommended by CREDP.[54]

Figure 2-59:
Lake Antoine, Guy Wires Measuring Tower

Figure 2-60:
Lake Antoine with existing 30 m Measuring Tower

Photo: B. Jargstorf (March 2007)

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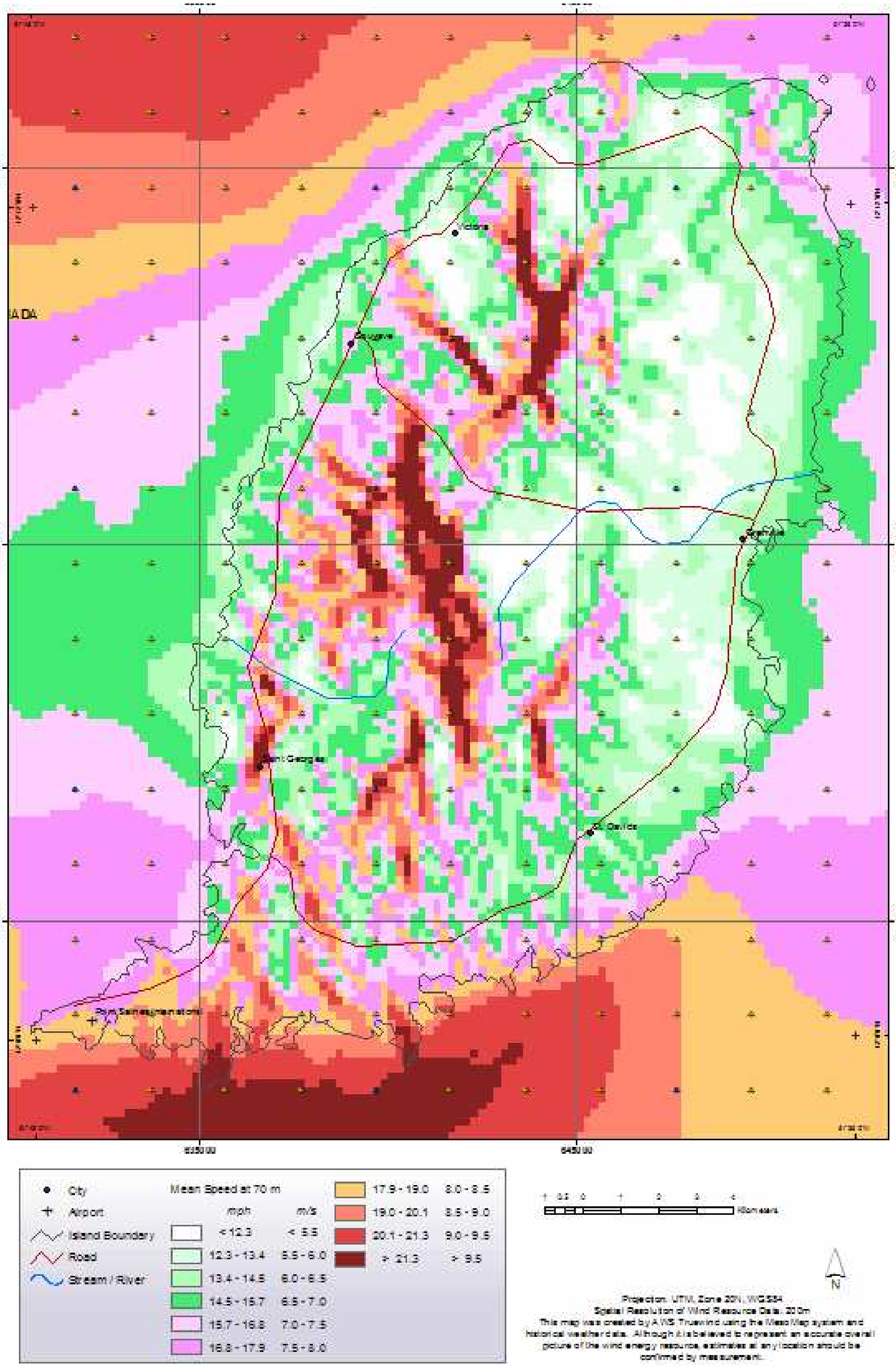
[52] See also CREDP/Factor 4 Energy Projects (B. Jargstorf), „Preparation of Wind Power Projects at Dominica, St. Lucia and St. Vincent", September 2005, p. 15

[53] Tennessee Valley Infrastructure Group, Inc

[54] see **Annex 8** for summary of results Grenada

Figure 2-61:
Wind Map for Grenada – with Annual Wind Speeds at 30 m above Ground



2.7.2 Current Plans of GRENLEC

By 2010, GRENLEC had identified a mountain site – Clozier – and installed a 50 m tower. Results of wind measuring were not made available. However, judging from the topography of the site and its situation on the island, an annual average wind speed in 50 m above ground of ~ 7.5 m/s is estimated. The site could not be visited, due to time constraints, thus, secondary signs of wind speeds in the vegetation could not be verified.

The site Clozier is estimated to be sufficient for a wind park of 6 to 8 MW, using wind turbines of the 1 MW class with 50 to 60 m rotor diameter. Details of GRENELC's plans have not been disclosed.

In general, there exists quite a number of places where extraordinary tree flagging can be observed in Grenada – these sites, however, are generally directly at the (Eastern) shore line (see **Figure 2-62**). How the mountain site Clozier compares with coastal sites was not communicated.

Figure 2-62:
Tree Flagging at Coastal Site

At the same time, GRENLEC has decided to simultaneously implement a wind diesel system in the neighbouring island of Carriacou, situated North of Grenada (see **Figure 2-49**).

2.7.3 Wind/Diesel System Carriacou

The average electric load requirements at Carriacou are just below 1 MW. The diesel power station has four generators, 3 x 640 kW and 1 x 1,280 kW. Annual generation is approx. 8,000 MWh.

GRENLEC has received funding for the design and implementation of a wind/diesel system on the island of Carriacou from the EUEI – the European Union Energy Initiative.

Currently, basic design alternatives are being checked and first simulation runs are undertaken using the software package HOMER.[55] Such simulations, where the main inputs are the daily load curves and the measured wind speeds, are necessary to determine the size of the wind park, the size of energy storage and the size of the dump load.

A dump load is required, when the battery is fully charged and the wind power in the grid exceeds the power demand of the island. Also, through fast-switching of the dump load controller, the frequency in the island grid can be influenced.

GRENLEC wants the results of the current wind/diesel planning to be treated confidential. Therefore, within the scope of this report, we shall use material from other sources and align it with the public information supplied by GRENLEC.

Figure 2-63 shows a principal layout of a wind/diesel system, based on information from Enercon GmbH. For their simulation, however, GRENLEC used the VERGENT 275 kW turbine[56] - also, GRENLEC did not consider flywheels for short-term energy storage, which are shown in this diagram. In the **red box** one sees the additional equipment required for diesel-off mode, i.e. for the operation of a "true" wind/diesel system.[57] In that case, the grid-forming abilities of the diesel generators have to come from Master Synchronous Machines (MSM), also called synchronous condensers or rotating phase shifters. The additional battery storage is then used to prolong the diesel-off mode and, thus, reduce the number of start/stop operations of the diesels. As the fuel consumption during start-up is considerably higher (and the wear and tear of the engines also increases) a reduction in diesel generator starts considerably increases fuel savings. Without battery, fuel savings with more than ~ 40 % are normally not possible.[58]

The current simulation runs of HOMER use estimated monthly wind speeds. But according to information from GRENLEC, by now 15 months of wind data from measurements at 50 m above ground are available – measured directly at the proposed wind park site in Carriacou.[59] Such kind of wind data seems indispensable for wind/diesel system design and planning.

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55) see http://homerenergy.com/

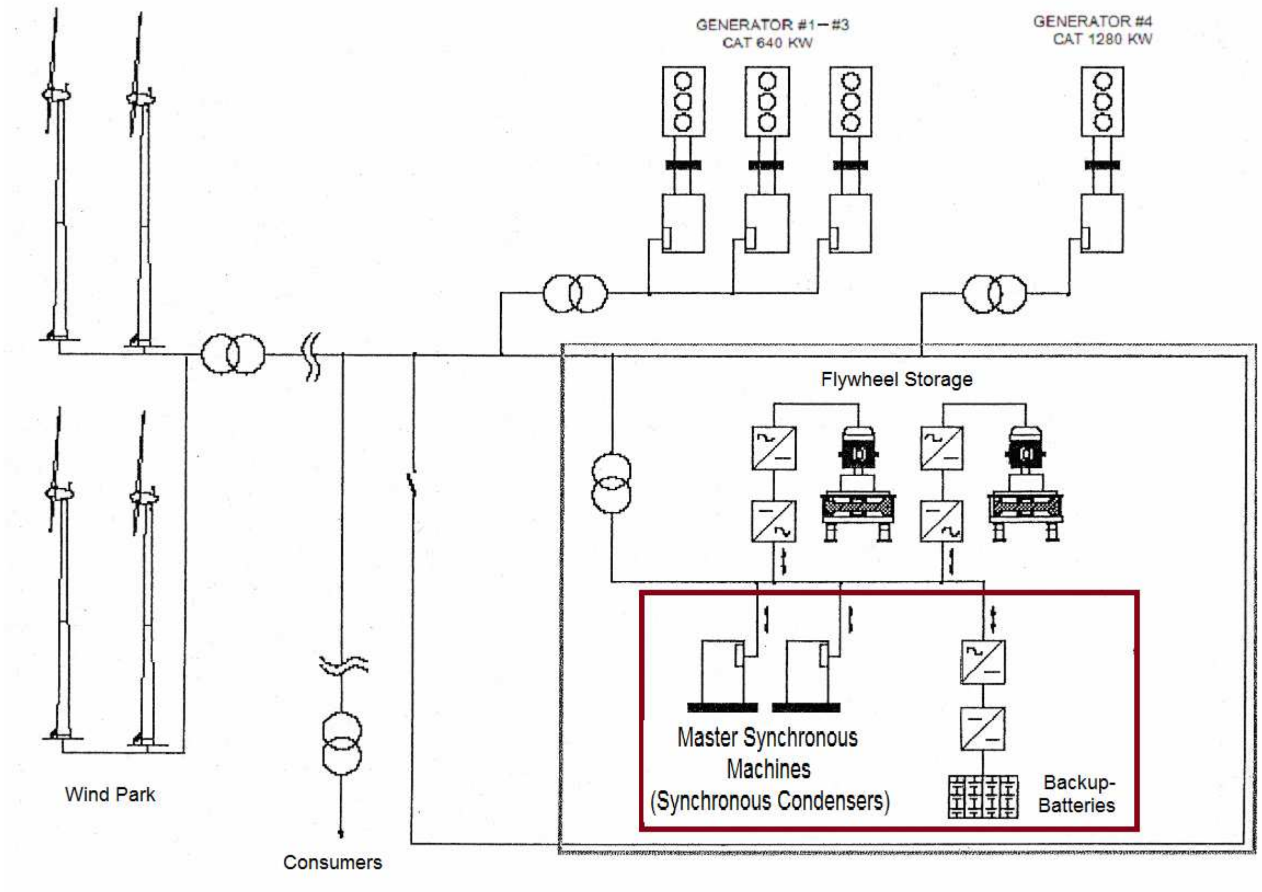
56) see **Section 2.10** Nevis for more details on this turbine

57) for a clarification of terms, see **Box 4** on page 44

58) see **Section 2.15 Bonaire**, and the **Appendix 2** and **3** in **Annex 12**

59) in an email from Robert Blenker, Vice President Renewable Energy, WRB Enterprises (31-03-2011)

Figure 2-63:
Potential Design of an Wind/Diesel System at Carriacou



Source: Enercon GmbH, *modified*

HOMER uses one hour averages for simulation and, therefore, only gives a first glance about the behaviour of an actually built wind/diesel system. More accurate results can be achieved when the 10-min averages from the wind measurements are used. For this normally an automatic data registration device is installed in the diesel power station, which makes the registration of 10-min load averages possible. These two data sets, consequently, can be used as basic input data for the wind/diesel simulation runs and the optimization of the components.

Unfortunately, HOMER does not allow to simulate an annual load increase – thus the results from this programme often do not agree very well with results obtained by actually built wind/diesel systems. Using estimated wind speeds, the first results GRENLEC has received from the HOMER model runs, indicate that a 59 % wind energy penetration rate is possible, with an installed wind park capacity of just below 2 MW (= 7 VERGNET turbines à 275 kW).

According to GRENLEC, this high penetration rate can be achieved without short-term storage (flywheels), just relying on VRLA batteries[60] and on a fast-switching dump-load.

This dump-load has principally the same task as a flywheel, but it can only cut out load peaks, not supply power during a lack of supply (see **Figure 2-72**). In a wind/diesel system, one would always like to keep the use of dump load to a minimum, as it destroys energy – very valuable frequency- and voltage-controlled energy – over a heat generating resistance.[61]

Considering the pre-selected wind turbine VERGNET, which features a directly-coupled generator, it is doubtful whether a actual built system can work without a flywheel storage. This would only be possible with indirectly coupled variable speed turbines, if at all. See the measured output of a directly coupled, fixed-speed turbine in comparison

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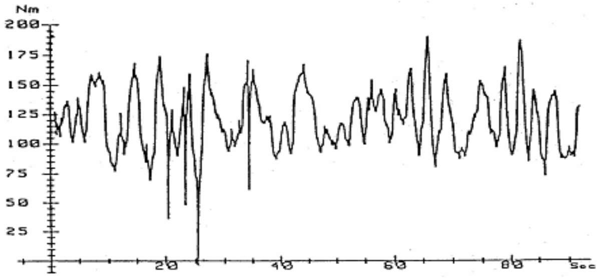
60) VRLA – Valve Regulated Lead Acid

61) if this heat energy can be used productively – such as in an Antarctic wind/diesel system for space heating – dump loads are not so “dumb” anymore. Otherwise, from an engineering standpoint …, see, for example http://www.antarctica.gov.au/living-and-working/stations/mawson/mawson-electrical-energy

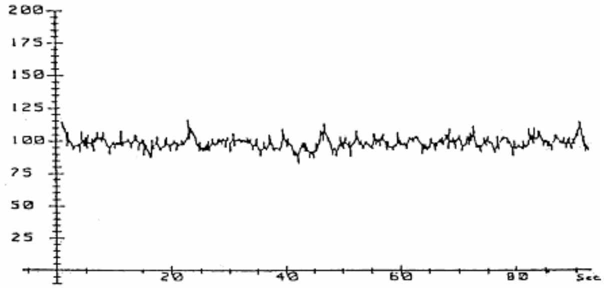
to a variable-speed, indirectly coupled turbine in **Figure 2-64**.

Figure 2-64:
Torque of Rotor Shaft

a) Directly Coupled - Fixed Speed Rotor (VERGNET)



b) Indirectly Coupled - variable Speed Rotor



Source: DEWI – Deutsches Windenergie Institut

It is obvious that the fixed-speed rotor converts all wind speed changes directly into torque and, consequently, into electric power. While this can be absorbed by the diesel generator when the diesels are still connected, it has to be absorbed to a large extent by the batteries during diesel-off mode.

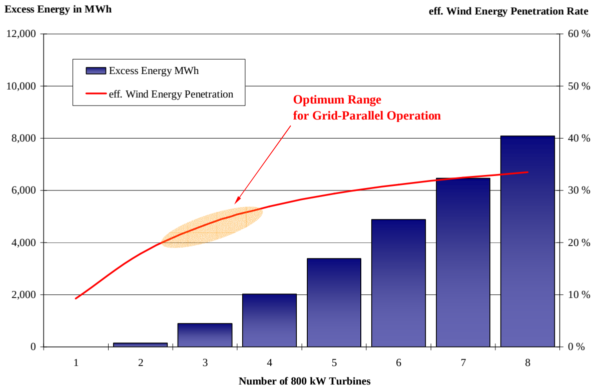
Conversely, an indirectly coupled variable speed turbine allows the rotor to speed up during a gust. The kinetically stored energy then fills the gap when the gust is over. As a result, the output is much smoother than that of a fixed speed machine. In other words: the rotor, gearbox and generator mass acts as a flywheel for levelling-out of torque fluctuations. This effect is biggest with direct-drive wind turbines – this technical concept, as a result, is the most suitable for wind/diesel systems.

A battery interprets a change in energy flow (from charge to discharge and vice-versa) as a load cycle, therefore the allowed 1,200 load cycles of a typical VRLA will be achieved very quickly. As a consequence, we don't think that it is possible to employ VERGNET turbines in a full-fledged wind/diesel system without flywheels.[62] In fact, a wind/diesel system built in Australia in 2008 with VERGNET turbines uses flywheel short term storage.[63]

Normally, when simulating wind/diesel operation, one gets an economic optimum for the combination of wind power capacity and storage capacity. While it is technically possible to design a wind diesel system with 100 % wind energy penetration, this is prohibitive from an economic point of view: this would require to dimension the battery (or other energy storage) according to the longest no-wind period and the worst load situation. Also, when installing a high wind energy capacity, large amounts of wind energy would have to be curtailed, i.e. pitched away or wasted in the dump load.

A typical optimization of a wind/diesel system is shown in **Figure 2-65**. The **red line** indicates the wind energy penetration rate, while the **blue columns** show curtailed energy (the unused, excess energy).

Figure 2-65:
Assumption of Monthly Wind Speeds in m/s



Source: ERGAL/Factor 4 Energy Projects GmbH, "Technical Review of Feasibility Study – Wind Park Baltra (Galápagos)" see http://www.ergal.org/imagesFTP/21706.Review_of_Feasibility_Study.pdf

This example is for grid parallel operation only, i.e. for a system without diesel-off mode (in **Figure 2-63** without the components in the **red box**). When diesel-off mode is introduced, part of the excess energy has to be used to charge the battery. Obviously, the economic analysis of a wind/diesel system with battery storage gets more complicated, as

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62) obviously, already in a standard-grid parallel system such as in Nevis their grid connection concept is not without problems (see **Section 2.10 Nevis**

63) see http://www.pcorp.com.au/index.php?option=com_content&task=view&id=136&Itemid=183

the energetic optimum (i.e. a maximum usage of generated wind energy) does not coincide with the economic optimum (because batteries are so expensive).

Also, battery storage has to be replaced regularly (normally a maximum life time of 3 years has reached in wind/diesel systems of this size), and flywheel storage has its own consumption which can be considerable, even if operated in a vacuum.

The economic effects are considerable, and very complex to take into consideration during the design and planning phase of a wind diesel system.

In summing up, the information on the planned wind/diesel system on Carriacou with a wind energy penetration rate of nearly 60 % are of a preliminary nature and confidential. In any case, it is doubtful, whether the envisaged technical concept without flywheel can be realized.

Box 4: Operation Modes of Wind Turbines and Diesel Generators

A. Interconnected Grid

More than 99 % of all wind turbines operating today world-wide – ca. 190,000 MW at the end of 2010 – generate electricity in parallel with the interconnected grid.

Operation of wind turbines in parallel with (small) isolated networks generally offers better economy, since generation cost in these isolated grids are generally quite higher than in an interconnected grid. On the downside, these applications depend generally on far higher efforts for design and system layout and need additional (electronic) equipment, as standard wind turbines have no grid-forming abilities. When wind turbines operate in parallel with an interconnected grid, the installed wind power is very small in relation to the installed power from other sources:

$$P_{Wind} << P_{interconnected\ grid}$$

This relationship leads to a situation that the power from the wind turbines can be absorbed by the interconnected grid at any time, without causing any (negative) influence on the grid.

Wind turbines operating in parallel with a (small) isolated electric network constitute a fundamentally different situation, as in the interest of satisfactory penetration rates the wind power in the grid has to be of the same or similar magnitude of the other generation sources in the isolated grid.

B. Isolated Grid

When integrating wind turbines into isolated electric networks, principally four different operating modes are possible: [64]

1. Standard Grid-Parallel Operation

Under this operating mode the maximum wind power output can be absorbed by the grid at any time without having any negative influence on the grid stability or grid parameters (frequency, voltage, power factor) of the isolated grid.

Normally, these systems are dimensioned according to the following rule of the thumb:

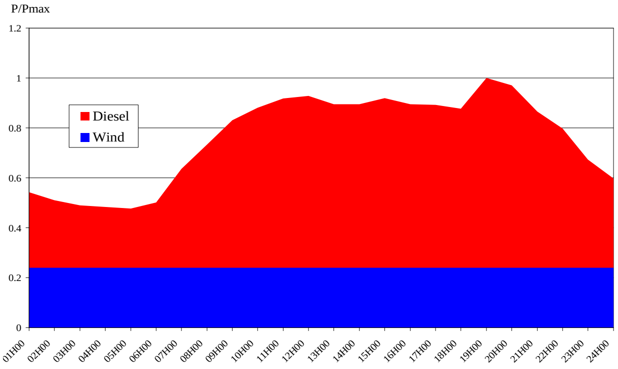
$$P_{wind,\ max} \le 0.5 * P_{grid,\ minimum}$$

This means, that the maximum wind power has to be less than 50 % of the absolute minimum load in the grid.[65]

Technically, this is the most simple operating mode (**Figure 2-66**). Under normal conditions, no additional measures have to be implemented for a successful integration of wind power into the grid.

In electric grids with a low load factor, i.e. a large difference between minimum load and peak load, standard grid parallel operation has the disadvantage of only allowing very low wind energy penetration rates of less than 15 %. In regions with only a moderate wind regime of less than 7 m/s annual average, these penetration rates fall to 5 to 10 %.

Figure 2-66:
Standard Grid-Parallel Operation (Schematic)



Standard grid-parallel operation requires the diesel power station to operate constantly – when the wind turbines generate electricity, the load of the diesel is reduced, accordingly. Therefore, this mode of operation is also called “fuel saver mode”.

2. High Penetration Grid-Parallel Operation

This operation mode is similar to standard grid-parallel operation, however, a much higher wind power capacity is installed along with additional measures, which keep the wind turbines from over-producing under a situation of high wind speeds and low grid loads (**Figure 2-67**).

The easiest way is to (manually or automatically) disconnect individual turbines of a wind park from the grid during times of low demand. A better solution is to install wind turbines with active pitch control and reduce the nominal power of the park

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64) the following discussion follows Section 2.3 from PIEPSAP – Pacific Islands Energy Policy and Strategic Action Planning/Factor 4 Energy Projects (B. Jargstorf), “Market Review for Small and Medium Size Wind Turbines”, Fiji Islands, October 2007

65) this value is for diesel generators, running on light diesel fuel. Diesel using heavy fuel or bunker oil normally cannot be operate in such an extreme part load condition. For them, other stability criteria apply.

according to the need. Another possibility lies in the integration of non-time-critical consumers such as water pumps or freezer plants into the system. These special consumers are connected to the grid with priority during times of high wind energy availability. Switching them on and off can be done manually or automatically by an integrated supervisory control system.

Normally, high-penetration wind systems are dimensioned according to the follwing rule of the thumb:

$$P_{\text{wind, max}} \leq 0.5 * P_{\text{grid, max}}$$

Theoretically, the maximum achievable penetration factor in high-penetration systems would be 50 %, however, practical values are 30 % at very high average wind speeds and about 15 – 25 % in medium wind regimes (anyhow, the penetration rates depend strongly on the load curve i.e. load factor).

Figure 2-67:
High-Penetration Grid-Parallel Operation (Schematic)

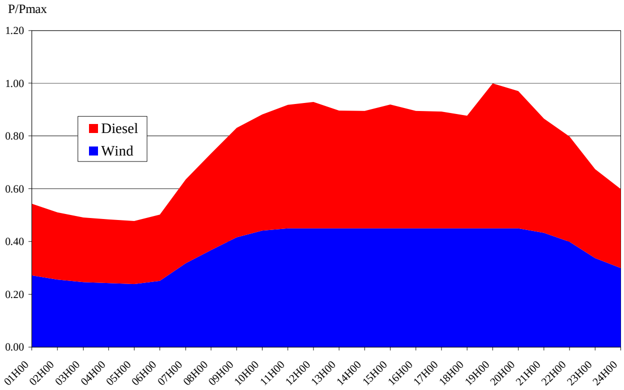
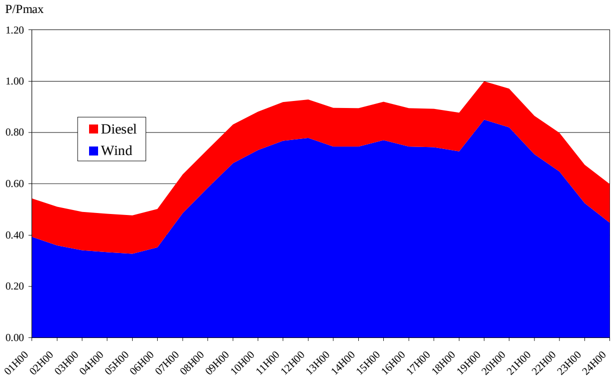


Figure 2-68:
Ultrahigh-Penetration Grid-Parallel Operation (Schematic)



Also in this mode, the diesel generators are operating constantly and provide, as a minimum, approx. 50 % of the grid load at any given time. The reason for this lies in the fact, that with more than 50 % coming from the wind turbines, the grid frequency, which is controlled by the diesel, can be increased by the wind turbines.

Then, the governor of the diesel will reduce the fuel injection rate of the diesel engine as this normally reduces the speed of the engine.

However, with wind turbines on the grid, reducing the fuel injection will further increase the frequency – in a final analysis, if the frequency increase is not prevented, the diesel will come to an emergency shut-down, indicating a governor/controller error. Therefore, suitable measures have to be undertaken for the diesel control in these operation modes.

Ultra-high penetration operation can be achieved, if special low-load diesel generators are employed, which allow to be operated regularly with less than 20 % of their nominal load (**Figure 2-68**).

3. Wind/Diesel Systems

Contrary to both standard and high-penetration grid-parallel operation, wind/diesel systems are designed in a way as to allow the diesel generator to be switched-off completely, when sufficient wind power is available. Naturally, these systems allow the highest wind energy penetration rates, up to 80 % under high wind regimes and ~ 30 to 60 % under moderate average wind speeds.[66] Switching the diesel generator off, however, requires extremely high technical efforts, since wind turbines have, contrary to diesel generators, no grid-forming qualities. This means, that they cannot control the grid frequency and voltage and are in no position to supply reactive power or circuit power to the grid – all of which are pre-requisites for the functioning of even the smallest, isolated grid.

As a minimum, wind/diesel systems require an additional electrical machine for the supply of reactive and short circuit power. This is normally a synchronous generator with a nominal power larger than the peak load in the grid, where a special electronic device allows the variation of the power factor. There are several terms being used the litera-

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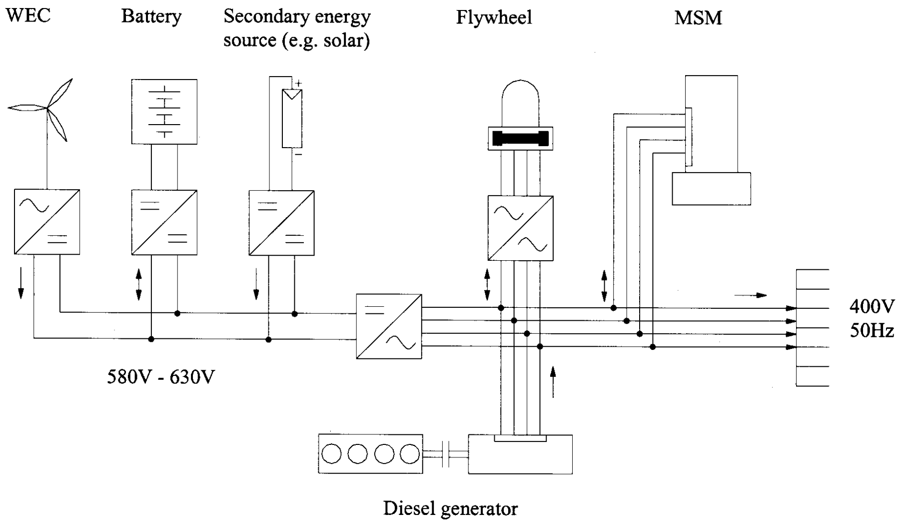
66) Of course, these systems can be designed to achieve a 100 % wind energy penetration. However, for the last 20 % of penetration rate generally the same amount of wind capacity has to be installed as for the first 80 %, making a 100 % rate normally uneconomical.

Figure 2-69:
Example of Wind Diesel System Layout with Flywheel



Source: Enercon GmbH, Aurich, WEC: Wind Energy Converter, MSM: Master Synchronous Machine

ture for this synchronous generator, such as "rotating phase shifter", "synchronous condenser" or "master synchronous machine". It is possible to connect the rotating phase shifter directly to one of the diesel generators of the isolated grid – in this case, it has to be mounted via an over-running clutch, which allows the phase shifter to continue rotation even when the diesel is switched off.

If a wind/diesel system would only consist of diesel generator(s), rotating phase shifter and wind turbine(s), the diesels could be switched off completely. However, frequent start and stops of the diesel generator under changing wind conditions and/or changing load conditions would increase the specific fuel consumption as well as the wear and tear of the diesel engine(s). Thus, any form of energy storage has to be integrated into the system, reducing the frequency of diesel start/stops. The energy storage has also to be used to reduce the short-term fluctuations of frequency and voltage when running with wind turbines only.

Early wind/diesel systems used only batteries as storage media – this produced disappointing life times for the batteries, as any battery interprets a change from charge to discharge as one load circle. Modern wind/diesel systems use flywheels for removing short-term fluctuations and batteries for medium-term energy storage and achieve much better battery life times (see **Figure 2-69** as an example for a wind/diesel system with a flywheel storage and additional photovoltaic generators).

Not shown in **Figure 2-69** is the supervisory control system which – using grid load, wind speed and battery capacity as input data – permanently has to determine the optimum combination of electricity sources.

The programming of the control system requires a high effort, as does the system design and layout of any wind diesel system. Finally, operation and maintenance of these systems depend on highly trained and experienced personnel.

4. Battery Operated Grid Systems

With the availability of cheap DC-AC inverters in the kW power range, battery-fed isolated grids or "mini grids" have increased considerably, supplied by wind or solar power (photovoltaic) or a combination of both (see example in **Section 2.4.3** - Suriname)

Normally, the size of these systems stays well below 50 kW, as the price of larger inverters as well as the battery storage necessary to feed them, increases disproportionately beyond that range. Battery-only wind systems are rare, since for a reliable AC energy supply large battery capacities would be needed. Instead, a small diesel or petrol generator is used as a backup power in these systems.

While such systems work exceptionally well when supplying energy to one (or just a few) customer(s) only, the experience with village electrification is not so good. There, an overloading of the inverter is much more likely, as villagers – seeing, that they get regularly AC power – tend to buy more and more electrical appliances. Also, the control over the connection of non-permitted consumers (f.i. electric power tools) is not as easy as with one customer/owner only. In the same way – and this can also apply to a wind/diesel system – any functioning autonomous energy supply system in remote areas over a longer period of time can lead to a unexpected load increase due to people moving in from neighbouring villages without power.

Summary of Operating Modes

Figure 2-70 lists the major characteristics of the four different operation modes for small AC grid systems suitable to be designed on the base of wind turbines in the 10 to 300 kW range.

Whereas the first three systems would be typically already existing small electricity supply systems, where wind power is later integrated, the fourth system – battery operated AC grid – would ideally be introduced where no previous grid electricity existed. In the same way, a comparison of achievable wind energy penetration rates makes only sense for the first three operation modes, since how often a (diesel) generator is started in a battery operated AC grid depends on the type of load and reliability of service one wants to guarantee.

As a rule, technical complexity, initial investment costs and operation & maintenance demand goes up with the desired wind energy penetration rate.

An economic optimum cannot be indicated on general terms – it would require a detailed analysis of the individual project. This would include as a prerequisite the detailed knowledge of the wind regime (correlation of wind speeds with load), the seasonal and diurnal load variations and several other technical and economical parameters.

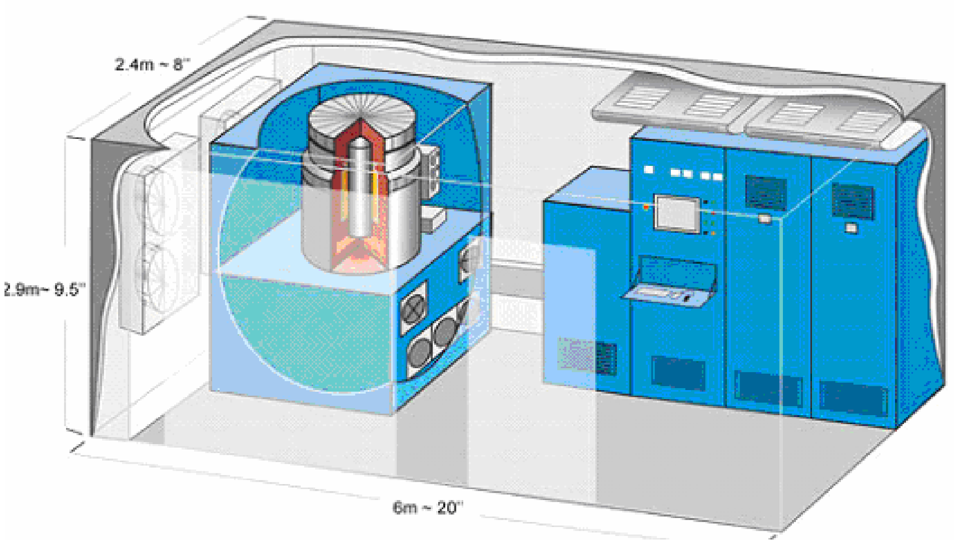
In practice, the high efforts for design and system layout, as well as for economic analysis and project implementation of such (small) wind energy projects has been a major constraint for a wider application on remote and isolated electric grids.

Figure 2-70:
Comparison of the four Major Operation Modes for (Small) AC Grid Systems with Wind Energy

	Typical minimum Load	Technical Complexity	Additional Measures needed	Penetration Rates	Diesel Generator
Standard Grid-Parallel	> 200 kW	low	none	5 to15 %	always on
High Penetration	50 - 2,000 kW*	medium	dynamic power factor compensation, load management, output reduction	15 to 30 %	always on
Wind/Diesel System	50 - 2,000 kW*	very high	modified wind turbine, rotating phase shifter, battery and/or flywheel storage, supervisory control system and more	30 to 80 %, depending on the wind resource	can be switched off
Battery Operated Grid System	< 50 kW	low to medium	depends mainly on battery storage, generally equipped with petrol or diesel back-up generator	not applicable	only as back-up or battery charger

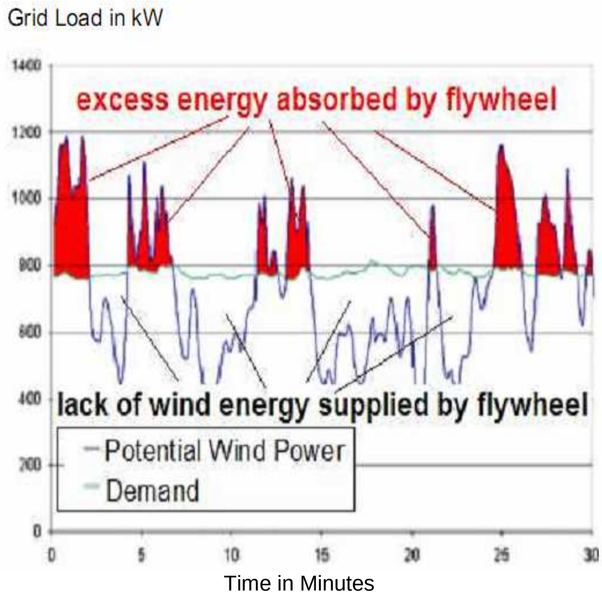
*) larger projects possible

Figure 2-71:
Example of Containerized Flywheel with Grid Connection Switch Cabinets



ource: PowerCorp, see http://www.pcorp.com.au

Figure 2-72:
Flywheel Operation - Schematic



Source: B. Ezawa, G. Windelberg, "Comparison of Wind/Diesel /Battery System Layouts and Control Strategies in Isolated Grids", paper presented at the European Wind Energy Conference EWEC 2008

A change in energy flow is interpreted by the battery as a charge/discharge cycle – thus the battery is ageing very quickly in a wind/diesel system. As can be seen in **Figure 2-72**, within a few minutes, several cycles occur – these can only reliably be absorbed by a flywheel.

Also, if the power fluctuations from the wind turbines are not absorbed by a flywheel (**Figure 2-71**), the diesel generators have to do this job and the specific fuel consumption will increase. This increase is even more drastic under the condition of extreme low load operation, which must be regarded as the standard operation mode.

In summing up, wind/diesel systems allow by far the highest fuel savings of the three different operation modes. They require, however, high efforts, both with regard to technical complexity and to investment and running costs (battery, flywheel). As a rule, penetration rates of > 40 % are not achievable without energy storage. Using batteries for short-term storage (= levelling-out of power fluctuations) shortens battery life drastically – for this, only flywheels are a suitable technology.

2.8 Dominica

2.8.1 Technical Assistance of CREDP

In December 2003 the first wind energy related mission was carried out with CREDP support in Dominica.[67] The general problems for wind energy in the Caribbean island states – namely, small size, limited land availability, complex terrain – are even more pronounced in the "Nature Island" of Dominica – due to the island's extreme topographic features (**Figure 2-74**).

A total of 14 sites had been considered, the majority of which would only allow the installation of a single turbine or a small wind park with up to three units. The proposed site Crompton Point in the Northeast of Dominica was one of the larger sites, allowing a wind park with several MW installed capacity (No 1 in the map in **Figure 2-73**).

At that time, the Dominica Sustainable Energy Corporation DSEC, with financial support from the Organization of American States FEMCIDI[68] had installed a wind measuring tower at Temple Estate, close to Crompton Point (**Figure 2-75**). Unfortunately, no data for this site were made available.

However, for another site – Point Mulaitre (No. 2 in **Figure 2-73**) 10 months of wind data from 50 m above ground could be obtained.

Figure 2-73:
Six Potential Wind Sites of DSEC[69]

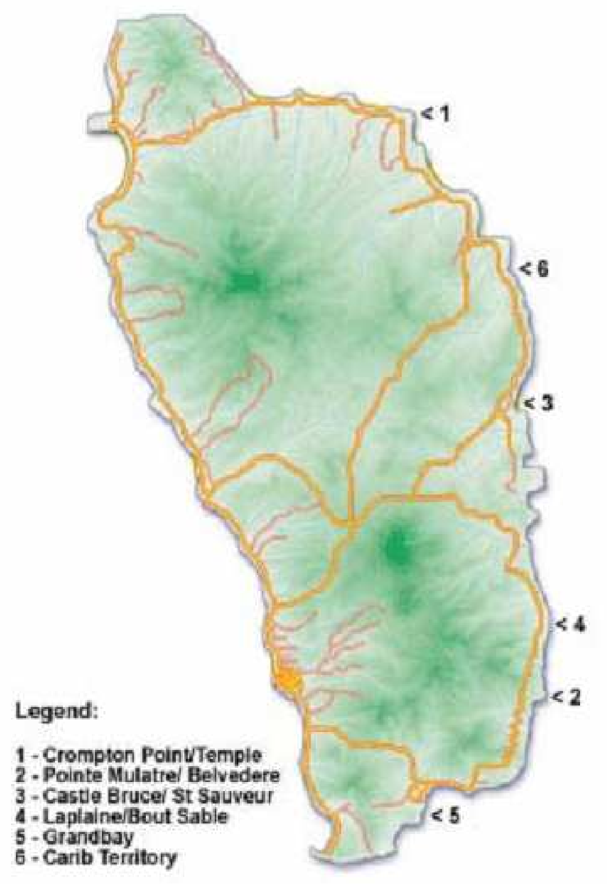


Figure 2-74:
Topographic Features of Dominica

Source: Dominica the nature island of the Caribbean (Tourist Office Dominica)

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67) CREDP/GTZ (John Whittingham), "Report on Wind Energy Assessment Dominica", Barbados, December 2003

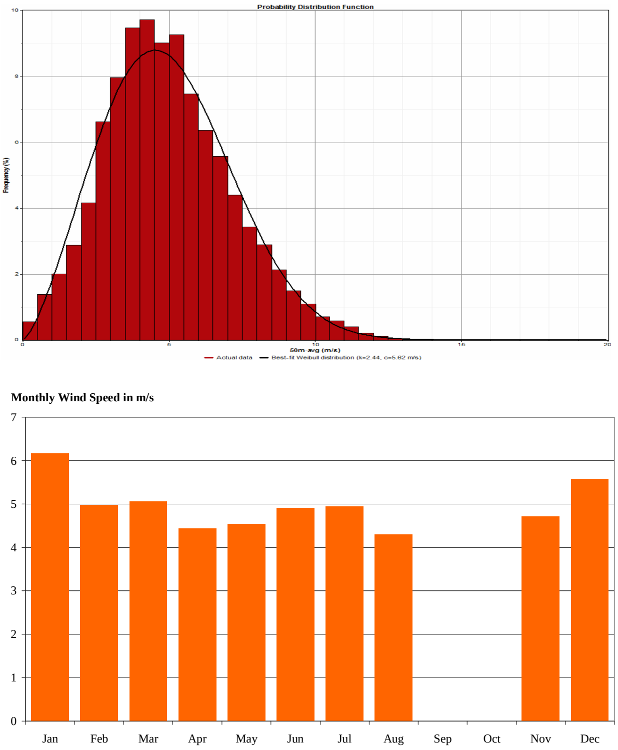
68) see http://www.apps.oas.org/projects/default.aspx, a total of 116,000 USD was allocated to the DSEC project

69) DSEC (Bevin Etienne), "Wind Energy Pilot Project Report", 06/25/2005, Dominica, p. 5

Figure 2-75:
Tree Flagging at Crompton Point[70]

Point Mulaitre, a site too small for a wind park, featured an annual average wind speed of 5 m/s at 50 m above ground and a frequency distribution according to **Figure 2-76**.

Figure 2-76:
Point Mulaitre – Results of Wind Measuring



These moderate wind speeds would only allow Wind Class III or IV turbines to operate with net capacity factors above 20 %. Compared with the wind resources measured at other islands – in particular in St. Lucia and St. Vincent – the site at Point Mulaitre must be regarded as suboptimal.

Another CREDP mission was carried out in 2004, when the consultant visited all previously proposed sites and recommended to engage into a wind measuring campaign for site selection, using (as a minimum) a 10 m tower at Compton Point and the existing telecommunication tower at Marigot at 40 m for reference measurements.[71]

The site at Crompton Point was at that time used as a dump yard – thus, no conflicting land uses for a wind park was envisaged here (**Figure 2-77**).

Figure 2-77:
Proposed Wind Park Site Crompton Point

Following the proposals of other consultants, DOMLEC engaged in a wind mapping exercise in 2005 (see **Figure 2-51**). They also installed a 50 m wind measuring tower at the leeward side of the island, at Tarou. This decision was obviously influenced by the availability of the site, i.e. Tarou had been acquired by DOMLEC as potential site for a diesel power station. For wind energy utilization, however, this site was not at all suitable – wind speeds below 5 m/s were measured there.[72]

Further consultancies of CREDP were not carried out until 2011.

2.8.2 Current Plans of DOMLEC

Within the scope of the current evaluation of ongoing wind energy projects in the Caribbean, DOMLEC was visited on 23rd of February, 2011.

In the meantime, DOMLEC had received a funding for a project entitled "Utility−Scale Small Wind Generation Pilot Project for the Nature Island of Dominica" from the Department of Energy of the

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[70] CREDP/GTZ (John Whittingham), op. cit.

[71] CREDP/Factor 4 Energy Projects GmbH (B. Jargstorf), "Preparation of Wind Power Projects at Dominica, St. Lucia and St. Vincent", September 2005, p. 26

[72] see **Annex 9** for a Summary of Results – June 2006

United States of America (DOE) within the scope of the programme "Low-Carbon Communities of the Americas". The programme is handled by the National Renewable Energy Laboratory NREL.[73]

The main goal of this project is to "prove the economic viability of small, distributed wind generation on a utility scale for the island of Dominica for replication in an effort to augment the penetration of renewables on our small grid" (see **Figure 2-78**). The project rationale was based on the "insurmountable difficulties with transport, combined with the relatively high cost of land acquisition and site construction" for the installation of wind turbines with 500 to 1,500 kW installed capacity.[74]

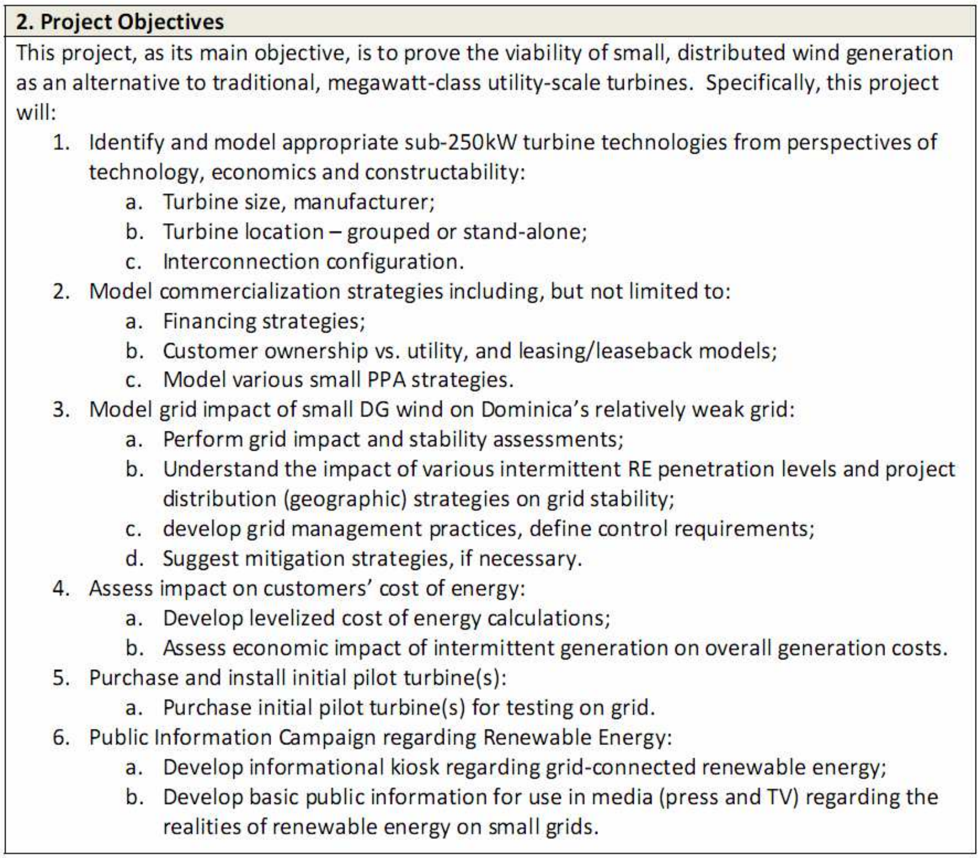
Instead using a cluster of wind turbines (wind park) DOMLEC proposed to install individual turbines in the sub-250 kW size to reach an installed capacity of 4 to 6 MW. Three turbines were named as potential technical partners

- Southwest Turbines (1.8 kW);
- Helix Wind/Equidex (50 kW vertical axis)
- Northern Power Systems (100 kW).

When checking the products of Southwest Windpower. there is only a 2.4 kW turbine available for AC, all other products of this company have DC generators.[75]

Assuming, therefore, a 2.4 kW turbine being the smallest unit size, we would need 1,667 individual turbines to arrive at the targeted 4 MW installed wind power, or 2,500 turbines for a total installed wind power of 6 MW.

Figure 2-78:
Utility-Scale Small Wind Generation Pilot Project for the Nature Island of Dominica



2. Project Objectives

This project, as its main objective, is to prove the viability of small, distributed wind generation as an alternative to traditional, megawatt-class utility-scale turbines. Specifically, this project will:

1. Identify and model appropriate sub-250kW turbine technologies from perspectives of technology, economics and constructability:
   a. Turbine size, manufacturer;
   b. Turbine location – grouped or stand-alone;
   c. Interconnection configuration.
2. Model commercialization strategies including, but not limited to:
   a. Financing strategies;
   b. Customer ownership vs. utility, and leasing/leaseback models;
   c. Model various small PPA strategies.
3. Model grid impact of small DG wind on Dominica's relatively weak grid:
   a. Perform grid impact and stability assessments;
   b. Understand the impact of various intermittent RE penetration levels and project distribution (geographic) strategies on grid stability;
   c. develop grid management practices, define control requirements;
   d. Suggest mitigation strategies, if necessary.
4. Assess impact on customers' cost of energy:
   a. Develop levelized cost of energy calculations;
   b. Assess economic impact of intermittent generation on overall generation costs.
5. Purchase and install initial pilot turbine(s):
   a. Purchase initial pilot turbine(s) for testing on grid.
6. Public Information Campaign regarding Renewable Energy:
   a. Develop informational kiosk regarding grid-connected renewable energy;
   b. Develop basic public information for use in media (press and TV) regarding the realities of renewable energy on small grids.

Source: Endorsement for the project "Building Low-Carbon Communities in the Caribbean" - Submission by Dominica Electricity Services Ltd., August 14, 2009

When checking the website of Helix Wind Corp.[76], the largest turbine offered features 4.5 kW – there might be a 50 kW version under development, but information about this turbine is not indicated.

With the 4.5 kW Helix Wind wind turbine we would need 889 individual turbines for 4 MW and 1,333 units for 6 MW installed wind power. Given the prices indicated at the website (see **Figure 2-79**) we would need an investment for the turbines alone of 15.6 million for 4 MW and 23.3 million USD for 6 MW installed wind power. Note, that this does not include costs for erection, grid connection etc. – it just for the turbines themselves.

The total costs for the 2 kW model are 21 million US$ for 4 MW and 31.5 million for 6 MW installed wind power. Thus, the distributed solution with these small turbines would result in specific investment costs of between 3,889 and 5,250 US$ per kW. Normally, wind turbines in the range between 500 and 1,000 kW feature ex-factory prices per kW of ~ 1,500 to 2,000 US$ per kW. In effect, the dis-

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73) see http://www.nrel.gov/applying_technologies/climate_initiatives.html

74) Endorsement for the project "Building Low-Carbon Communities in the Caribbean" - Submission by Dominica Electricity Services Ltd., August 14, 2009

75) see http://www.windenergy.com/products/products.htm and also http://www.skystreamenergy.com/skystream-info/

76) see http://www.helixwind.com/en/S322.php

tributed installation of small grid-connected wind turbines would give effectively twice the specific generation costs – or, the typical installation costs of nuclear power plants with a unit size of 1,000 MW.[77]

Figure 2-79:
Helix Wind – Vertical Axis Turbine[78]


S594 Wind Turbine

Pricing Information

Retail Price: $17,500 USD

Includes:

- 4.5 kW (peak) vertical axis wind turbine
- Inverter - Aurora PVI 6000
- Wind Interface Module
- Diversion Load

Using the largest turbine size – Northern Power – with 100 kW, we still need to install 40 turbines for 4 MW and 60 units for 6 MW. Identifying 60 suitable sites for the 100 kW model seems extremely difficult, given the topographic characteristic of Dominica. The advantage of the Northwind 100 kW turbine, however, concerns the possibility of installing the wind turbine without a crane (**Figures 2-80** and **2-81**).

But technically, the Northwind – as a stall controlled turbine – has decisive disadvantage in a relatively weak grid. Also, acquiring and installing 60 wind turbines by means of auxiliary cranes (~ 3 days per turbine) will result in prohibitive costs, when compared with a “standard” solution of a 4 to 6 MW wind park.

Figure 2-80:
Northwind NW100 – Tilt-up Tower

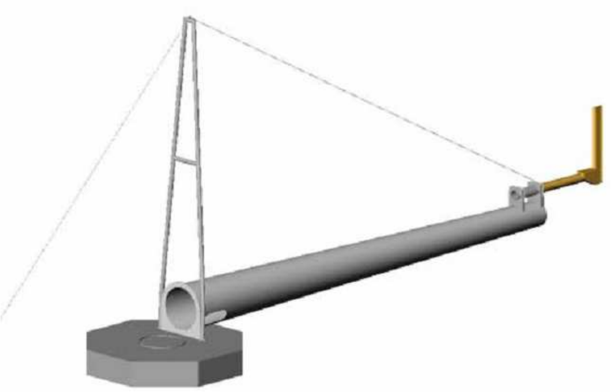

Figure 2-81:
Northwind NW100 – Nacelle Installation with Auxiliary Crane

Source: Northwind 100 company brochure

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[77] Amory B. Lovins, Imran Sheikh and Alex Markevich, “Forget Nuclear”, RMI Solutions final version for press 6-4-2008 see http://www.rmi.org/rmi/Library/E08-04_ForgetNuclear

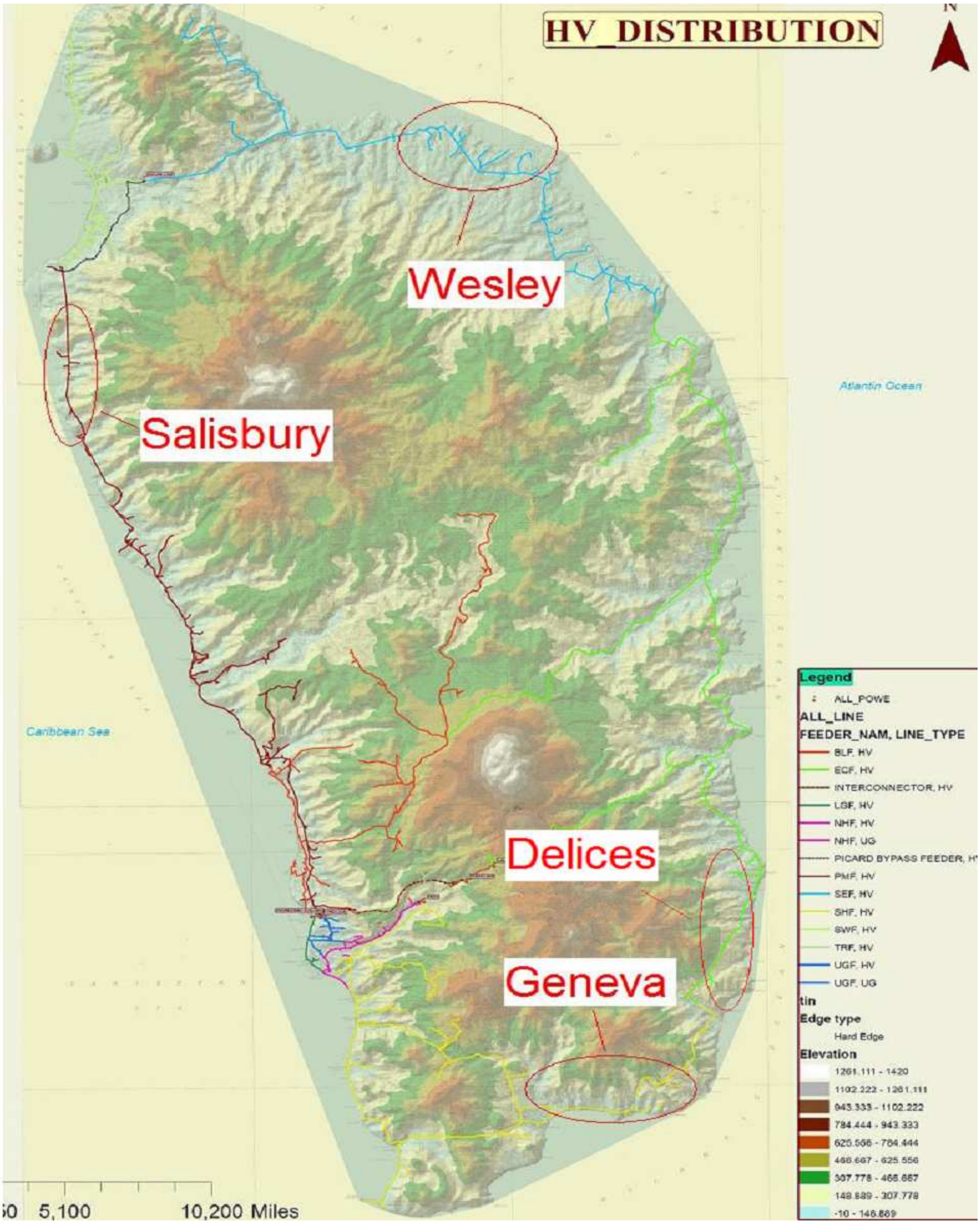
[78] http://www.helixwind.com/en/S594.php

2.8.3 First Results of the DOE Project

Possibly, the ad-hoc considerations undertaken in the preceding section led the consultant of the DOE/NREL project – Quanta Technology LLC – to disregard the proposed wind turbines from the application form, but study the effects of four miniature wind parks with 2 units of 275 kW instead.

As can be seen from **Figure 2-82**, the site Wesley is close to the Compton site proposed since 2003

Figure 2-82:
Proposed Wind Turbine Locations – Four times 2 x 275 kW



Source: Quanta Technologies, “DOMLEC Wind Generation Studies - Impact Analysis”, November 2010, p.29

by CREDP, while two other sites (Delices and Geneva) are at the Southern tip of Dominica, where above average wind speeds can be expected. The fourth site – Salisbury – is located on the leeward side of Dominica. It is questionable whether the wind regime there is sufficient for an economic operation of two individual 275 kW turbines.

2.8.4 Technical Review / Recommendations

The technical results of the Quanta study shall not be discussed here. Integrating power generations with just about 0.5 MW into a 11 kV distribution grid is not a technically demanding task. As a rule of thumb, only larger generation facilities with approx. 5 MW and more need a careful consideration and, optimally, a load flow calculation.

The general approach of distributed wind energy utilization on an island like Dominica seems to have too many disadvantages as to receive serious attention.

This is due to the following main reasons:

The specific unit costs of energy are known to increase with smaller size, thus, the “real” small units as originally envisaged by the project application (2 to 100 kW) are prohibitive on the base of investment costs.

A size range below 5 kW would principally offer the advantage that these small wind turbines can theoretically be installed without a complicated planning procedure. But already with 10 or 20 kW units, larger safety distances would have to be adhered to, noise impacts would have to considered and a general planning permission would have to be obtained. The sheer number of these installations renders such an approach impracticable.

Given the problems with identifying suitable sites for wind energy utilization under the highly complex terrain of Dominica, reducing the individual turbine size as extremely as it has been done in the original distributed energy approach (i.e. to 100, 50 and 1.8 kW per turbine) must be regarded as inappropriate for Dominica.

In the draft consulting report from Quanta four sites with 2 x 275 kW have been surveyed with regard to their electrical connection. However, the wind regimes of the four selected sites have not been checked, as well as the availability of land for the installation of the turbines.

In general, installing 8 turbines in four groups, considerably increases the noise impact area – this is the reason why elsewhere in the world, all serious wind power development strategies rely on larger clusters of wind turbines, and discourage the installation of individual turbines.

Given the image of Dominica as “Nature Island” installing larger number of individual turbines or four times two turbines, seems contradictory, especially when using turbines with guy wired towers. The visual impact of guy-wired turbines is considerably higher than that of tubular towers.[79] Also, one has to be aware that it is not only guy wires, but also the gear for the tilting mechanism (gin pole, block and tackle etc.) which is visible and, over time, deteriorates (see **Figures 2-83** and **2-84**).

Figure 2-83:
Guy-Wires and Tilting Mechanism/Gin Pole

Photos: B. Jargstorf, Guadeloupe, June 2006

Figure 2-84:
Visual Impact of Guy-Wires

Photo: B. Jargstorf, Guadeloupe, June 2006

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[79] For more information on the Vergnet 275 kW turbine, see also **Section 2.10** Nevis

Figure 2-85:
Wind Turbines from 2.4 to 1,000 kW – Key Data and Capacity Factor

	Installed Power (kW)	Units needed	Hub Height	Wind Speed	Annual Output in MWh Turbine	Total	Capacity Factor
Southwest	2.4	1,667	33 m	6.3	4.2	6,971	**19.9 %**
Northern Power	100	40	37 m	6.4	185	7,400	**21.1 %**
Vergnet GEV	275	14	55 m	6.9	592	8,288	**24.6 %**
Vergnet MP	1,000	4	70 m	7.1	2,461	9,844	**28.1 %**

Figure 2-86:
Wind Turbines from 2.4 to 1,000 kW – Area Needed and specific Production

	Installed Power (kW)	Units needed	Hub Height	Safety Radius	Safety Area in m^2 Turbine	Total	Production in kWh/m^2
Southwest	2.4	1,667	33 m	50	7,857	13,098,036	**0.53**
Northern Power	100	40	37 m	200	125,716	5,028,640	**1.47**
Vergnet GEV	275	14	55 m	300	282,861	3,960,054	**2.09**
Vergnet MP	1,000	4	70 m	400	502,864	2,011,456	**4.89**

Given the constraints for distributed wind energy utilization in Dominica – particularly in the originally targeted size range between 1.8 and 100 kW unit size – it is recommended that DOMLEC reverts to the planning of a “conventional” wind park. Then there will be only the task of acquiring land for one wind park – instead of four – there will be only one Environmental Impact Assessment – instead of four – there will be only one licensing procedure – instead of four – and only one implementation planning procedure – instead of four.

Concerning the size of the wind turbines, the 250 kW class has definitely advantages with regard to transport and installation. However, the space requirements per kW increase considerably, when compared with a typical wind turbine of the 1 MW class. At the same time the annual energy yield of the larger machine is for to five times larger. As a result, the energy yield per used area is about three to four times higher than with the 250 kW wind turbine.

In **Figure 2-85** the key data of the distributed wind generation with different wind turbine sizes – 2.4 kW, 100 kW and 275 kW – are compared with a conventional wind park with 1 MW machines for a total installed power of 4 MW.

This comparison uses the following wind turbines:

- Southwest Skystream 3.7 (2.4 kW);
- Northern Power Systems (100 kW)
- Vergnet GEV (275 kW)
- Vergnet MP (1,000 kW)

The assumption for the annual power output calculation is an average wind speed of 6.8 m/s in 50 m above ground.

One can see that, with increased size of the wind turbines, the annual average net production increases – the calculated capacity factor goes up from 20 % to 28 %. The better output of the larger machines is not only the result of a better overall efficiency of the larger turbines, but also of the increased annual average wind speeds due to larger hub heights. They increase from 6.3 m/s in 33 m to 7.1 m/s in 70 m.

The most important difference between the distributed solution with smaller turbines and the “standard” solution with 1 MW turbines can be demonstrated through the environmental impact of the wind turbines (see **Figure 2-86**).

With the assumption of a safety radius of 50 m for the 2.4 kW turbines, 200 m for 100 kW, 300 m for 275 kW, and 400 m for the 1,000 kW wind turbine, we calculate total safety areas of between 13 km^2 for the 2.4 kW turbines and only 2 km^2 for the 1 MW turbines. These values, however, assume only individual turbines – if turbines are put in clusters (wind parks), the space requirements can be reduced considerably.

The Southwest 2.4 kW turbine produces just 0.5 kWh/a per m^2 of space requirement, whereas the 1,000 kW turbine has 4.9 annual kWh per m^2.

In summing up, we can conclude that the distributed generation with wind power – while offering advantages with regard to transport and installation – is economically unfavourable, has generally a lower energy efficiency and, most importantly, requires unfeasibly high (safety) areas.

Thus, due to the considerable larger environmental impact of distributed wind generation, the higher installation and operation costs and the lower overall specific production, this option seems to be suboptimal for Dominica.

2.9 Saint Vincent

2.9.1 Technical Advice of CREDP

Already in 1985, the British company James Howden & Co, Ltd carried out a market study for their wind turbines in the Caribbean and also considered Saint Vincent.[80] Then, in 1991/2, St. Vincent and the Grenadines had been studied by Transenergy Consultants, Ltd. with funds from the British Development Division in the Caribbean and the OECS Secretariat (Organisation of Eastern Caribbean States). Within the framework of the 1991/92 study, wind measurements were carried out at St. Vincent, Canouan and Union Island.

A wind assessment study was carried out by CREDP/GTZ in 2004, in which the sites for a wind park from previous studies were evaluated. In this study, the average wind speeds measured at Argyle (St. Vincent) were indicated as 8.1 m/s.[81] Unfortunately no additional information about this measurements (or the raw data) could be obtained. Without the information about measuring height, averaging times and the exact location, this figure only indicates that wind speeds at St. Vincent are sufficient for wind energy utilization.

The area around Argyle in the South-East part of the island would definitely be a suitable location for a wind park. But this area at that time had already been selected for an international airport – which is, by now, well under construction.

VINLEC choose a two step approach to site selection, i.e. to install a 10 m tower using a standard utility pole for site selection first (**Figure 2-88**) and, in a second phase, hub height measurements for the determination of achievable wind energy output later. After the measurements at 10 m resulted in an annual average wind speed of 7.44 m/s,[82] a land availability study was carried out and a site close to the 10 m tower was identified, which had no conflicting land use interests.

This was the peninsula Ribishi Point, crown land and adjacent to the official municipal dump site. There a 30 m tower was installed (**Figure 2-89**) – an annual average wind of 8.43 m/s was established through measurements over the next four years.[83]

Figure 2-87:
St. Vincent -Tree Flagging at Brighton

Figure 2-88:
Installation of Anemometer Station at Brighton

Photo: Thomas Scheutzlich 2004

Calculating the annual average energy output for two reference turbines resulted in 2,817 and 3,128 MWh for the Enercon E44 and the UNISON U50, respectively. This corresponds, under optimistic assumptions, to calculated capacity factors of 35.7 and 47.6 % and demonstrates the extraordinary wind resources of the site Ribishi Point.

Figure 2-90 shows the monthly wind speeds.

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80) out of this study came the installation of the wind turbine in Barbados – see **Section 2.6.1**

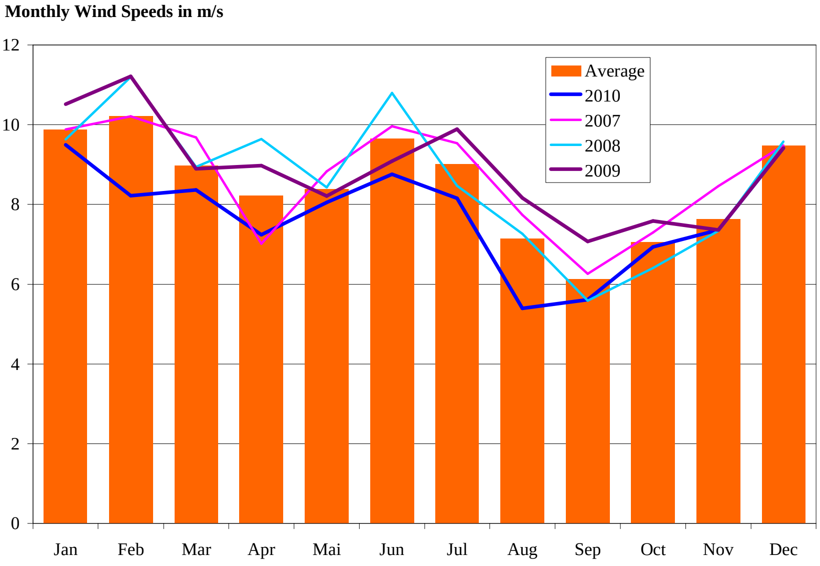
81) CREDP/John Wittingham Consultancy Services, "Wind Energy Assessment St. Vincent and the Grenadines", Barbados, May 2004, p. 11

82) it was estimated that this would result in a hub height wind speed of 8.4 m/s

83) CREDP/Factor 4 Energy Projects GmbH (B. Jargstorf), "Wind Data Evaluation Ribishi Point, St. Vincent", January 2011

Figure 2-89:
30 m Lattice Tower at Ribishi Point

Figure 2-90:
Ribishi Point - Monthly Average Wind Speeds in m/s (2007 – 2010)



Based on the results of this four year wind measurements a feasibility study was carried out, assuming an investment costs of 6.63 million US$ for a 4 unit wind park with 3 MW installed capacity.

The specific dynamic generation costs with a discount rate of 10 % were calculated to 7.153 US$cts per kWh with a variation between 6.157 (pessimistic assumptions) to 8.105 US$cts/kWh.[84]

Figure 2-91:
Ribishi Point – Investment Cost 4 x 750 kW

	Unit costs in US$	Total costs in US$
4 Wind turbines with 750 kW*	1,496,000	5,984,000
Switch gear, metering, protection		30,000
Foundation and cable trenches	60,000	240,000
Access roads and building of grid station		20,000
Sub total		6,274,000
Constingencies (~ 5 %)		315,000
Installation Costs in US$		**6,589,000**
*) including grid transformers, transport, training, erection etc.		
Installation of stand-by generator		40,000
Extra Costs for Anti-Hurricane Measures		40,000
Total Project Costs in US$		**6,629,000**

The unit cost of energy between 6 and 8 US$cts per kWh compares favourably with corresponding generation cost in VINLEC's major thermal power plant at Lowmans Bay. There costs as a function of the oil price per barrel have been established, varying from 6 US$cts per kWh for an oil price of 30 US$ and 13.5 US$cts per kWh for an oil price of 100 US$ per barrel (see **Figure 2-92**).

Thus, a wind park at Ribishi Point is an economic favourable venture as long as the oil price is above 50 US$ per barrel.

With current oil prices in excess of 115 US$, one cannot realistically expect that we shall return to a level with below 50 US$ oil prices. Under this situation, and with the results of the Feasibility Study for Ribishi Point one can safely say that wind power in Saint Vincent can be produced at about half the costs as in the diesel power plant of LUCELEC – as long as the oil price is above 90 US$ per barrel.

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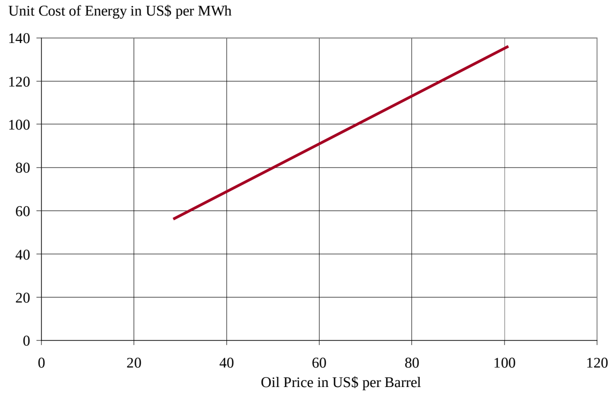
[84] CREDP/Factor 4 Energy Projects GmbH (B. Jargstorf), "Feasibility Study for a grid-parallel Wind Park at Ribishi Point, St. Vincent", February 2011, p. 16

Figure 2-92:
Diesel Power Station Lowmans Bay - Unit Cost of Energy as a Function of Oil Price per Barrel[85]



Similar results as in the feasibility study in Saint Vincent have been obtained for the project Sugar Mill in Saint Lucia.[86]

2.9.2 Ribishi Point and Argyle Airport

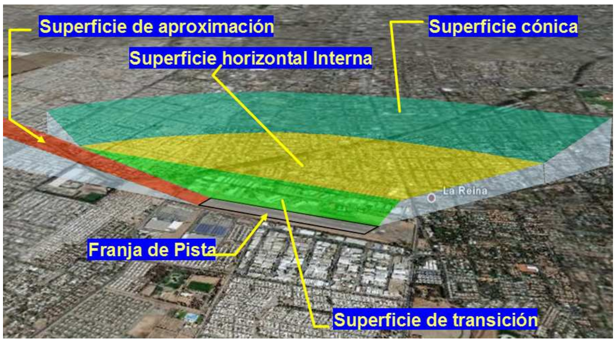
The international airport at Argyle is by far the greatest infrastructure project in Saint Vincent. With an estimated total investment of more than US$ 260 million it dwarfs the wind park Ribishi Point with just below US$ 7 million.

Due to international aviation rules, however, there might be a problem for the building permission of the wind park, as there is a chance that the wind turbines violate obstacle limitations, an airport has to consider, in order to be internationally recognized.

Until February 2011, no formal permission (or refusal, for that matter) for the wind park Ribishi Point could be obtained from the official aviation agency of Saint Vincent.[87]

In this situation, using an early publication of the airport runway planning and information available in the internet about airport safety areas, **Figure 2-94** has been compiled.[88] According to this map, half of the Ribshi Point peninsula would be affected, in principal, by the airport safety rules. On the other hand, there is always a slope indicated, by which the airplanes will approach, land and start. This can be seen in the airport security check for (an old, and now defunct) inner-city airport in Santiago de Chile in **Figure 2-93**).

Figure 2-93:
Airport Security Zones – Santiago de Chile



Source: Rodrigo Silva Salbach –Administrador de Aeropuertos “Plano de Proteccion des Aerodoromo Tienienete Rodolfo Marsh Martin”, presentation from June 2006

Generally, a slope of 3 % for the approach to the runway is required. With this slope, the peninsula Ribishi Point would not face any problems from the Aviation Agencies.

2.9.3 Request for Proposal – Ribishi Point

In December 2008 VINLEC issued a professionally compiled Request for Proposal (RFP), asking for bids from private investors for the installation and operation of a 6 – 8 MW wind park at Ribishi Point.[89]

Bids from three companies were received, none of which had prior experiences with projects in the Caribbean, and none of which had prior experiences with wind parks operating in parallel with a (small, weak) electric grid, powered by diesel generators. One bidder offered two different turbine types a alternatives: the 1 MW VERGNET GEV HP, and the NORWIN 47 –ASR-750 kW.

The NORWIN turbine uses the active stall control principle (ASR – Active Stall Regulation), which is an advantage over passive stall as in the Wigton I wind park (Vestas 900 kW). However, NORWIN still employs direct grid coupling (compare **Figure 2-11** and **Figure 2-41**)).

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85) CREDP/Factor 4 Energy Projects GmbH (B. Jargstorf), “Pre-Feasibility Study for a Wind Park at Brighton, St. Vincent”, October 2006, p. 11

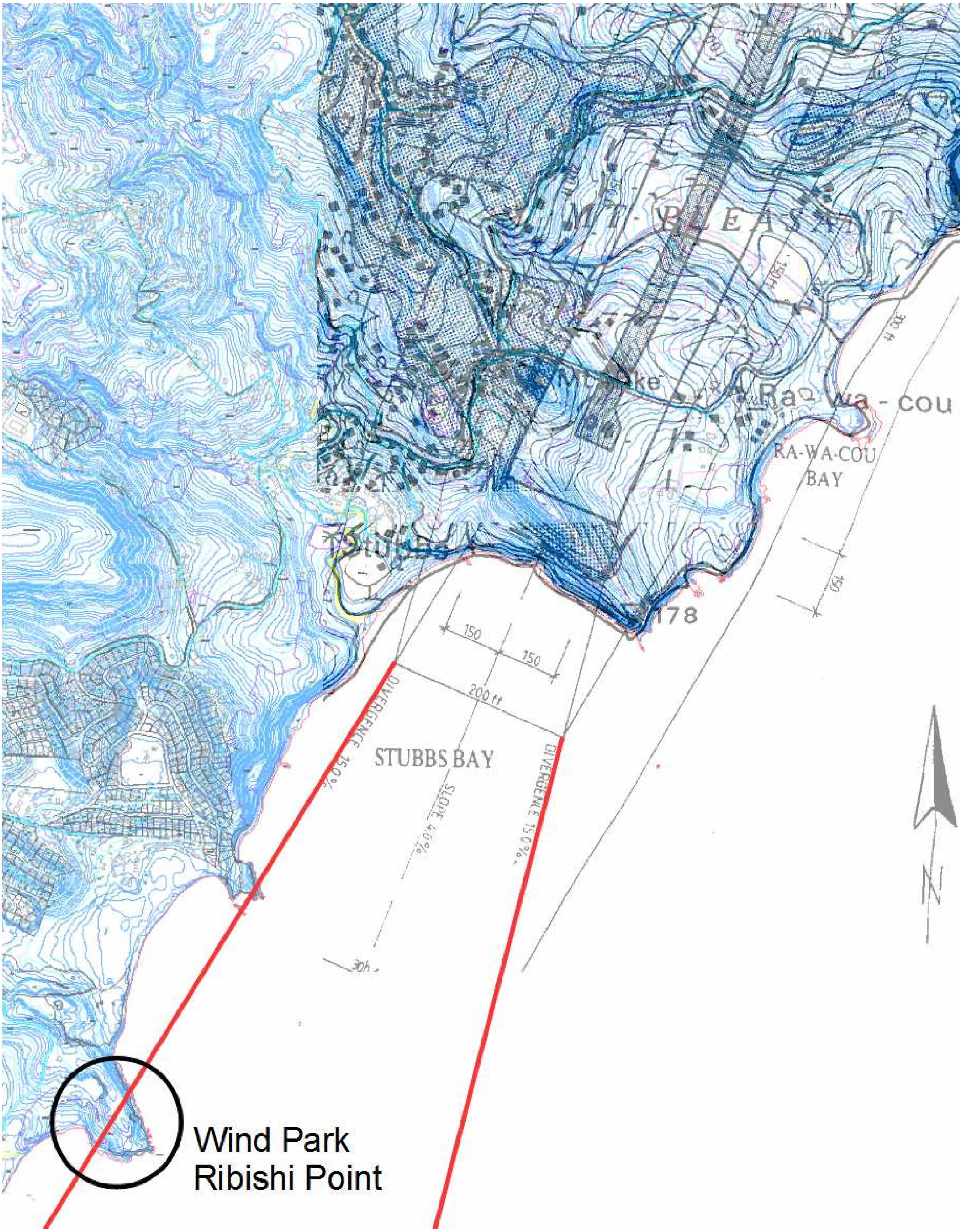
86) see **Section 2.12.1 Saint Lucia**

87) personal information, Vaugh Lewis, VINLEC, 24th of February 2011

88) please note that the consultant is electrical engineer, and has no prior experience with airport obstacle engineering – only the siting of two wind parks close to airports in Bremerhaven (see **Figure 2-32**) and on Galápagos (Baltra)

89) see **Annex 10 – RFP VINLEC**

Figure 2-94:
Argyle Airport and Ribishi Point)



Source: **black map**: Susan Lewis, "Argyle International, 'No more delays' PM assures Vincentians" in THE NEWS, Friday August 12, 2005, St Vincent and the Grenadines, No. 838, *modified*, **blue map:** VINLEC

With this kind of generator concept, grid stability problems at a site like Ribishi Point were expected, where the turbines were planned to deliver their power to the distribution network through two separate feeders.

The wind turbine VERGNET GEV MP, as offered, is a Wind Class III machine (rotor diameter: 62 m, tower height 70 m), the rotor of which could be lowered in case of hurricanes. A Wind Class III turbine is deigned for an annual average wind speed of 7.5 m/s whereas Ribishi Point features in 30 m already 8.4 m/s. At 70 m hub height, close to 9 m /s can be expected. At the time of offer, the newly designed machine had not received a class certification from a respected Certification Agency. Also, only one project with the newly developed 1 MW machine was currently being planned (in Ethiopia).[90]

Also another bidder offered the same type of wind turbine.

The third bidder proposed to install the WinWinD WWD-1 turbine, also with 1 MW of installed power. This turbine has been developed in Finland with a licence from MULTRIBRID (Germany). It employs a 1-stage gear box and a medium-speed synchronous generator with permanent magnet excitation and water cooling – similar to the UNISON U5x generator, but with higher rotational speeds and smaller diameter. The WinWinD turbine was offered with a special hydraulic tilting mechanism, designed from Alizéo (France).[91]

Two bidder mention a cooperation with the Australian company PowerCorp, which they want to integrate a flywheel for increasing the wind power penetration and grid quality.[92] However, no details were indicated – and it was doubtful whether the bidders had actually contacted PowerCorp and asked for a technical offer.

After lengthy discussion with the first-placed bidder (VERGNET 1 MW), VINLEC finally decided to abandon the tender procedure without having taken a decision. This pull-out was strongly influenced by the fact that the bidders – in the view of VINLEC – had not sufficiently prepared their bid. Some even compiled their offer without conducting a site visit.

Figure 2-95:
Tilting mechanism of Alizéo /France

2.9.4 Summary / CREDP Proposals

The proposed wind park Ribishi Point offers excellent wind resources, which would allow net capacity factors close to 40 %. Being government land, in the vicinity of the dump yard there does not seem to exist competitive land use plans.

Under this situation, it is proposed to continue with the preparation of this project, and undertake the following tasks:

1. check the site with the airport authorities, get a written decision;
2. check the grid connection possibilities. As an new distribution line has to be build for the airport anyway, it should be considered to have a dedicated distribution line from Ribishi Point to the next substation;
3. consider to implement the project as a VINLEC only venture, without investors from abroad;[93]
4. get in contact with Wigton and Munro in Jamaica, and with Windwatt in Nevis when designing a stable grid connection;
5. Consider government support for the implementation of the wind park – after all, with oil prices over 100 US$ per barrel, introducing wind to the current diesel/hydro energy mix will reduce the end use tariffs in Saint Vincent.[94]

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90) in the meantime, the type classification has finally be refused and VERGNET has offered to finish the 120 MW project in Ethiopia with Alstrom wind turbines. The future of the VERGNET GEV MP turbine is not clear. Obviously, the first 30 MW in Ethiopia will use these turbine – even without a type certification. It is estimated that this will cost VERGNET considerable extra warranties.

91) see http://www.groupe-alizeo.com/

92) see **Figure 2-59**

93) see **Annex 12 – "To IPP or not to IPP"**

94) see example from Bonaire in **Section 2.15**

2.10 Nevis

2.10.1 Technical Assistance of CREDP

Upon request of NEVLEC – Nevis Electricity Services – the wind energy expert of CREDP visited Nevis in June 2006. In collaboration with NEVLEC possible wind park sites were evaluated and proposals worked out for project implementation

At that time, the isolated electrical grid, operated by NEVLEC had an absolute minimum load of approx. 5 MW, which would result in a maximum installed wind power of about 2.5 MW or – with an anticipated load growth during the time of project planning and execution of ca. 3 MW.

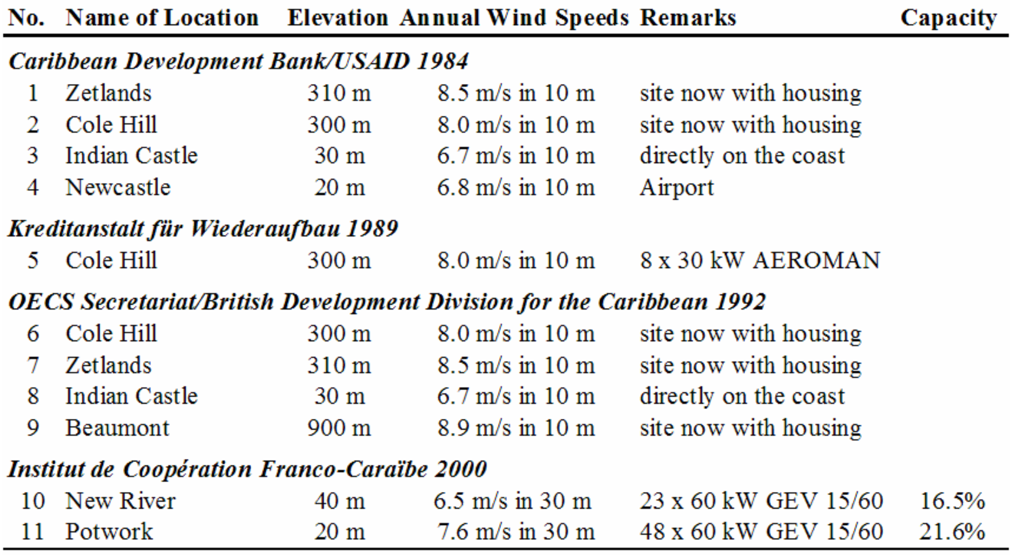
In his report, CREDP's wind energy expert argued that such a small project (between 10 x 300 kW, 5 x 600 kW and 3 x 1,000 MW installed wind power per unit) was not likely to raise the attention of major wind turbine manufacturers, given the current market trends with full order books and a focus on utility wind turbines in the 2 to 3 MW range.[95]

An analysis of previous wind energy project proposals yielded a stunning 11 potential sites which had been considered for wind energy utilization on Nevis between 1984 and 2000 from different organisations. One site with an annual average wind speed of 8 m/s in 10 m above ground – Cole Hill – had been considered by three different organisations between 1984 and 1992 (see **Figure 2-96**).

In 2006, this site was covered with houses and was no longer suitable for the installation of a wind park (**Figure 2-99**).

Under the assumption that wind turbines below 500 kW would require too much space – especially considering future extensions needed for the operation of high-penetration grid parallel or wind-diesel systems, CREDP was evaluating potential wind park sites for a minimum of 3 MW total power (i.e. 5 x 600 up to 3 x 1,000 kW). Assuming a three rotor diameters distance between the turbines perpendicular to the main wind direction, this would mean a site stretching a minimum of 500 m in 90° to the prevailing eastern wind direction.

Figure 2-96:
Nevis - Proposed Wind Park Sites from Wind Energy Missions 1984 - 2000



No.	Name of Location	Elevation	Annual Wind Speeds	Remarks	Capacity
Caribbean Development Bank/USAID 1984					
1	Zetlands	310 m	8.5 m/s in 10 m	site now with housing	
2	Cole Hill	300 m	8.0 m/s in 10 m	site now with housing	
3	Indian Castle	30 m	6.7 m/s in 10 m	directly on the coast	
4	Newcastle	20 m	6.8 m/s in 10 m	Airport	
Kreditanstalt für Wiederaufbau 1989					
5	Cole Hill	300 m	8.0 m/s in 10 m	8 x 30 kW AEROMAN	
OECS Secretariat/British Development Division for the Caribbean 1992					
6	Cole Hill	300 m	8.0 m/s in 10 m	site now with housing	
7	Zetlands	310 m	8.5 m/s in 10 m	site now with housing	
8	Indian Castle	30 m	6.7 m/s in 10 m	directly on the coast	
9	Beaumont	900 m	8.9 m/s in 10 m	site now with housing	
Institut de Coopération Franco-Caraïbe 2000					
10	New River	40 m	6.5 m/s in 30 m	23 x 60 kW GEV 15/60	16.5%
11	Potwork	20 m	7.6 m/s in 30 m	48 x 60 kW GEV 15/60	21.6%

Source: CREDP/Factor 4, see **Annex 11**

As can be seen in the cross section of Nevis from North to South in **Figure 2-98**, suitable, high-lying areas with flat terrain were practically all densely populated. Therefore, CREDP discussed the following alternative potential wind park sites:

1. Round Hill South;
2. Indian Castle Hills;
3. Saddle Hill South; and
4. Hick's Estate Hills/Maddens Estate

Of this site list, Hick's Estate/Maddens Estate was considered the most promising site.

CREDP proposed to install a data logger with two anemometers at the existing telecommunication tower at Maddens Estate (**Figure 2-99**) and proposed a plan of action ("road map to wind energy") for Nevis. Among others, the joint tendering of a 3 MW wind park within the CAWEI was recommended.[96]

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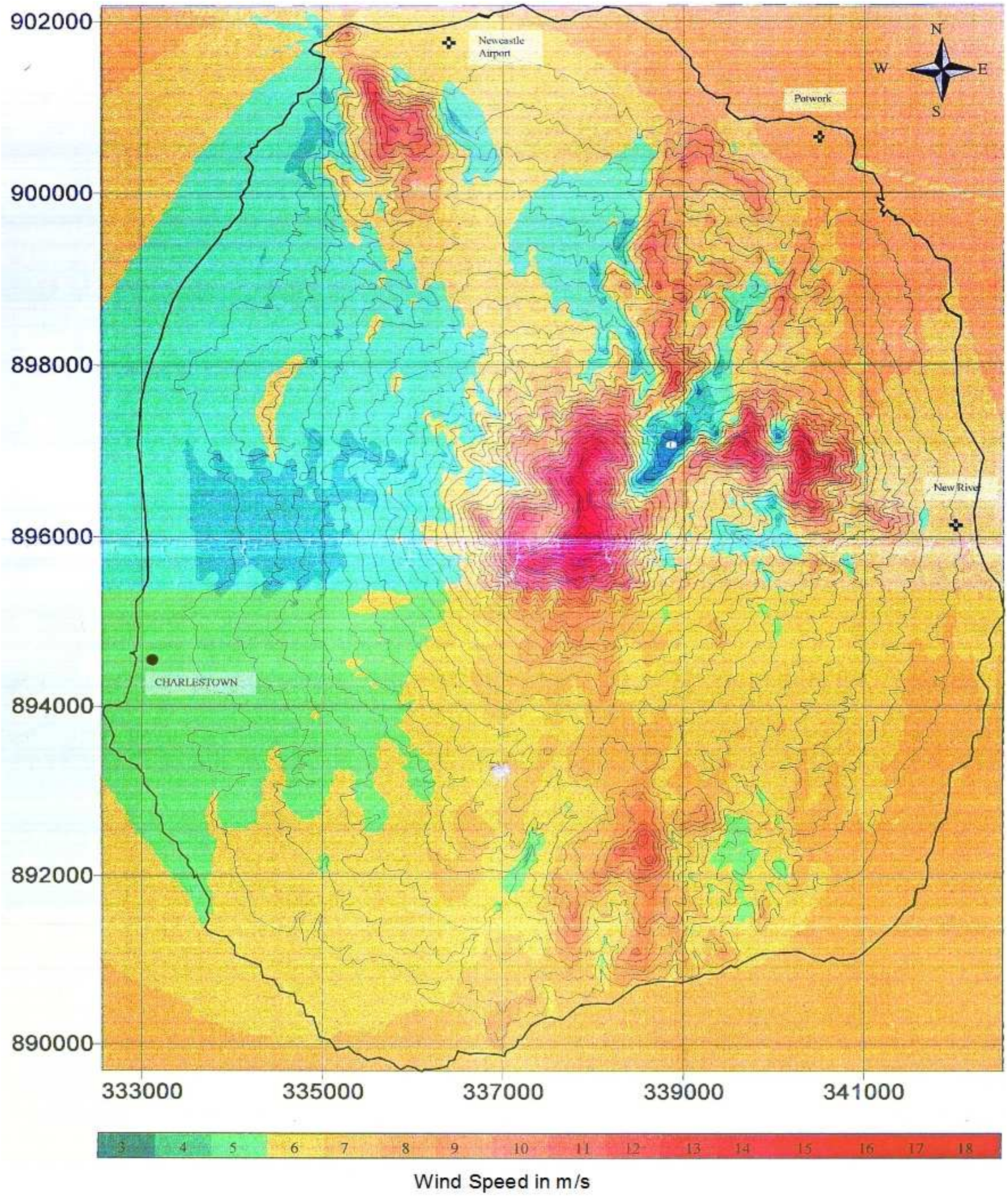
[95] see CREDP/Factor 4 Energy Projects GmbH (B. Jargstorf), "Summary of Results – Wind Energy Project Preparation at Nevis", St. Lucia, 22nd of June 2006, in **Annex 11**

[96] for more details, see **Annex 11**, paragraph 34

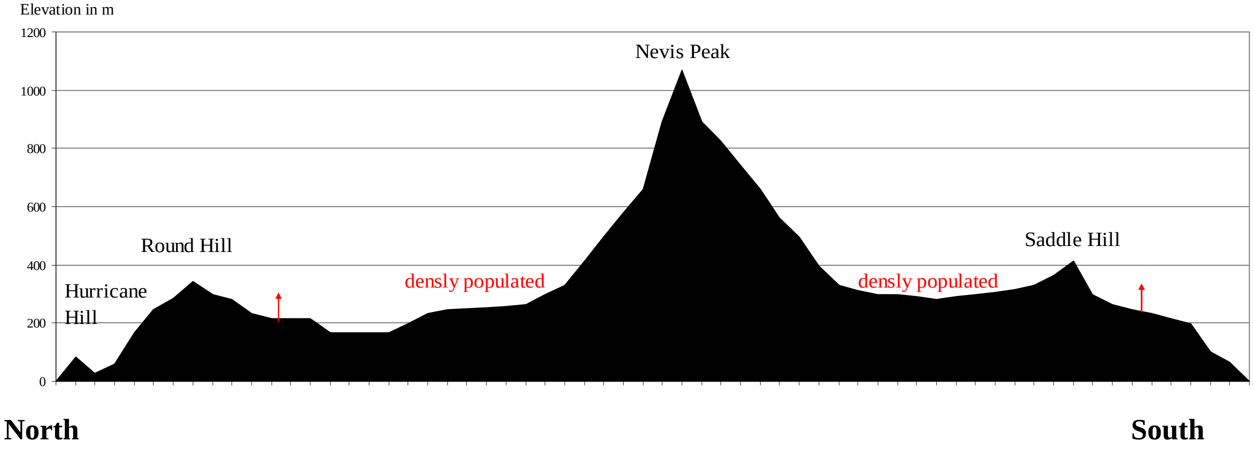
Figure 2-97:
Wind Flow Modelling Nevis



Source: Institut de Coopération Franco-Caraïbe et VERGNET Caraïbes, "Study of the Wind Potential of Nevis – Wind Measuring Campaign June 1999 – September 2000", November 2000, p. 41

A study by the Institut de Coopération Franco-Caraïbe and VERGNET Caraïbes in 2000 site established a wind flow modelling for Nevis and indicated annual average wind speeds in 30 m above ground (**Figure 2-97**). This wind flow model was based on two measurements in 30 m at Potwork and New River – two sites on the Eastern shore of Nevis. This model has quite different results when compared with that used for Grenada and Dominica and does not show the highest wind speed over sea, as did the AWS Truewind model (compare **Figure 2-49**, **Figure 2-51** and **Figure 2-61.** The site at Potwork with 7.6 m/s at 30 m above ground lies below ~1 km to the NW of the wind park Maddens.

Figure 2-98:
Nevis - Proposed Wind Park Sites from Wind Energy Missions 1984 - 2000



Source: CREDP/Factor 4, see **Annex 2**

Figure 2-99:
Antennae Tower at Maddens Estate with two proposed Anemometers

Photo: B. Jargstorf, June 2006

Figure 2-100:
Cole Hill in 2006 – Houses Everywhere

Photo: B. Jargstorf, June 2006

2.10.2 Maddens Wind Park

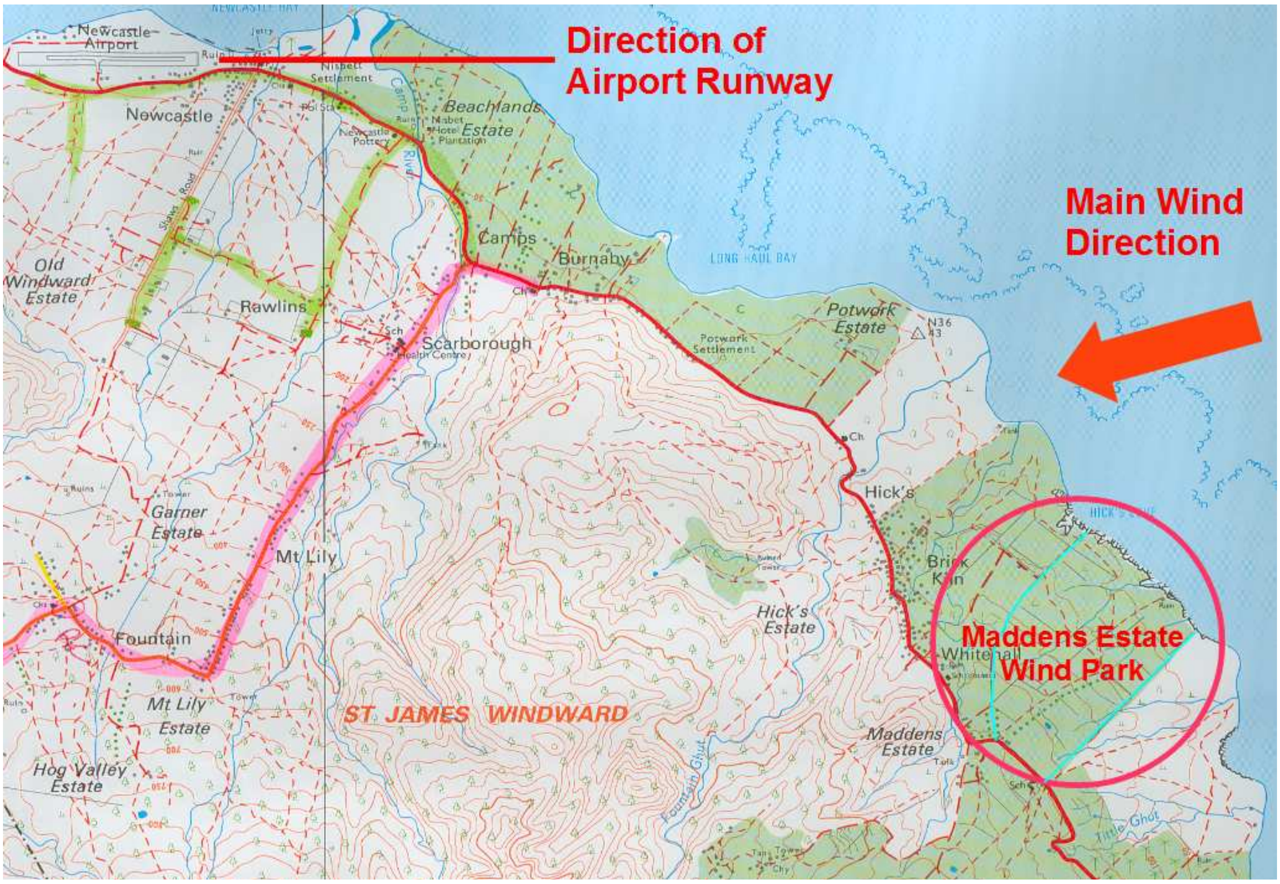
In June 2010, the private wind park developer Windwatt Nevis Ltd. installed a wind park with 2.2 MW installed power just below the telecommunication tower at Maddens Estate, obviously without having undertaken prior long-term wind measurements. Instead, Windwatt relied on the wind measurements from 30 m undertaken with the support of VERGNET Caraïbes.

About 4 months before commissioning the wind park – consisting of 8 units of the 275 kW Vergnet turbine – a 50 m wind measuring tower (**Figure 2-103**) was installed half way between the wind park and the telecommunication tower from **Figure 2-99**.

Windwatt Nevis Ltd and NEVLEC Electricity Services Ltd. negotiated a IPP contract (Independent Power Producer), which originally considered a maximum power of 2.2 MW to be fed into the distribution network of NEVLEC at any time.

Figure 2-101:
Nevis –Maddens Wind Park – as seen from the Road (with 1 Unit down)

Figure 2-102:
Nevis –Maddens Wind Park - Location



It is assumed that a clause in the contract allowed NEVLEC to reduce this figure should grid stability problems or problems with extreme low load or with spinning reserve in the diesel power station occur.

According to oral information received during the visit of the wind park Maddens Estate on 28th of February, currently 1.1 MW can be produced by the wind park at any time, and a maximum of 1.6

MW are possible when NEVLEC’s load situation allows it.

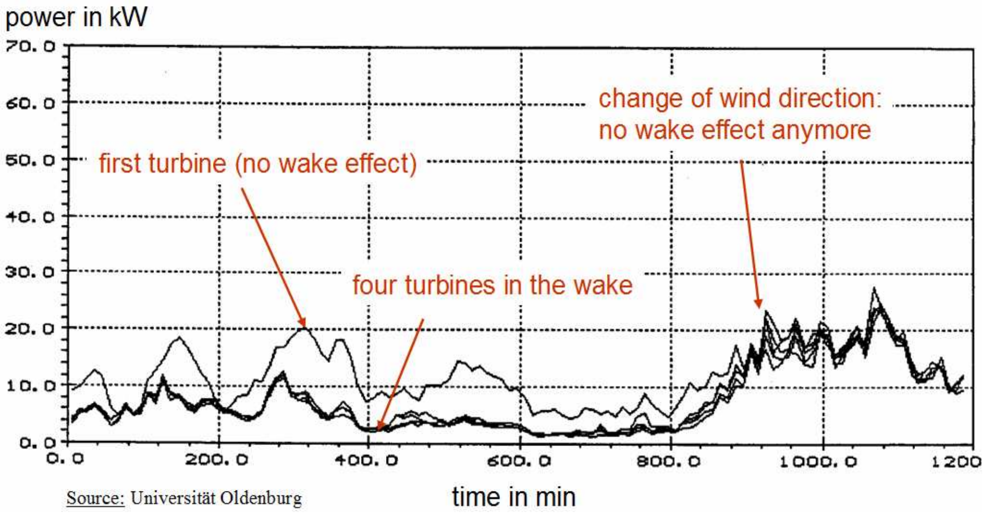
As the wind park feeds directly into the islands 11 kV distribution grid, higher values of instantaneous wind generated electricity from the Windwatt project allegedly causing problems with grid stability. While the nature of these problems have not identified in detail, it is estimated that the directly coupled asynchronous generator (induction generator) of the VERGNET turbines and their associated demand for reactive power is a major contributing factor (for more information, see **Section 2.1** Jamaica, with regard to reactive power consumption).

With a maximum allowed wind park power of 1.1 MW, the private investor is confronted with a situation that only 50 % of his investment can earn interest all of the time. And with 1.6 MW during peak demand times in the grid, about 72 % of the investor’s money is allowed to earn interest part of the time.

Figure 2-103:
Maddens Wind Park – General View with 50 m Measuring Tower

Photo: B. Jargstorf, February 2011

Figure 2-104:
Measured Output Power Reduction (Turbines with 4 Rotor Diameter Distance)



Source: Universität Oldenburg

This situation must be regarded as a very unusual arrangement for a private wind park developer.

2.10.3 Wind Park Layout

The wind park is located at the North Eastern part of the island, directly at the shore line (see **Figure 2-101**). The wind park micro-location features two rows of four and three turbines in a row, with another turbine having been placed in the middle of the rows (**Figure 2-103**).

Thus, seven turbines of the wind park are regularly in the wake of each other, as they operate practically with only about 100 m distance in the main wind direction from each other. With a rotor diameter of 32 m, this means that just 3 rotor diameters distance exists from turbine to turbine in the main wind direction – just half of what is recommended.

As a result, a regularly reduced output of the turbines is expected in the wake, and, as a long-term effect, a much higher wear and tear on the turbines must be feared due to the operation in higher-than-average turbulence levels.

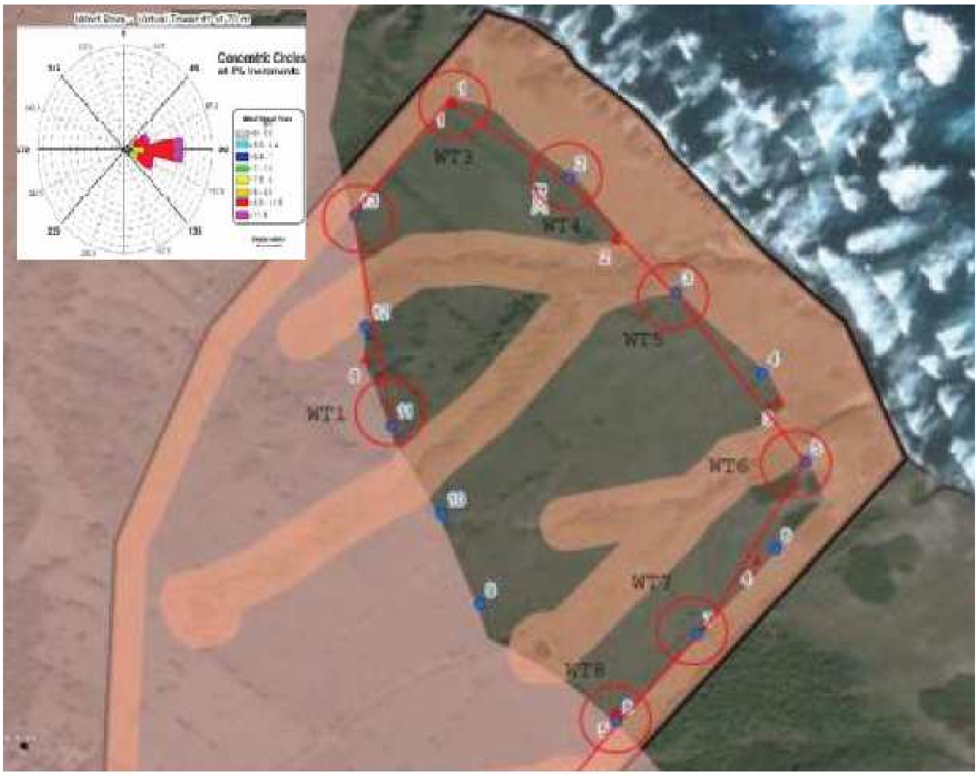
Output measurements undertaken on a wind park with 4 rotor diameter distance show that the pro-

production of the turbines in the wake is reduced to about 50 % (see **Figure 2-103**).

Thus with only about three rotor diameters distance at Maddens Estate, even higher losses must be anticipated.

During the time of the visit (26 to 28th of February, 2011) wind speeds averaged between 10 and 13 m/s, thus the turbines were producing around nominal power. However, the last turbine in the row regularly switched over to the lower rotor speed, indicating that the turbine only saw wind speeds below ~ 7 m/s.[97]

Figure 2-105:
Nevis – Micro-siting Draft (Not the final Version)



Source: NEVLEC Ltd.

When asked about the rationale about the micro-siting, the Operations and Maintenance Manager of the park informed the consultant that Windwatt Nevis Ltd. was not involved with the wind park configuration, but left this task to the wind turbine manufacturer VERGNET. A draft version of the micro-siting in **Figure 2-105** showed that originally a row with 4 turbines directly at the shoreline was planned. One can also see that the correct prevailing wind direction from East has been assumed for the micro-siting.

Under this situation it can only be speculated why such an unfavourable final wind park configuration has been chosen. Maybe the engineers of VERGNET wanted an easy way for the physical planning of the turbine's guy wire system: As there is practically a constant slope of the wind park area from the shore line up to the street in the West, placing of the foundations is simple perpendicular to the slope.[98]

This has the added advantage, that the turbine is not directly horizontal when put down (see **Figure 2-106**) – thus the strain in the hoisting gear is reduced (even 5 to 10° drastically reduce the initial strain in the wires and on the hoisting winch).

During the time of visit, routine maintenance was carried out at one machine. The nacelle was easily reachable by means of a ladders, a control panel, connected to the wind turbine via cable, allowed the same access to the turbine's functions as did the control panel in turbines switch and transformer station beside the bottom of the tower.

During the time of visit it was observed that one turbine regularly went 90° out of the main wind direction and, consequently stopped (see **red circle** in **Figure 2-109**).

This has been observed with VERGNET GEV wind parks elsewhere. It is due to the fact that, as a passively controlled down-wind machine, the turbine needs to operate on a perfect horizontal azimuth plane.

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97) the VERGNET GEV 275 kW is a turbine with a 4 pole/6 pole generator and two rotor speeds. The lower speed is used up to ~ 7 m/s (generator with 1,000 rpm), with higher wind speeds, the rotor switches to high speed (generator with 1,500 rpm). For technical details of the turbine, see **Box 5** on page 69.

98) the guy wire length perpendicular to the hoisting plane has to be exactly equal – in unequal terrain this would have required the construction of special (non-standard) foundations, which increases the cost of civil work

Figure 2-106:
Maddens Wind Park with One Turbine Down for Maintenance

Figure 2-107:
Access to Nacelle by Means of Ladders

Figure 2-108:
Using the "Copy Panel" of the Turbine Controller for Maintenance

Photos: B. Jargstorf, February 2011

Upon request, the Operation and Maintenance manager of Maddens informed that already 0.5° deviation out of the horizontal plane of the tower top flange would cause the turbine to behave like that. There is a high-precision sensor in the azimuth plane, giving the signal to manually change the tension on the guy wires.

This is done first with the tension of the upper guy wires, following by a fin tuning with the lower sets of guy wires. It is estimated to be a quite time-consuming exercise – but if not done regularly or properly, a very suboptimal operation of the turbines is the result (see **Figure 2-109**).

Figure 2-109:
Turbine 90° out of the Wind Direction

Photos: B. Jargstorf, February 2011

Of course, every time after putting the turbine down, the correct setting of the horizontal azimuth pane has to be repeated.

In general, what must be regarded as a principal advantage of the turbine – the easy access of the nacelle when the turbine is down – might also cause considerable extra work. This is the case, when a sensor of cabling error is detected – then one has to put the complete turbine down, just so exchange a small electronic part. With no ways of testing the turbine in operation when down, one has to erect the turbine, adjust the azimuth pane etc. and make it operationable.

Only then one can test whether it was the sensor which caused the turbine to behave abnormally. If it wasn't, then the whole process has to be repeated. Thus, trouble-shooting a wind turbine with a tiltable tower can be a strenuous exercise.

2.10.4 Production Figures

NEVLEC provided production figures for the Maddens wind park which had been automatically registered on a weekly basis. Due to the weekly reading schedule, data up to November 2010 do not exactly cover the calendar months (see **Figure 2-110**). The remaining months, however, are correct.

One can see that, referenced to the current maximum allowed wind park production of 1.6 MW, the monthly capacity factors vary from 13 to 30 % and give an average of 24.3 % in the period from July to March 2011. Referenced to the total installed wind park power of 2.2 MW, this value reduces to 17.7 %.

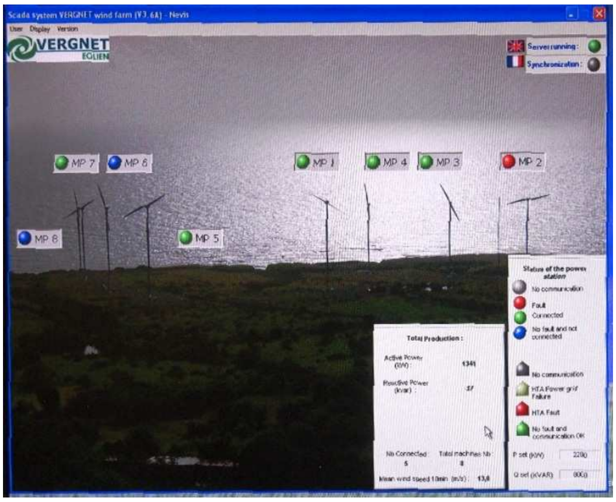
Judging from an estimated average wind speed between 7.5 and 8 m/s, this relatively low capacity factor is an indication of quite a high percentage of deliberately switched-off wind power, due to potential grid problems.[99] The operator in the diesel power station of NEVLEC has access to the wind park via SCADA and can reduce the power output of the wind park in times of need via an internet connection (**Figure 2-111**).

Figure 2-110:
Maddens Wind Park - Monthly Production

	Production	Capacity Factor	
	in kWh	2.2 MW	1.6 MW
Jul 10	354,394	21.7 %	29.8 %
Aug 10	160,243	10.1 %	13.9 %
Sep 10	139,511	9.4 %	13.0 %
Oct 10	153,384	10.4 %	14.3 %
Nov 10	305,371	17.5 %	24.1 %
Dec 10	238,900	14.6 %	20.1 %
Jan 11	505,257	30.9 %	42.4 %
Feb 11	457,452	30.9 %	42.5 %
Mar 11	223,459	13.7 %	18.8 %
Total	2,537,971		
Average	281,997	17.7 %	24.3 %

When a situation is encountered which forces one or more of the six diesel power generators into low-load operation or when the reactive power demand of the wind park starts to endanger grid stability, the personnel of the diesel power station can switch off individual turbines or limit the output power output of individual turbines.

Figure 2-111:
Maddens Wind Park
SCADA Screen Shot - 28-02-11



Total Production :

Active Power (kW) : 1341

Reactive Power (kvar) : 37

Nb Connected : 5

Total machines Nb : 8

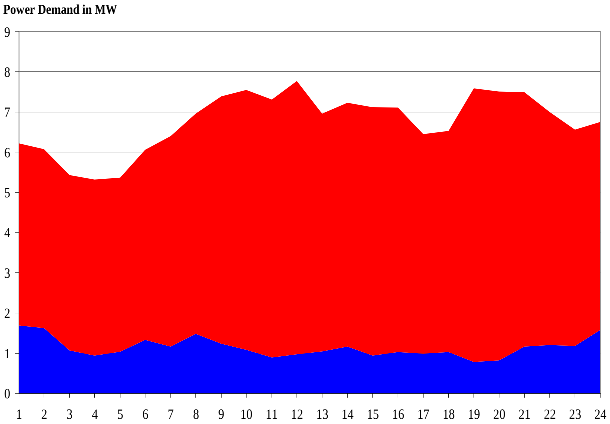
Mean wind speed 10min (m/s) : 13,8

P set (kW) 2200

Q set (kVAR) 800

Figure 2-111 shows the daily load curve from 27th of January 2011, a day with good wind resources. The highest hourly production from wind has been 1.69 MW – the absolute peak demand in Nevis has been 7.77 MW, the minimum load was 5.32 MW. During this day, the wind energy penetration has been 27 %.

Figure 2-112:
Wind and Diesel Load Distribution 27-01-11



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[99] it could also be an indication of a low technical availability of the wind turbines – however, larger technical problems have not been reported by the Operation and Maintenance Manger during the visit in February 2011

2.10.5 Summary Nevis

Since July 2010 Nevis features a grid-parallel wind park with 2.2 MW installed power. The Maddens wind park is operated by Windwatt Nevis Ltd, which has negotiated an IPP contract with NEVLEC, Nevis Electricity Company. Originally planned in three phases of 1.1 MW, 3.9 and 5 MW installed wind capacity, the project features now a wind park with 2.2 MW – eight turbines with 275 kW each. Currently, 1.1 MW of this capacity can be sold at any time to NEVLEC, higher wind capacities up to 1.6 MW are only possible when the grid allows to do so upon decision of NEVLEC.

Unfortunately, accurate production data were not provided for the complete operation period, but had to be calculated from secondary sources up to November 2010. The data for the complete period indicate a capacity factor of 24.3 % when referenced to the 1.6 MW maximum allowed power or 17.7 % when referenced to the installed power of 2.2 MW. Assuming an average monthly electricity demand of ~ 5,000 MWh, these production data indicate a **wind energy penetration rate of 5.6 %**, which is expected to result into a fuel saving in the power station of the same range.

The operator of the wind park has stationed permanently an Operation and Maintenance Manager on the island, who is assisted by a technician in the maintenance of the wind park. Judging from the two day visit in February 2011 and discussions with Windwatt Nevis and NEVLEC personnel, the maintenance requirements of the wind turbines seems rather high. At the time of visit, one turbine was down for maintenance, two other turbines were not operating properly, due to a slight misalignment of the azimuth pane. It is known that feeding wind power into the distribution grid can be problematic[100] - limiting the wind power in Nevis to just 1.1 MW seems to be a result of grid instabilities induced by the induction generators of the wind turbines.[101] One can conclude that the static compensation of the directly coupled induction generators does not avoid voltage problems at the point of interconnection.

Under this situation it is recommended to install a dynamic reactive power compensation at the grid station of the wind park or at suitable location(s) within the distribution grid – to increase the allowable wind power in the grid. A fuel saving of just 5.6 % is a disappointing result for 2.2 MW installed wind capacity. Judging from practical experiences with wind power in similar-sized isolated grids elsewhere, a maximum wind power capacity of ~ 50 % of minimum load in the grid can be absorbed without any stability problems. In the case of Nevis, this would be 2.5 MW.

Thus, the installed 2.2 MW should be the correct match for the island grid in Nevis – it is obviously the grid connection and/or the reactive power demand and/or the operation mode in the diesel power plant which currently limits the wind power to just between 1.1 and 1.6 MW.

In trying to interpret the strange situation that there is 0.6 MW unused installed wind power (= 37.5 % of usable power) the consultant has to reiterate his recommendation, not to encourage IPPs to operate the first wind park on such a small island grid.[102]
It creates an antagonism between the grid and thermal power plant operator who wants to fend off any ‘attack’ on the grid stability (and, consequently, ask for reduced levels wind power) and the IPP who wants all his wind power to be fed into the grid, at any given time

Such an antagonism obviously leads to a reduced wind power penetration rate, and keeps the power supply system as a whole – i.e. the combined wind and diesel power generation plants – from being optimized in its every-day operation.[103]

However, if the operator of wind park, thermal power plant and distribution grid is identical, such an optimization is a quasi natural result of the ownership situation: owning the wind park is the strongest motive to make sure that all its potential power is absorbed by the grid. Not owning it – as in the case of Nevis – does not give any incentive to try harder to increase the wind energy penetration rate.

The advantage of wind and diesel power plant owned by the same operator, can be demonstrated nicely with the 35 % wind energy penetration rate of the energy supply system of Bonaire (for details, see **Section 2.15**).

It is strongly recommended for NEVLEC and Windwatt to get together and find technical solutions for a situation, in which potential environmental-friendly wind energy is replaced by more expensive and “dirty” diesel power.[104]

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100) see **Section 2.2** Wind Park Munro

101) compare **Figure 2-11**

102) see **Annex 12** – **“To IPP or not to IPP”** - Options for the organizational Structure for Wind Development in (small) Island Grids

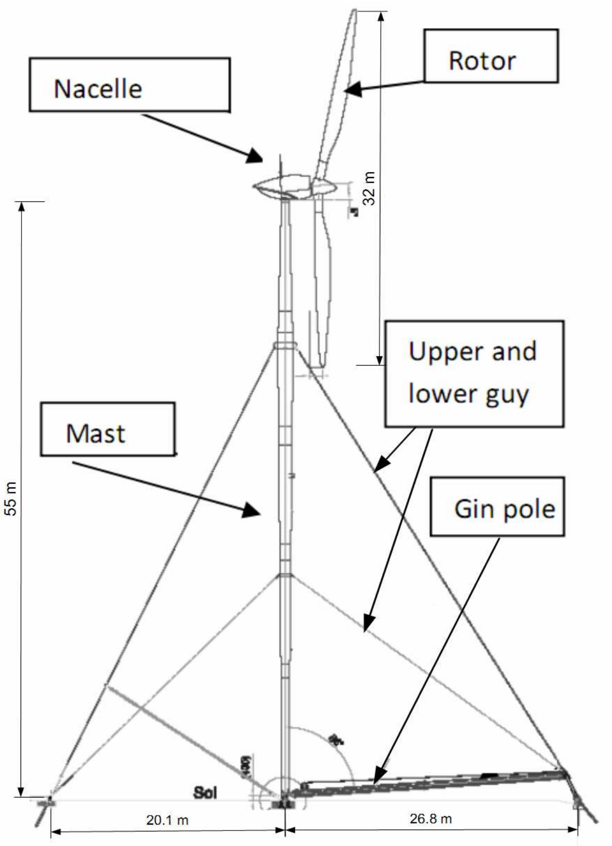
103) see also the example from San Cristóbal (Galápagos) in **Annex 12**, *Appendix 2* and *3*

104) unfortunately, the grid connection study of the wind park has not been made available to the consultant – so no more concrete proposals could be made within the scope of this study

Box 5: Technical Specification of the Wind Turbine VERGNET GEV MP

The VERGNET GEV MP wind turbine is a two-bladed down-wind turbine with tiltable 55 m tower and an installed generator power of 275 kW (see **Figure 2-113**).[105]

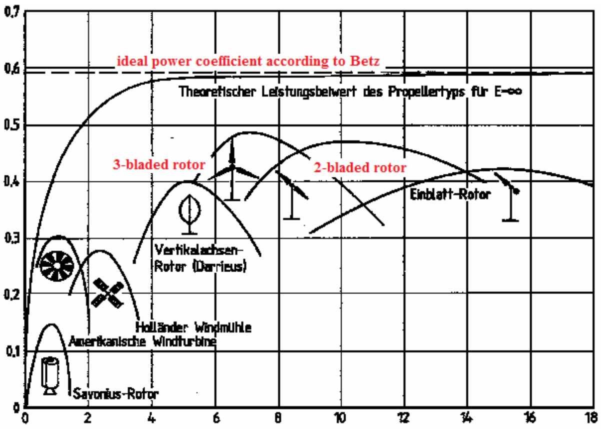
Figure 2-113:
VERGNET GEV – Overall Dimensions



Together with its larger sister – the VERGNET GEV HP 1 MW – the GEV turbine one of the few two blade turbines left on the market. Compared to three-bladed rotors, the maximum efficiency of a two bladed rotor is reached at higher rotor speeds. **(**see two-bladed rotor in **Figure 2-114**). In practice, a two-bladed rotor with the same rotor diameter has generally about 10 % less energy output than a three-bladed one.

In addition, a two-bladed rotor features a dynamically unbalanced rotor which exercises considerably forces on the azimuth drive – this is non-existent with a three-bladed system. However, as an advantage, a two bladed rotor allows the introduction of a teetering hub.

Figure 2-114:
Efficiency of Different Rotor Concepts



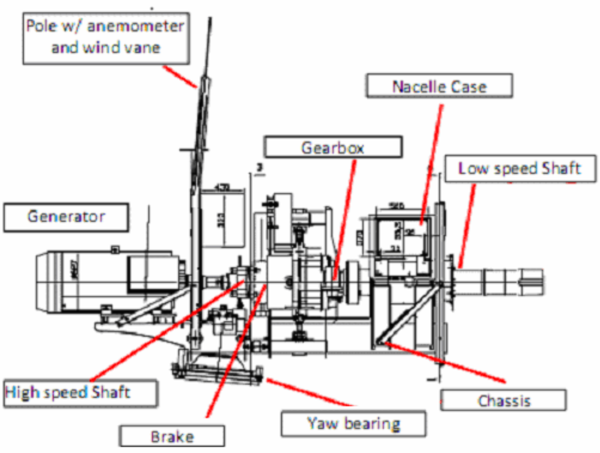
Source: R. Gasch, J. Twele, "Wind Power Plants - Fundamentals, Design, Construction and Operation, Berlin 2002, p. 183, *modified*

In comparison to a fixed hub – featured by practically all other turbines on the market and a geometrical must for 3-bladed machines – a teetering hub reduces greatly the loads in the hub and allows a weight saving design of rotor and hub.

Thus, the rotor of the VERGNET machine with 32 m diameter weighs only 1.9 tons (blades ~ 750 kg each, hub only ~ 400 kg, see **Figure 2-116**), whereas a three-bladed rotor with the same diameter would typically weigh about 4 tons.[106] On account of the 50 % weight savings of the rotor, also the remaining components of the turbine can be constructed light-weight.

Figure 2-115 shows the nacelle layout with the major components: generator (1.2 tons), gearbox (1.4 tons) and low speed shaft.

Figure 2-115:
VERGNET GEV MP – Nacelle Layout



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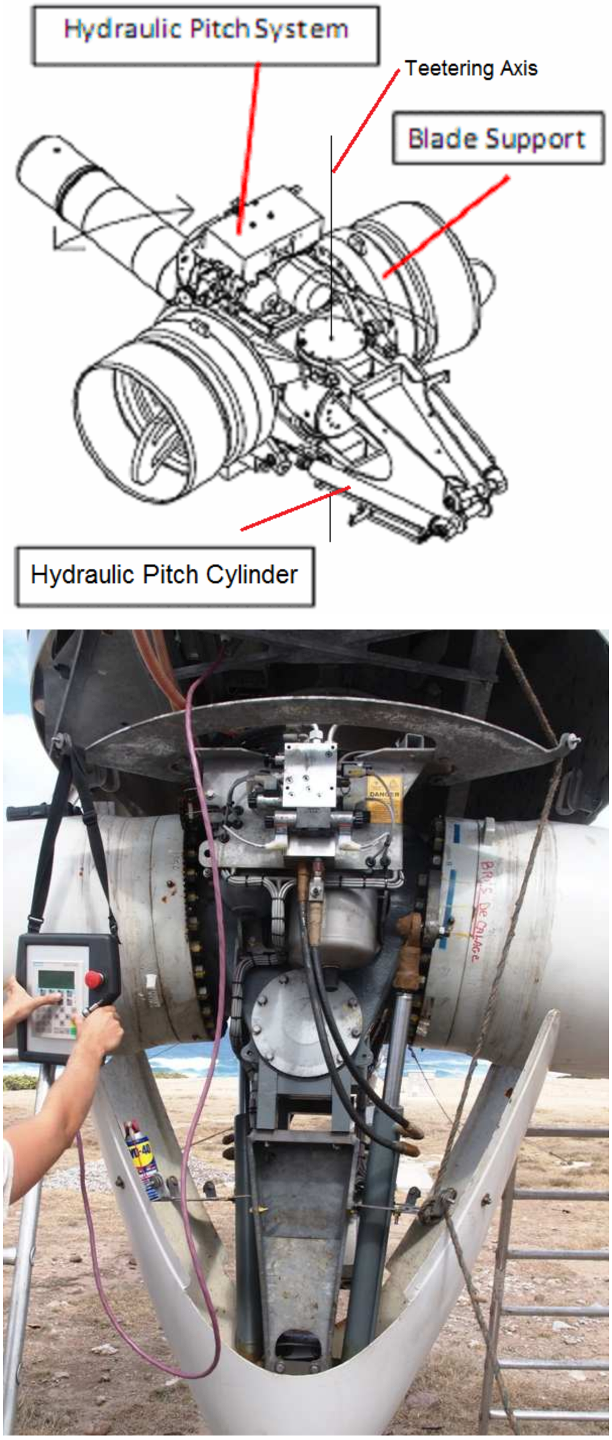
105) the following information is taken from the GEV MP Operation and Maintenance Manual and the company brochure

106) example for the ENERCON E30 with 30 m rotor diameter

Figure 2-116:
VERGNET GEV MP – Hub Assembly



Through placing the hydraulic pitch system at the rotating part of the hub (**Figure 2-115**) problems are avoided with bringing the hydraulic pressure from the nacelle to the hub. Two identical hydraulic systems take independently care of the blades.

The compact two-stage planetary gear box is fitted with an oil cooler. The electric generator allows two speed operation (4 and 6 pole pairs) – the power curve in **Figure 2-117** shows the operating range of the small and large generator. The different specific generator power – 341 W/m^2 for the large and 93 W/m^2 for the small generator shows clearly in the different slope of the power curve. Also, one can see the reason why VERGNET introduced the small generator: with one large generator, the turbine would only start at > 5 m/s – thus, a certain proportion of available wind power would be lost.

Figure 2-117:
VERGNET GEV MP – Power Curve

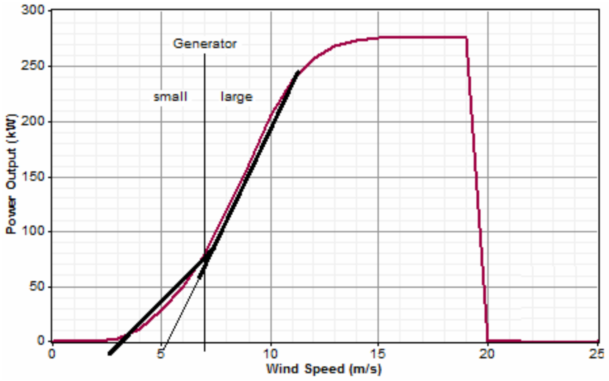
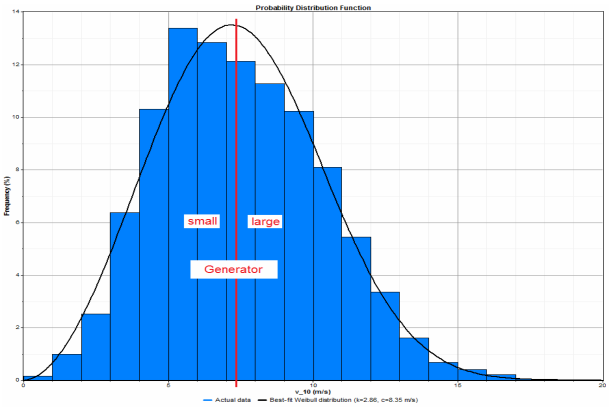


Figure 2-118:
Typical Caribbean Frequency Distribution



The typical Caribbean wind speed frequency distribution shows that the dividing line between small and large generator lies approximately at the average wind speed. In practice, the small generator will operate at about 30 % of the time and produce less than 10 % of the turbine output, the large generator produces 90 % during the remaining time.

Note, that wind turbines with variable speed operation do not need two generators – they always run in aerodynamic optimal conditions, instead of two different rotor speeds they have several different ones (see UNISON turbine in **Section 2.2**).

The tilting of tower, nacelle and rotor with a total weight of 7.2 tons is done by means of mobile hydraulic unit, with is connected to the hydraulic winch, mounted to the bottom section of the tower (**Figure 2-119**).

Figure 2-119:
Mobile Hydraulic Unit

Raising and lowering of the turbine needs a minimum of one hour and requires three persons. The rotor blades rest on rubber tyres when lowered – this does not seem a professional solution and obviously does not keep the blades from being damaged (see **Figure 2-120**). However, until the turbine is ready for operation, several more working hours are needed – for example, for the adjusting of the azimuth pane (compare **Figure 2-109**).

Figure 2-120:
Blade Damage through Hoisting/Lowering

The tower tilting mechanism needs quite a lot of maintenance, primarily to fight corrosion - especially at a site like Maddens, within 100 m of the ocean shoreline.

Figure 2-121:
Gin Pole with Hoisting Mechanism

When lowered, the turbine is designed to withstand maximum wind speeds of 80 m/s (1 sec average). This is ~ 10 m/s more than the maximum gust a wind class 1 turbine designed according to IEC rules can withstand in the up-right position.[107] However, a rotor on the ground can be damaged by debris flying around under hurricane conditions.

In the opinion of the consultant, this 10 m/s higher safety speed of the VERGNET turbines comes with a high price: considerably higher maintenance requirements for the turbine and the hoisting mechanism, high efforts for anti-corrosion measures etc.

As a general concept, a wind turbine with two rotor speeds is inferior to more modern designs with variable rotor speeds. A directly coupled induction generator is definitely a disadvantage in small, isolated grids, especially with a connection to the distribution system.

The passive yawing mechanism of the VERGNET turbines – being an advantageous design feature of the smaller predecessors of the 275 kW turbine – seems to be a suboptimal design: it requires an extremely exact alignment of the tower top flange. For the de-twisting of cables and for service, however, a hydraulic assistance yaw drive is needed, undermining the simplicity of the original design.

In summing up, the maintenance needs of this turbine seem to be definitely higher than average for a turbine of this size. The number of independent hydraulic and oil systems may be regarded as a first indication for this: two hydraulic pitch systems, hydraulic yaw assistance, oil cooler for gearbox and mobile hydraulic system for lowering and hoisting.

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107) compare **Figure 2-39** where the 10 min average of 50 m/s as V_{ref} is indicated. Assuming a Rayleigh wind speed distribution, 50 m/s over 10 min has a maximum gust of 70 m/s as 3 sec average

2.11 Saint Kitts

2.11.1 Technical Advice of CREDP

In collaboration with St. Kitts Electricity Department and Mr. Malcolm Knight, the director of AVEC (Advanced Vocational Education Centre) possible wind park sites were evaluated during a CREDP mission in 2006.[108]

According to a simplified wind flow model two areas with local wind speed amplification were identified, in the North and the central part of the island. Four candidate wind park areas were proposed (see **Figure 2-122**):

- Hermitage Estate;
- Greenhill Estate;
- Mount Pleasant Estate/Profit; and
- Olivees (near Shadwell Estate)

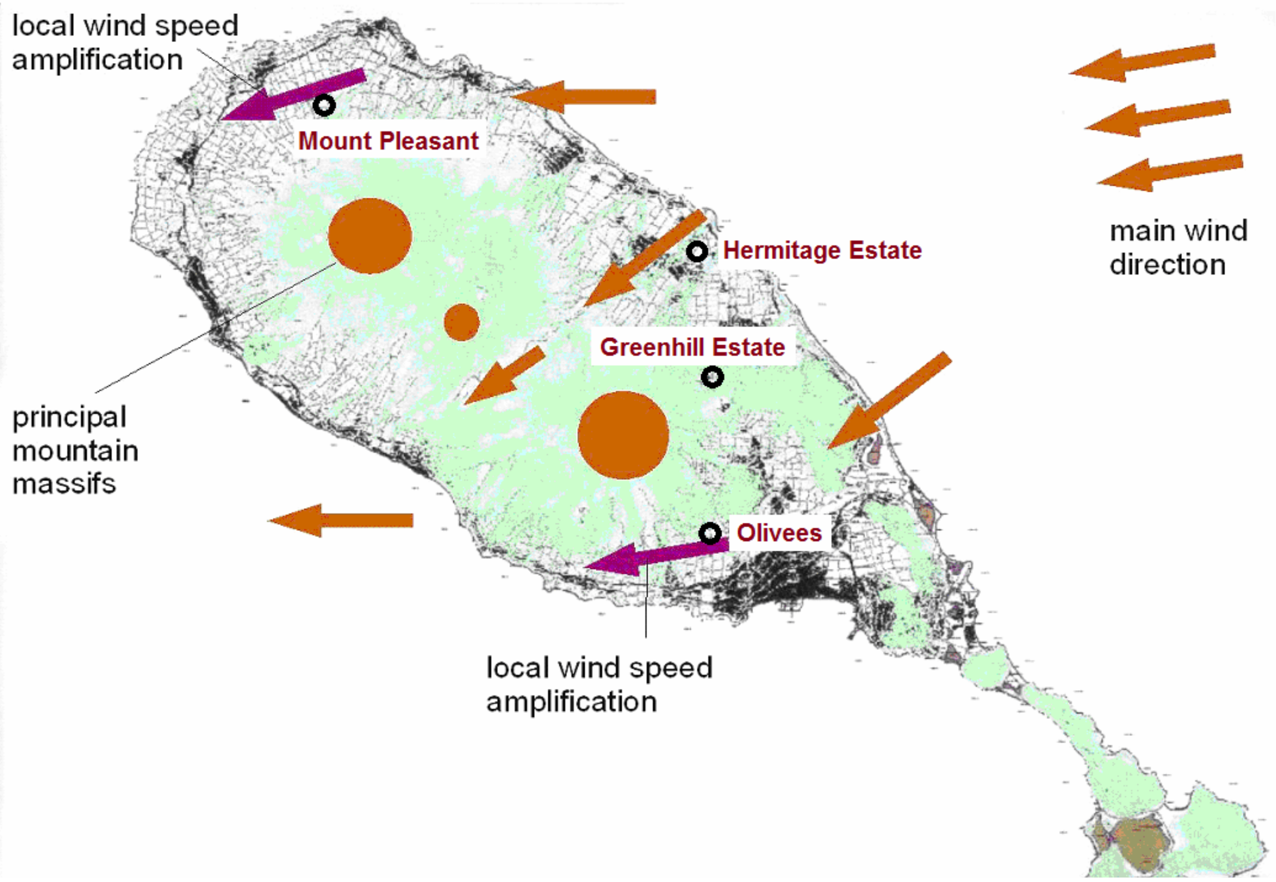
For an inexpensive wind measurement campaign – representative for the central area of Saint Kitts – the television tower close to Bayfords was proposed. This tower – with more than 80 m height – would have allowed the determination of wind speeds at hub height.[109]

During CREDP mission the involvement of the St. Kitts Electricity Department was rather limited – obviously the interest of AVEC to start a wind energy project in St. Kitts was much greater than that of the utility.

In 2006, St. Kitts featured a maximum load of 21 MW and an absolute minimum load of 15 MW (see **Figure 2-123**). Assuming a stable grid connection – preferably a dedicated line between wind park and diesel power station – a wind park in St. Kitts could have a maximum installed capacity of 7 MW, without undertaking additional measures for grid stability.

However, when feeding into the distribution grid, the potential installed power was estimated to be quite smaller – depending on the load situation in the feeder(s) where the wind park would be connected. As such, the site Mount Pleasant, was considered problematic (distance to power station).

Figure 2-122:
General Wind Flow over Saint Kitts with Four Wind Park Site Proposals



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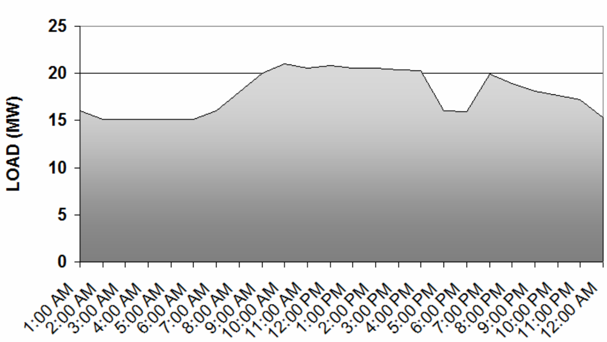
[108] see **Annex 13** – Summary of Results – Wind Energy Project Preparation at Saint Kitts, July 2006

[109] compare **Figure 2-25**

Figure 2-123:
St. Kitts - Typical Weekday Load Profile



Source: St. Kitts Electricity Department, 2006

2.11.2 Current Plans at Saint Kitts

By October 2010, peak demand in St. Kitts had reached 24 MW. In this situation, a private tourism developer, North Star Development, decided to build the first wind park at St. Kitts. The president of the company, Mr. Mark Tippett, said that since the 2008 financial crisis, he had temporarily abandoned plans to build a resort in St. Kitts and focused entirely on the wind park, to be constructed close to Belle Vue.[110]

This site is in the North of island, just East of CREDP's proposal Mount Pleasant. North Star Development plans to install three Vestas V90 turbines, with 1.8 MW installed generator power. North Star has a contract with the Government of St. Kitts to install up to 20 MW of wind power on the island. The first phase with 5.4 MW is expected to be installed at the end of 2011.[111]

This turbine has a maximum weight for transportation of 70 tons – as such, it will definitely put some strain on the infrastructure of St. Kitts.

Further details, especially on the grid connection or the feed-in tariff, were not available.

2.11.3 Summary St. Kitts

Similar to Nevis, St. Kitts has decided to have its wind resource be developed by private investors. Being a tourism developer, North Star Development will have to rely completely on technical know-how from outside, when planning the wind park project.

The grid connection of this 5.4 MW wind park is expected to be critical – due to the distance to the diesel power station.

But also employing a wind class II machine is expected to cause additional risks, with regard to hurricanes. A class II wind turbine has a maximum design wind speed of 42.5 m/s (95 mph) as 10 min average, which gives ~ 60 m/s maximum instantaneous gust wind speed (3 sec). In contrast, a Wind Class I turbine features 50 m/s (111 mph) as 10 min average and about 70 m/s as 3 second gust.

Against this background, an IEC wind class I turbine offers quite a higher safety margin during hurricane conditions. Also, as a minimum, a stand-by generator for the wind park is recommended, which allows the wind turbines to align their nacelles in the main wind direction during a hurricane (when the island grid is de-electrified).[112]

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110) see **Annex 14 – Developer backs Wind over tourism in St. Kitts**

111) personal information, Mark Tippett,

112) see **Annex 15 – Hurricanes in the Caribbean**

2.12 Saint Lucia

2.12.1 Technical Assistance of CREDP

Already in 2003, LUCELEC charged the British consultancy company PB Power with a study to identify potential wind park sites on the island.[113]

This study evaluated a total of 31 potential sites and proposed four sites for further investigation. Of these, Point de Caille was rated first, and proposed for the installation of a two unit demonstration/test wind park using turbines of the 600 kW class. Upon successful testing, the wind park was later to be enlarged to 10 or even 15 turbines (6 to 9 MW).

Unfortunately, the PB study had to rely on scanty wind data from the near-by Hewanorra airport and data from the World Wind Atlas. No on-site measurements were undertaken at that time.

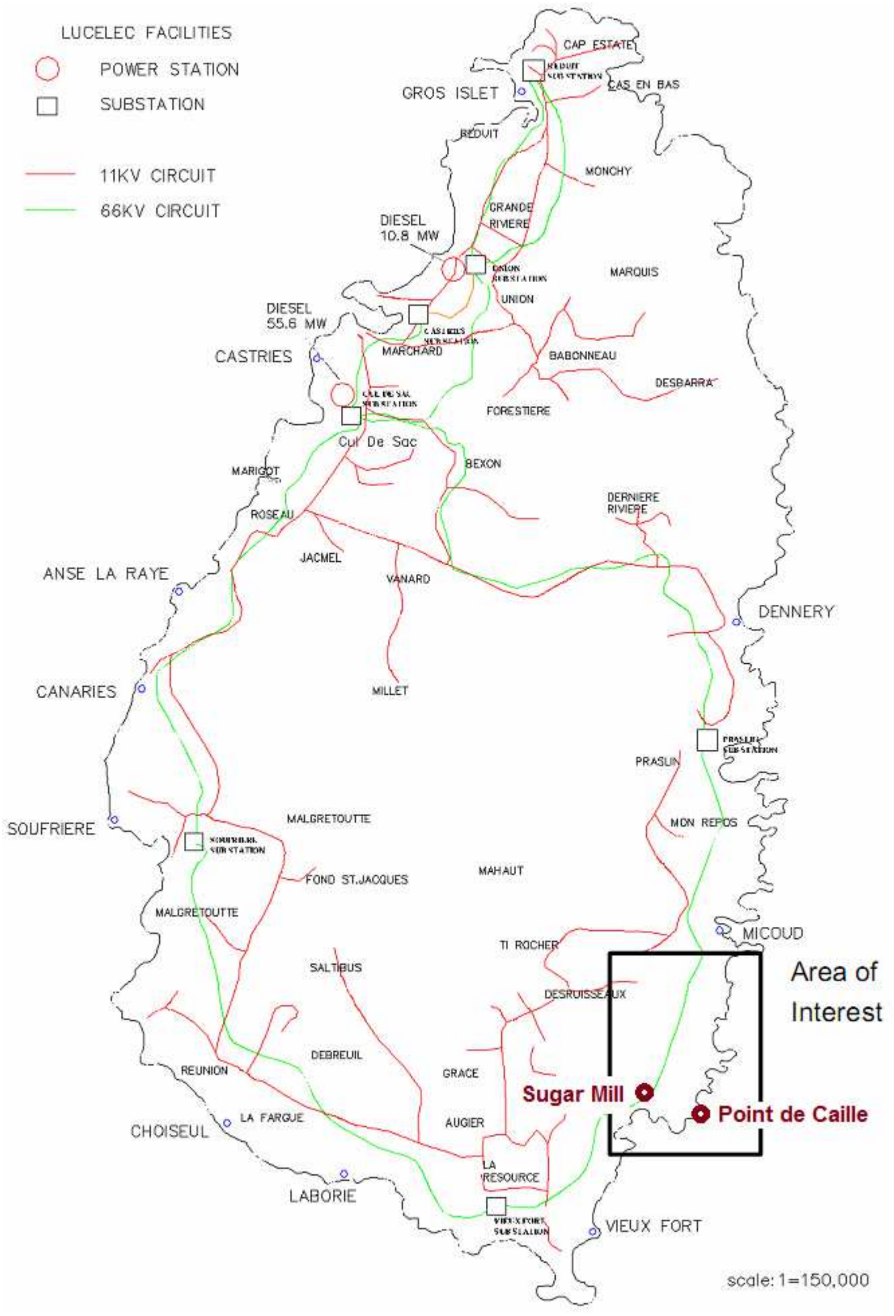
When CREDP was asked by LUCELEC to provide consultancy for wind development, it was proposed to immediately start on-site wind measurements. Also, a test facility with two turbines was not considered necessary: for such a small wind park, the infrastructure cost for grid connection and access roads have the tendency to be unproportionally high. Besides, wind turbines do not need further testing – they are a mature, of-the-shelf product.

Soon it became clear that the owner of Point de Caille was thinking of a tourist development and was not willing to even allow the temporary installation of a wind measurement tower.

In this situation, the management of LUCELEC declared that the alternative site Sugar Mill would be acquired, even if the help of the government and compulsory acquisition was needed.[114]

Consequently, a wind measuring station in 10 m above ground was commissioned at Sugar Mill, using an existing 66 kV transmission tower. When comparing Point de Caille with Sugar Mill, the latter has the added advantage of higher elevation, and larger distance to the sea (less marine climate).

Figure 2-124:
St- Lucia - Transmission/Distribution Grid with Wind Park Area



Source: RB Power, op. cit., p. 16, *modified*

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[113] PB Power, "LUCELC – Review and Recommendation of Potential Wind Farm sites on St. Lucia", January 2003

[114] for details on CREDP recommendations, see **Annex 16**

Using LUCELC’s own 66 kV mast had the advantage that the measurements could be started right away.

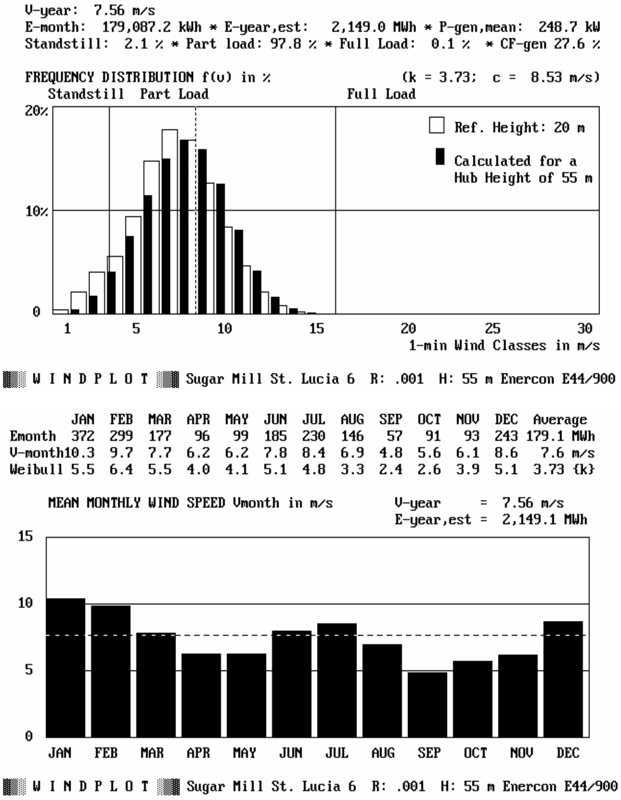
<u>Figure 2-125:</u>
St- Lucia – Wind Measurements at 66 kV Mast

Over three years, an average of 6.5 m/s was measured in 10 m above ground. With a conservative projection to 50 m, an annual average wind speed of 7.6 m/s can be expected. With these wind speeds, an Enercon E44-900 kW calculates an annual energy yield of 2,150 MWh per turbine and a capacity factor of 27.6 % (see **Figure 2-126**).

With these good results of the 10 m measurements, LUCELEC decided to go ahead with the wind park Sugar Mill, which was to consist of up to 14 units of the 1 MW class in its fist phase.

As the vicinity of the wind park area was similarly suitable for wind energy utilization, it was proposed to have a larger area officially declared as a zone for wind energy application.

<u>Figure 2-126:</u>
Sugar Mill – Projection to 55 m Hub Height



```
V-year:  7.56 m/s
E-month:  179,087.2 kWh * E-year,est:   2,149.0 MWh * P-gen,mean:  248.7 kW
Standstill:  2.1 % * Part load: 97.8 % * Full Load:  0.1 %  * CF-gen 27.6 %

FREQUENCY DISTRIBUTION f(v) in %                    (k = 3.73;  c =  8.53 m/s)
```

```
         JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  Average
Emonth   372  299  177   96   99  185  230  146   57   91   93  243 179.1 MWh
V-month10.3  9.7  7.7  6.2  6.2  7.8  8.4  6.9  4.8  5.6  6.1  8.6   7.6 m/s
Weibull 5.5  6.4  5.5  4.0  4.1  5.1  4.8  3.3  2.4  2.6  3.9  5.1  3.73 {k}

    MEAN MONTHLY WIND SPEED Vmonth in m/s         V-year      =  7.56 m/s
                                                  E-year,est =  2,149.1 MWh
```

Thus, such an area would allow to follow a medium- and long-term wind energy development strategy, with different phases:

1. standard grid-parallel operation (~ 12 MW);
2. high penetration grid-parallel operation (~ 20 MW);
3. high penetration with pumped storage (~ 30 MW)

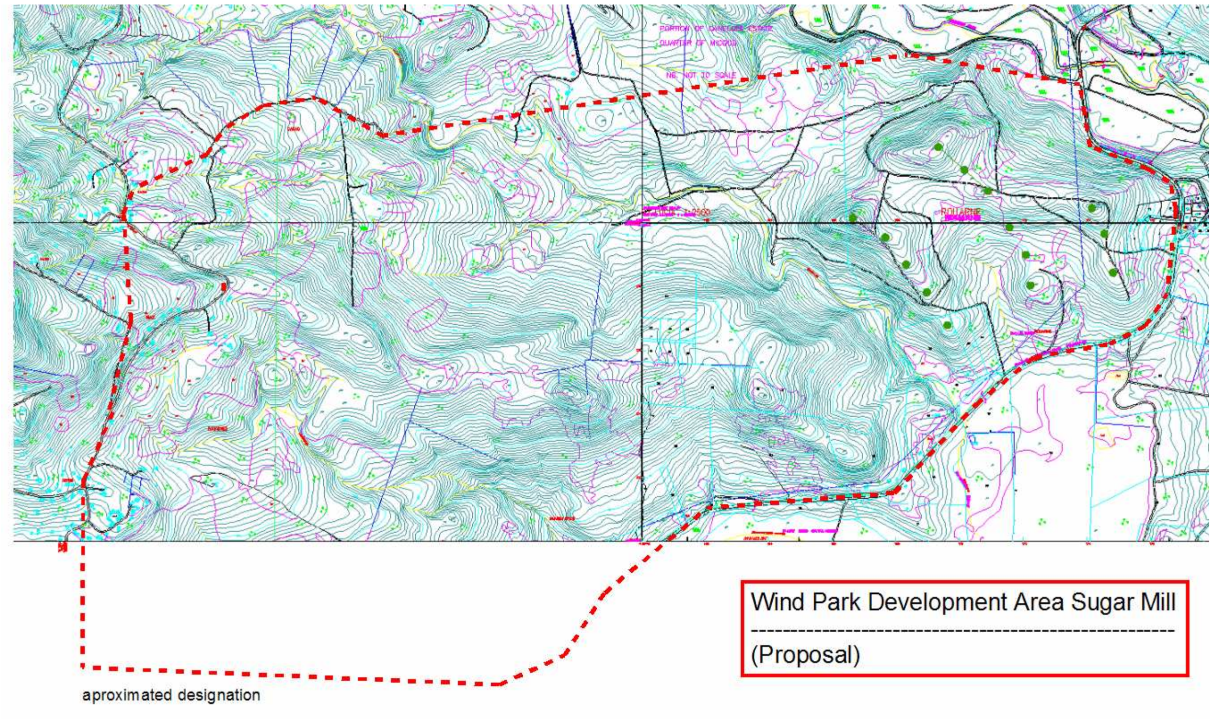
The designated area according to **Figure 2-127** would allow the installation of these wind energy capacities, the 66 kV overhead line passing over the wind park area would be suitable to transport the energy to the next LUCELEC substation in less than 4 km distance.

Unfortunately, the acquisition of the land was met with the fierce resistance of the land owner(s). Consequently, the government started the procedure for a compulsory acquisition of the designated wind park area.

Eventually, this was completed successfully – but the results of the value assessment for the land came out with such a high figure that LUCELEC eventually backed out.

Also, it turned out that the land owner(s) in question had extremely good political connections – in the end, LUCELEC decided not to continue with a further planning of the site Sugar Mill.

Figure 2-127:
Sugar Mill Wind Park Development Area – Phase 1 and Spare Area for further Phases



2.12.2 Current Situation

After nearly five years of planning, this means that LUCELEC is back to square one, with regard to wind park site selection.

This is a bit embarrassing considering the official plans of the St. Lucia government, according to which 30 % of the electricity needs of the island should come from RE in the year 2010.

CREDP has proposed that LUCELEC compiles a map of the island indicating larges patches of government land. Starting with this, a new round of site evaluation should be carried out.

The problems with identifying a site for wind energy application are particularly frustrating when looking at the priority the tourist development gets on the island.

For example, a large resort for which considerably spaces had been cleared on top of a hill went bankrupt in the aftermath of the credit crunch in 2008 (see **Figure 2-128**).

Since 2008 all works have stopped – the hill would be principally suitable for wind power development – but the near-by resort eventually gets built, and probably the tourists wouldn't like to see, where their electricity comes from.

Besides – the tourists would need a golf course – CREDP's proposal to have a multi-purpose wind park cum golf course have not been accepted, so far.

Figure 2-128:
Abandoned Tourist Development (Golf Course)

Photo: B. Jargstorf, March 2011

Currently, LUCELEC has started a re-evaluation of potential wind park sites – with no usable results so far.

2.13 Curaçao

The islands of Curaçao, Aruba and Bonaire – formerly part of the Netherlands Antilles – are no CREDP countries (see **Section 1.1.1**).

In spite of that, the islands are included in this evaluation, as they feature the longest continuous history of wind energy utilization in the Caribbean on the one side (since 1993), as well as a novel approach to a high penetration wind energy system at the island of Bonaire, in operation since 2010.

The information in the following sections are derived from a visit in May 2011, which was supported by CREDP's consultant Ms. Margo Guda from the island of Curaçao.

2.13.1 Wind Park Tera Kora

This was the first commercial wind park in the Netherlands Antilles. It consists of 12 units with 250 kW each from the Dutch manufacturer Nedwind (3 MW total), was installed in 1993, and shut down after 15 years of operation in 2008.

Originally operated and maintained by the Curaçao utility AQUAELECTRA, Delta Caribbean N.V received an maintenance contract in 2000, to look after the machines. At that time, Delta had just installed the second wind park of Curaçao – Playa Kanoa with 9 MW (see **Section 2.13.2**), also from the same manufacturer Nedwind.

Obviously, AQUAELECTRA considered the maintenance efforts of the 3 MW wind park as being too high in relation to the resulting production and had neglected routine and preventive maintenance. As a result, Delta Caribbean had a had time to keep the turbines in operation.

In 2005, the average technical availability of the wind park was indicated as being 93 %, with a net capacity factor of 40 % and annual net productions of 8,000 MWh.[115]

Figure 2-129:
Wind Park Tera Kora (2006)

Photo: Julissa Tromp, "Wind Turbine & Balance of Plant", Presentation at the conference "Wind Farm Operation, Integration and Maximum Penetration for Caribbean Electric Utilities", Jamaica, 18-20 October, 2006, *organized by CREDP*

Since 2008, the wind park is standing erected, but is not in operation anymore. When the new wind parks currently in the planning stage with 3 MW machines are going to be installed, Tera Kora is going to be dismantled. Together with the wind turbines from the Playa Kanoa wind park, the tur-

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115) Julissa Tromp, "Rising Winds with DELTA Caribbean", paper presented at the SATIS 2005 conference, Curaçao, August 2005

bines will be dismantled and the parts – especially the tubular steel towers – will be sold as scrap metal.

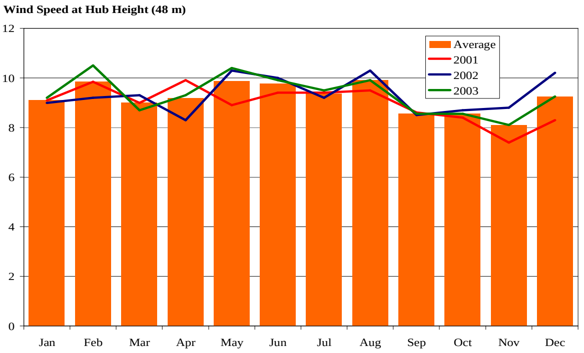
2.13.2 Wind Park Playa Kanoa

The wind park Playa Kanoa, consisting of 18 units of 500 kW Nedwind turbines was commissioned in December 2000. With annual average wind speeds at hub height of 48 m between 9.0 and 9.5 m/s the site features one of the best wind resources in Central America, if not in the world.[116]

Figure 2-130:
Wind Park Tera Kora, 12 x 250 kW, Curaçao

Photo: B. Jargstorf, May 2011

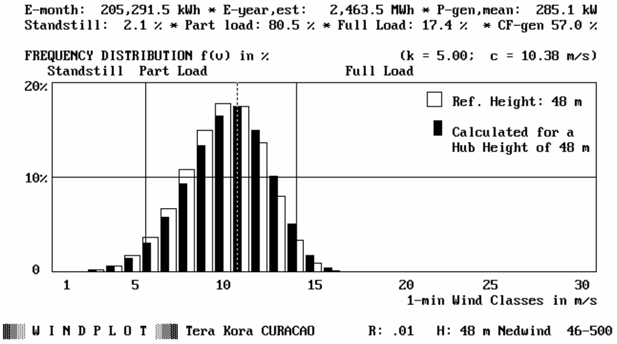
Figure 2-131:
Playa Kanoa - Monthly Wind Speed at Hub Height of 48 m (2001 – 2003)



According to measurements taken at a 48 m measuring tower at the centre of the wind park an annual average of 9.2 m/s is calculated as a mean value for the first three years (see **Figure 2-131**).

Net capacity factors between 57 and 67 % have been recorded during the same time, very much in line with the theoretical capacity factor according to the calculation with *Windplot* in **Figure 2-132**.

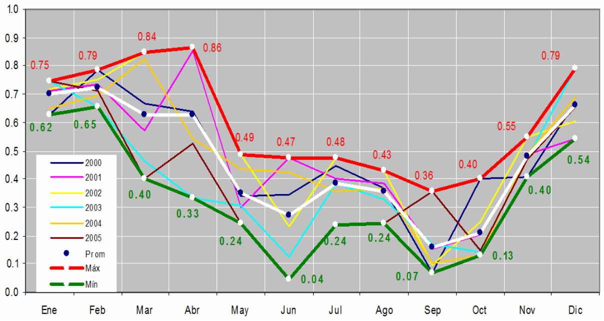
Figure 2-132:
Playa Kanoa – Calculated Annual Power Output for Nedwind NW46/3/500 kW



Source: *Windplot*, Ver. 5.4 © Factor 4 (B. Jargstorf)

According to figures published by DELTA Caribbean (at that time the operator of the wind park) Playa Kanoa had a net capacity factor of 61 % in 2002. In the same year, the best wind park in Costa Rica – also with annual wind speeds above 9 m/s – operated under a net capacity factor of 52 %.

Figure 2-133:
***For Comparison:* Net Capacity Factors in Costa Rica (2000 to 2005)**



Source: O. Jiminez, Instituto Costarricense de Electricidad Centro Nacional De Planificacion Electrica, "ELECTRICAL GENERATION EXPANSION PLAN 2006 – 2025, September 2006

In any case, the 9 MW wind park Playa Kanoa has been one of the highest-production wind parks of the world. Now, after 10 years of operation, plans are underway for a re-powering of the wind park with 3 MW wind turbines. The 500 kW units will be replaced by 5 Vestas V90 turbines with a total installed capacity of 15 MW.

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116) there are a few confirmed annual averages from mountain sites with more than 10 m/s, see, for example Koudia Blanco in Morocco (www.wind-energie.de/fileadmin/...A-Z/.../GTZ_terna-jargstorf_2006.pdf) or wind park sites on the Azores (Pico, Flores)

The following description go back to a half-day visit of the wind and discussions with the Chief Engineer Eelke Jongsma and the Operations & Maintenance Operator Ms. Julissa S. Tromp. The wind park visit had been facilitated by CREDP's wind energy expert from Curaçao, Ms. Margo Guda.

2.13.3 Playa Kanoa - Technical Issues

Technically, the Nedwind 500 kW turbines feature several particularities: they use pitch control to induce the stall effect on the blades (also called "active stall")[117], they have two identical 250 kW generators, one of which is used for wind speeds below ~ 8 m/s. **Figure 2-134** shows clearly the different slope in the power curve for the two operation modes with 250 kW (1 generator) and 500 kW (2 generators). While two identical generators have advantages with regard to spare part organization, it is unusual for a stall-controlled turbine, where normally the small generator is about 25 to 30 % of the nominal power.[118]

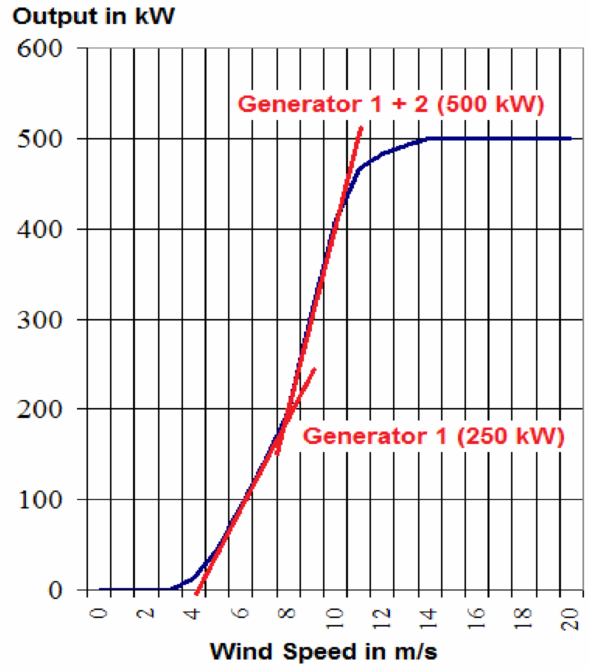
Also, a two-generator layout is normally combined with a two-speed design of the rotor: this increases the aerodynamic efficiency of the turbine for lower wind speeds. The Nedwind 500 kW turbine, however, is a turbine with a single, fixed rotor speed with the known disadvantages, i.e. suboptimal aerodynamic efficiency of the rotor at lower wind speeds.

Also the yawing system of the Nedwind is unusual: it features a 4 cm thick steel wire which is operated by hydraulic plunger. In practice, this novel design caused quite a lot of problems: the steel wire regularly broke and had to be replaced.

The chief engineer of NuCapital also reported about problems with the cooling system of the turbine. Obviously, under the higher ambient temperatures of the Netherlands Antilles, the major components of the turbine suffered from intolerable high operating temperatures. The cooling fan of the electrical generators, for example, originally made of plastic, had to be replaced by metal fans, as the plastic regularly melted.

The basic design of the cooling flow – originally air was sucked in from the back of the nacelle to cool gear box and generator – also proved insufficient: the operator of Playa Kanoa had to redesign the cooling system, and introduced an opening in the nacelle (see **Figure 2-135**). In spite of this modifications, the generators of the turbines overheated regularly and had to be replaced about 50 times during the 10 years of operation (**Figure 2-136**). The generators could get new windings at the island – this reduced the replacement costs. Obviously, the higher operating temperatures of the generators – due to the higher ambient temperatures and the considerably higher wind resources in Curaçao then at the Netherlands – also caused a higher-than-average failure of generator bearings (**Figure 1-137**).

Figure 2-134:
Power Curve Nedwind 46/3/500 kW



As the manufacturer Nedwind ceased to exist in 2003, the operator of Playa Kanoa had to undertake the modifications of the turbine all by himself. In practice, he had to make the turbine (which had been designed for a European wind regime and moderate climate) into a design fit for both the high wind resources and the high temperatures of the Caribbean

By far the most costly repair works were required by gear box failures, which occurred also relatively often. In the beginning, a gearbox failure (**Figure 2-138**) typically led to 67 days of non-availability or about 460 MWh of lost production. On account of preventive maintenance and the preparation of spare gear boxes, the outage time of a gearbox fail-

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[117] as does the 750 kW NORWIN turbine, see section **2.9.3 Request for Proposal – Ribishi Point**

[118] see **Box 5: Technical Specification of the Wind Turbine VERGNET GEV MP**

ure could be reduced to 24 days or about 170 MWh of lost production.[119]

Figure 2-135:
Modifications on the Nacelle of Nedwind 500

Photo: B. Jargstorf, May 2011

Apart from problems caused by an inadequate design of the turbine, also natural phenomena, especially lightning strikes, caused expensive repairs and prolonged outage times. It is obvious that the lightning protection of the Nedwind 500 – a turbine designed in the mid-1990 – was inappropriate, when compared with that of modern turbines. At the time of the visit, two turbines were out of operation due to (minor) blade damages.

But also major damages, requiring (costly) blade replacements had happened during the past 10 years (**Figure 2-139**). In addition, lightning strikes sometimes also caused damages to the turbine controllers (**Figure 2-140**).

Figure 2-136:
Generator Shortcut of the Nedwind 500

Source: Julissa Tromp, "Rising winds with DELTA Caribbean"

Since the original manufacturer of the controller went out of operation, the repair and replacement of the controller caused a lot of problems for the operator. It also involved a re-programming of the original software of the Nedwind 500, to allow it to run on replacement controllers.

Figure 2-137:
Failed Ball Bearings in the Generator

Source: J. Tromp, "Rising winds with DELTA Caribbean", op.cit.

Figure 2-138:
Gearbox Failure Nedwind 500 kW

Source: J. Tromp, "Rising winds with DELTA Caribbean", op. cit

2.13.4 Playa Kanoa - Current Situation

In December 2010 an error occurred in the substation of the wind park which required a spare part to be shipped from Europe to Curaçao. During three weeks the wind turbines were de-electrified. This caused a copper wire theft at 14 of the 18 turbines: the thieves opened up the tower door by force and pulled out the copper conductors between the switch cabinet on the base of the tower and the transformer (**Figure 2-140**).

The original openings in the transformer station had been of iron – due to the high level of corro-

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[119] Julissa Tromp, "Rising winds with DELTA Caribbean", op. cit.

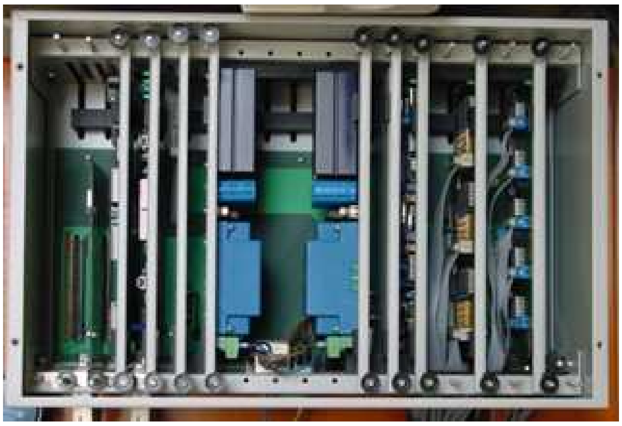
sion, they had to be replaced by wooden structures. These were forced open by the thieves to disconnect the cables from the transformer switch gear.

Figure 2-139:
Rotor Blade Damage due to Lightning Strike

Source: J. Tromp, “Rising winds with DELTA Caribbean”, op. cit

Figure 2-140:
Burned-Out Controller of Nedwind 500 kW

Inside of Turbine Controller before …



… and after a lightning strike.

Source: J. Tromp, “Rising winds with DELTA Caribbean”, op. cit

According to information from the Chief Engineer of the Playa Kanoa wind park, currently 10 of the 18 units are operationable. While the work with the replacement of cables was going on, the park was not in operation.

Complaints about theft and vandalism at the wind park also concerned other aspects: part of the environmental impact assessment required to the operator of the park to replant the vegetation which was cut down to make room for the foundation. Being secured by fence, did not keep away thieves from steeling the new plants. Also the fences around the substation (**Figure 2-142**) and around the foundation (**Figure 2-143**) were stolen.

Figure 2-141:
Stolen Copper Conductors

Photo: B. Jargstorf, May 2011

Even though the generators of the wind park are standard induction generators – with their high reactive power consumption[120] – the grid operator AQUAELECTRA allowed the capacitors for a static compensation to be disconnected altogether (mounted in the right door of the control cabinet in **Figure 2-141**).

Obviously, the size of the capacitors was inadequate from the beginning. Also, operating under the elevated ambient temperatures at Curaçao, they failed regularly and caused fire hazard in the tur-

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120) see Section **2.1.1 Wigton Windfarm**

bine controller. Thus, all turbines were operated without compensation; and – very unusual – the operator of the grid and the other generation facilities on the island did not insist to be compensated for the supply of reactive power.

Figure 2-142:
Fence around the Substation - Stolen

Photo: B. Jargstorf, May 2011

Figure 2-143:
Original Fencing around the Foundation (2002)

Photo: Martsan, taken from Google Earth

That such a suboptimal electrical connection of the wind turbines did not cause any instabilities in the grid has to be attributed to the favourable grid connection of Playa Kanoa: The 30/11 kV substation of the wind park is connected via underground cable to the next AQUAELECTRA substation in 7 km distance. This design of the grid connection not only guaranteed a minimum visual impact of the wind park (no overhead lines), but made it also possible to operate the 9 MW induction generators without reactive power compensation.[121]

In summing up, one has to conclude that a turbine inadequate for the wind regime and the climate of the Caribbean had been installed at Curaçao, which, in addition, had not reached technical maturity yet. The manufacturer was not available for technical improvements, and the operator of the wind park had to come up with quite a number of modifications – in particular with a re-design of the cooling system of the nacelle.

Also, an unfavourable micro-siting of the turbines must be attributed to the above-average level of technical problems at Playa Kanoa. As can bee seen from the Google Earth picture in **Figure 2-144**, the main wind direction is exactly from the East (please note the two landing strips for model airplanes at the bottom of the picture).

Figure 2-144:
Playa Kanoa – Partial Google Earth View

Source: Google Earth, accessed 09th of May, 2011

As a result, the turbines of Play Kanoa were operating constantly in the partial wake of each other, thus increasing the turbulence levels and, as a consequence, the loads on the rotors. Even though the wake effects are only partial and not full (see **Figure 2-145**), it is expected that they had a permanent negative influence on the life-time of the machines and their components. As such, this wind park ex-

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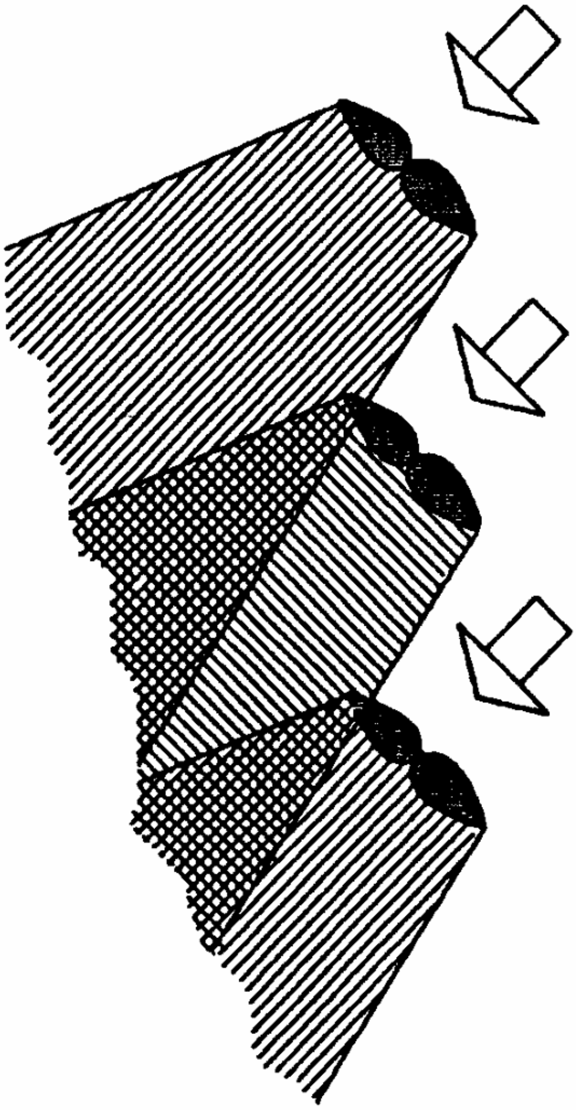
[121] compare this to the situation at the wind park Wigton I in Jamaica (**Section 2.1**)

periences a similar unfavourable operating condition as the wind park in Nevis, including the associated reduction of both energy yield and life time of the turbines.

Figure 2-145:
Turbines in Partial Wake Effect as in Playa Kanoa



Source: DEWI, Deutsches Windenergie Institut

According to an internet announcement, the complete wind park has already been sold[122]. At the same location, a wind park with 5 units Vestas V90 (5 x 3 MW) is planned by NuCapital.[123] When these turbines are installed – and because a 500 to 750 ton mobile crane has to be brought to Curacao – simultaneously another 5 units Vestas V90 will be installed at the site of the current Tera Kora wind park. Thus, both Aruba and Curaçao will see the first re-powering project in the Caribbean.

In a final analysis, the project Playa Kanoa shows drastically the technical problems first-generation wind turbines have been plagued with. In the meantime, and with more practical experience with wind turbine operation, manufacturers have improved the in-built lightning protection in the blades. Now blade damages such as in Playa Kanoa are practically impossible, special lightning conductors inside the blade can discharge the lightning strike reliably with currents of more than 50,000 Amps into the earthing system.

Also, gearbox design and manufacturer have been improved considerably. The impact of short-term peak loads (torques) on shortening the life-time of the gearbox is well-known, by now. Gearboxes today are designed taking inside and outside dynamic additional loads into account (according to DIN 3990), also safety factors according to ISO 6336 are being taken into account, i.e. the gear box components are designed with about 20 % to 50 % higher loads than anticipated.

In addition, new design methods which consider dynamic loads – such as multi-body simulations of drive trains[124] – are employed for the design of MW-scale gearboxes. However, gearboxes in the MW-scale are still the most sensible and maintenance-intensive part of the wind turbine – therefore, more and more manufacturers turn towards gearless wind turbine designs.[125]

The most important factors which have contributed to the long list of defects and damages in the 10-year life-time of the Playa Kanoa project must be seen as being the fact that the Nedwind 500 turbine was not adapted to the climatic conditions of the Caribbean on the one side, and that the company ceased to exist after a few years, on the other side.

That the operator of Playa Kanoa was able to keep up the operation of the wind park under this situation, shows his extraordinary commitment and technical expertise.

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122) http://www.mywindpowersystem.com/marketplace/18-nedwind-46-500kw-second-hand-wind-turbines-for-sale/

123) www.nucapital.nl

124) http://en.wikipedia.org/wiki/Multibody_system

125) for example SIEMENS WIND POWER, NORDEX and GE (http://www.siemens.com/press/en/presspicture/?press=/en/presspicture/2011/renewable_energy/soere201103-02.htm, http://www.windpowermonthly.com/news/1066426/Close---Nordex-N150-6000-offshore-turbine/, http://www.technologyreview.com/energy/23517/

2.14 Aruba

Aruba is the most Western of the three ABC islands and has an area of 180 km^2 and 103,000 inhabitants. Together with the Netherlands, Curaçao and Sint Maarten, Aruba is one of the four constituent countries which form the Kingdom of the Netherlands.

All electricity on Aruba is generated by large steam turbines and generators by WEB (Water en Energiebedrijf Aruba NV) and distributed by ELMAR (Electriciteit-Maatschappij Aruba).

The total power generating capacity of the steam turbines amounts to 149 megawatts. There is also a 22 megawatt gas turbine as a backup unit, while a 6.5 MW diesel generator serves as an emergency unit. WEB N.V. produced an average of 60 MW, which together with a contracted supply from the refining company, is sufficient to comply with the average demand of 77 MW on the island.

WEB N.V. delivers electricity to the distribution company ELMAR. Consumption of electricity has increased steadily since 1986 from 219,000 MWh to 701,577 MWh in 2003.[126]

This increase has been managed by a comprehensive and adequate electricity distribution network, which is continuously upgraded. Both WEB and ELMAR are independently managed companies residing under the Government-owned holding company Utilities Aruba N.V.[127]

2.14.1 Vader Piet 30 MW Wind Park

The private investor of Aruba's first larger wind park, NuCapital held an international tender procedure for the wind park at Vader Piet, asking for wind turbines of more than 1 MW installed capacity per unit. While Enercon offered its E44 with 900 kW installed capacity, Vestas wanted to install its V90 turbine with 3 MW installed capacity.

Under consideration of the considerable higher infrastructure costs for the smaller turbines (foundations, access roads and electrical connection), NuCapital decided for a 10 unit wind park with the Vestas 3 MW turbines.

Installation of the turbines took place from July to December 2009. Vestas brought in, together with the turbines, its own 750 ton crawler crane, which was used for the first time in one of Vestas projects.

Figure 2-146:
Vader Piet Aruba – 10 x 3 MW Vestas V90

Photo: B. Jargstorf, May 2011

2.14.2 Micro-siting, Wind Park Design

The turbines are located approx. 250 m away from the shore in a line in parallel to the beach and perpendicular to the main wind direction. Turbine to turbine distance is 300 m or 3.3 rotor diameters

In the centre of the wind park, the substation is located. All cabling is underground, even the high voltage grid connection to the next substation of the island's grid operator ELMAR. As a result, the wind park has a minimum visual impact and looks nicely integrated into the landscape (see **Figure 2-146** and **2-147**).

Figure 2-147:
Vader Piet Aruba – Substation

Photo: B. Jargstorf, May 2011

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[126] more recent figures could not be obtained

[127] http://www.thearubahouse.com/electricity.html

The wind park is located immediately beside the entrance to the Arikok National Park (see **Figure 2-148**), thus, it might have been an requirement of the environmental impact assessment to build a grid connection with underground cable only. The effect – similar to the situation without overhead lines at the wind parks at Curaçao and Bonaire – is a very pleasant one.

Figure 2-148:
Vader Piet Aruba – Entrance to Arikok National Park

Photo: B. Jargstorf, May 2011

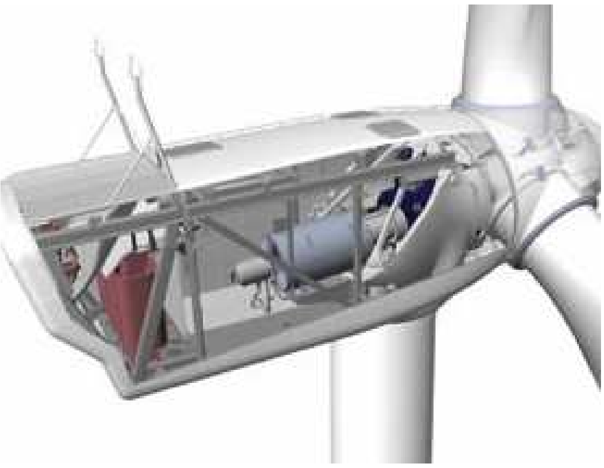
It is hoped that this positive example will be copied also in other islands of the Caribbean. After all, a large proportion of the Caribbean economic turnover depends on the pleasant environment of the islands.

2.14.3 Vestas V90 – Technical Features

The wind turbine V90 has been marketed by Vestas as a major technical break-through, as it features a tower head mass similar to the V80 with 2 MW installed generator power. This was possible because Vestas integrated the main bearing into the gear box, designing, in effect, a wind turbine without main shaft. Essentially, the main gearbox bearing doubles as the main (and single) rotor bearing.

As such, a very compact nacelle design was possible, which resulted in considerable weight savings. Even though the transformer has been moved from the tower bottom into the nacelle (see **Figure 1-149**), the overall nacelle weight of the Vestas V90 remained at 70 tons (identical to that of the V80 with 2 MW) the rotor has 40 tons.[128] Compared to the "conventionally designed" Vestas V80 – with rotor shaft and two main rotor bearings – this is indeed a considerable improvement with regard to specific weight: The V80 nacelle weighs 67 tons, and its rotor 37 tons.[129]

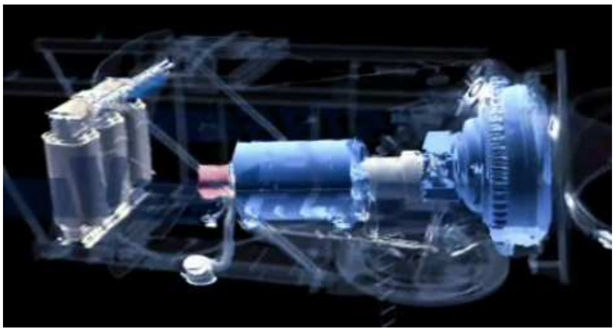
Figure 2-149:
Nacelle Design Vestas V90



The technically simple design of the integrated gearbox and main rotor bearing can be seen in the 3D photo in **Figure 2-150**. The gearbox consists of two planetary stages and a helical stage.

While Vestas delivers the V90 for projects in Europe with a double-fed induction generator, patent issues with the US required the use of another generator concept here in Aruba – an induction generator with variable slip.

Figure 2-150:
Nacelle Design Vestas V90 - Detail



Source: Vestas promotional movie V90

This generator design introduces resistances into the rotor windings and a fast electronic switch to activate these resistances (**Figure 2-151**). As the

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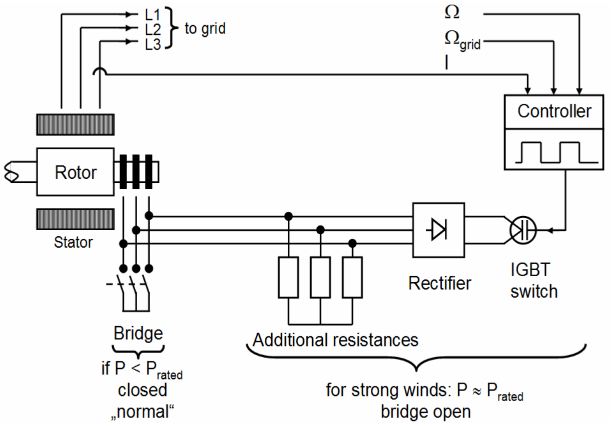
[128] company brochure Vestas V90

[129] http://www.solardyne.com/vev80lawitur.html

slip of an asynchronous generator (induction) is proportional to the electrical resistance in its rotor winding, such a system allows over-speeding of the rotor.

Figure 2-151: Induction Generator with Variable Slip



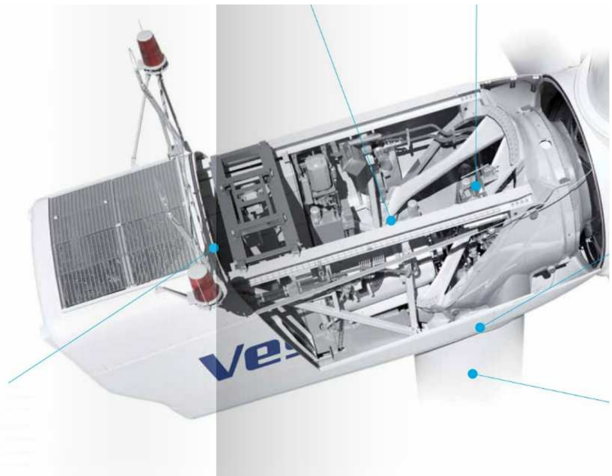
Source: Prof. Dr.-Ing. Robert Gasch, InWEnt/NPU Training Course “Grid connected Wind turbines”

While Vestas has been using the variable slip generator since its 500 kW turbine in 1994, the disadvantage of such a generator design is its efficiency: Increasing the slip in the generator by 1 % (i.e. from a standard value of 1.2 % to 2.2 %), generates 1 % heat losses, i.e. 30 kW. In practice, up to 20 % slip changes (= 20 % changes in rotational speed) are allowed, but only for a very short time. during this time, the (relatively slow) hydraulic pitch system of the turbine has to curtail the wind energy which would lead to an overload of the generator.

Vestas also integrated into the nacelle design an auxiliary crane, which enables all major components to be exchanged without the need of a mobile crane, apart from the gear box. As such, the transformer (weight ~ 9 tons) can be exchanged, as well as the electrical generator (~ 8 tons). Even the helical stage of the gearbox can be dismantled and exchanged.[130] The functioning of the overhead gantry crane can be seen in **Figure 2-152**.

To this gantry crane a 3 ton electric winch is connected, which allows with a 1 to 3 block and tackle up to 9 tons lifting capacity. This winch is normally stored in the spare part storage room (**Figure 2-153**). by means of the auxiliary crane installed in the nacelle, where it can be lifted up and mounted to the overhead gantry crane.

Figure 2-152: Vestas V90 – Nacelle Design with Auxiliary Crane



Source: Vestas company brochure

Source: Vestas promotional movie V90

Through openings in the bottom of the nacelle, transformer, generator or third-stage of the gear box can be lowered an hoisted.

Figure 2-153: Electric Winch Stored in the Workshop (for a maximum lift of 9 tons

Photo: B. Jargstorf, May 2011

In case the gearbox as a whole has to be replaced, and no suitable mobile crane is available, Vestas

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[130] personal information Ronald Bouma, Vestas Operation Manager Vader Piet Wind Park, Aruba, 8th of May, 2011

has developed another auxiliary crane, a so-called “climber” (**Figure 2-154**). This unit can be shipped to the island and is mounted to the tower, where it “climbs” all the way up to a position just beneath the nacelle. In this position, the inbuilt hydraulic crane can lift up the complete gearbox (~ 20 tons) and install a replacement.

Figure 2-154:
“Climber” Crane for Exchange of Gearbox

Photo: Vestas

Another technical speciality concerns the tower design: With steel weights of between 150 and 200 tons per tower, both costs and weights of these tubular towers contribute considerable to the overall investment and transportation costs.

Due to structural requirements, any welding in the tower structure has to be checked by x-ray and verified. Also, an opening in the tower surface – for the access door, for example – requires additional structural enhancement.

Here Vestas uses now patented magnets for the attachment of the major fittings in the tower (**Figure 2-155**), including the main entrance door and the ladder, leading up to the micelle. In fact, only the lowest tower platform features a welded connection to the tower structure – all other fittings are by means of (standardized) magnets. As a result, the weight of the tower could be reduced by approx. 25 % as compared to a standard welded tower construction.[131]

Figure 2-155:
Permanent Magnets Used for Tower Fittings

Photo: B. Jargstorf, May 2011

Figure 2-156:
Permanent Magnets to mount the Main Tower Entrance Door

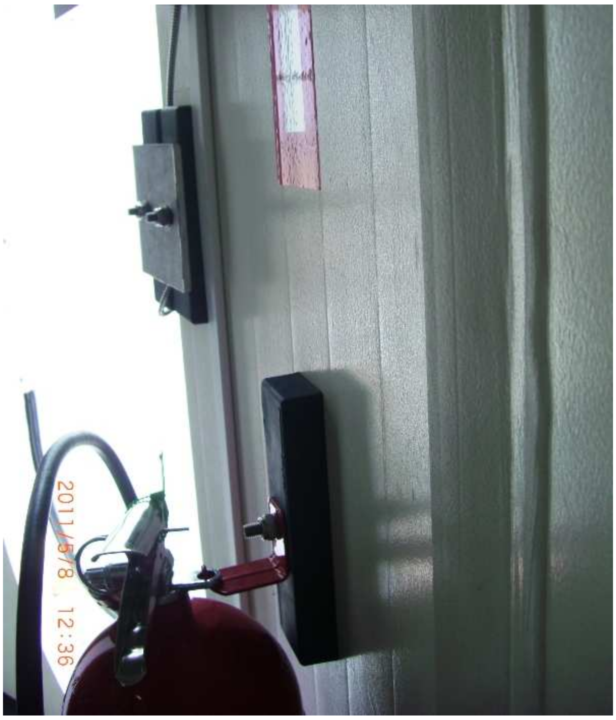

Photo: B. Jargstorf, May 2011

In **Figure 2-156** the use of the standardized permanent magnets can be demonstrated: two magnets in the left part of the photo hold the main entrance door at the tower base, while a single magnet is used to mount the fire extinguisher to the tower wall. Also, the doubling of the tower wall thickness can be seen. Instead of a conventional reinforcement around the door opening, which requires much more welding work (and the consecutive expensive checking for the integrity of the welded seam – x-ray), the area around the door has received a double wall thickness.

Vestas installs an elevator in its 80 m towers (**Figure 2-157**) which allows two people simultaneous

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[131] personal information, Ronald Bouma

access to the nacelle. Parallel to the elevator, a ladder leads up to the different platforms and the nacelle.

Figure 2-157:
Vestas V90 - Elevator leading up to the Nacelle

Photo: B. Jargstorf, May 2011

2.14.4 SCADA System

As all modern wind parks, Vader Piet is connected via SCADA to the internet and can be remotely monitored and controlled. The hardware for the SCADA is located in the switch cabinet building of the substation. From here each individual turbine can be accessed (**Figure 2-158**).

The main panel of a single turbine can be seen in **Figure 2-159**: apart from current wind speed and active power output, rotor and generator speeds also temperatures of the main components can be checked. From this panel a direct influence on the active and reactive power output of the turbines can be exercised.

Figure 2-158:
Vestas - Main SCADA Computer at the Substation

Photo: B. Jargstorf, May 2011

Figure 2-159:
Main Control Panel of an Individual Turbine


Vestas V90 Status, WTG01 [35677]

Status
1466.9 kW
9.0 m/s
Mode Run Pending Run Time 5/8/2011 12:40:06 PM
Status 0000 Turbine OK
Info

Meteorology
Direction
Nacelle 123 °
Wind 120 °
Temperature
Ambient 28 °C

RPM
Generator 1743.4 RPM
Rotor 16.0 RPM

Pitch system
Main pressure 183.1 Bar
Pitch angle -2.2°

Source: Screenshot Vestas SCADA, 08.05.11, 13:15 h

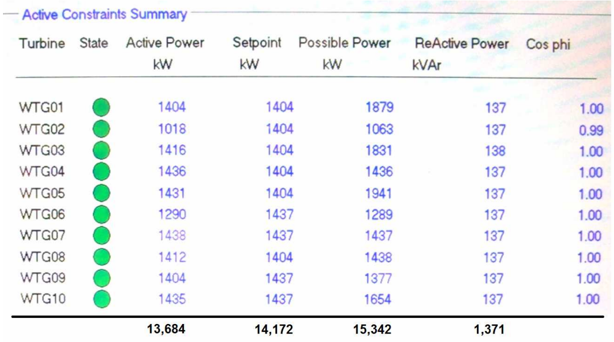
As a copy of this software runs in the control room of the thermal power plant, the wind park can be easily controlled by the power plant operator of Aruba, AQUAELECTRA. In case of need for a power limitation, it is not necessary to set the power limitation for each turbine – just the maximum power output of the park has to be set. The software then controls the individual turbines in a way that the maximum total power is not exceeded.

This SCADA feature allows an easy integration of the wind park into the electric grid of the island.

During the time of the visit at Vader Piet, a thunder storm was developing and a dark rain cloud was approaching the wind park. As this normally leads to a short-term increase of wind speed and, consequently, to a steep increase of output power, the operator had limited the maximum power output of the wind park to the average value during the past hours – in this case to 14 MW.

In **Figure 2-160** the so-called Active Constraint Summary shows the current set points, the actually produced power (active power) and the possible power of the individual turbines.

Figure 2-160:
Active Constraints Summary



Active Constraints Summary

Turbine	State	Active Power kW	Setpoint kW	Possible Power kW	ReActive Power kVAr	Cos phi
WTG01	●	1404	1404	1879	137	1.00
WTG02	●	1018	1404	1063	137	0.99
WTG03	●	1416	1404	1831	138	1.00
WTG04	●	1436	1404	1436	137	1.00
WTG05	●	1431	1404	1941	137	1.00
WTG06	●	1290	1437	1289	137	1.00
WTG07	●	1438	1437	1437	137	1.00
WTG08	●	1412	1404	1438	137	1.00
WTG09	●	1404	1437	1377	137	1.00
WTG10	●	1435	1437	1654	137	1.00
		13,684	**14,172**	**15,342**	**1,371**	

Source: Screenshot Vestas SCADA, 08.05.11, 13:30 h, *modified*

One can see that the wind park currently produces 13.7 MW, has a set point at 14.2 MW and a "Possible Power" of 15.3 MW.[132]

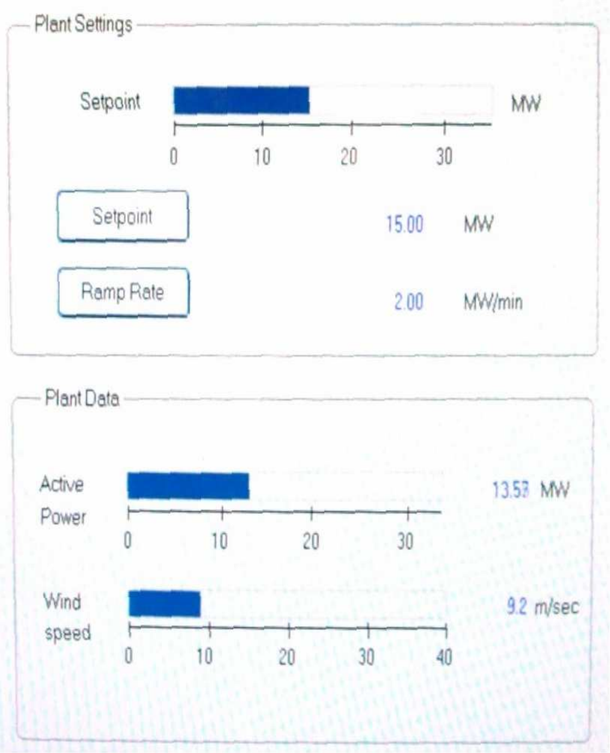
For the system operator, not only the maximum instantaneous wind power is of interest, but also the power gradient of the wind park output, i.e. how much more power can be fed in during a given time. Vestas calls this power gradient "Ramp Rate" and indicates it in MW/min.

In limiting this to a certain value – 2 MW/min in **Figure 2-161** – the thermal power plant is kept from having to tolerate sudden increase of wind power. Thus, the controller of the thermal generators is allowed to slowly decrease its output power.

The term "Possible Power" denominates the potential power output, the wind park could generate without a power output limitation (= set point). The amount of "Possible Power" is calculated by the SCADA using the measured wind speed at the nacelle anemometer as input.

In this moment, 1.6 MW (= 15.3 – 13.7) are curtailed through employing a suboptimal pitch angle at the turbines. This can be seen in **Figure 2-159** for a single turbine WTG01, where a pitch angle of - 2.2° reduces the potential instantaneous wind power of 1.879 kW (calculated with the measured wind speed of 9 m/s) to the required value of 1,467 kW (pitch angle for maximum power: 0°).[133]

Figure 2-161:
Setpoint and Ramp Rate Menue



Setpoint 15.00 MW

Ramp Rate 2.00 MW/min

Active Power 13.53 MW

Wind speed 9.2 m/sec

The IPP contract of the operator of Vader Piet stipulates that the "Possible Power" is paid, and not the actually produced power (= active power).[134] This means that only under exceptional situations (such as during an impeding thunderstorm event) the control room of the power plant will use the power output function.

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132) during the time of the visit, a maximum power of 15 MW had been set by the control room of the WEB power plant.

133) please note that the screen shot in **Figure 2-158** was taken 15 minutes before the one in **Figure 2-159** – as a result, the values of the actual power output are slightly different (1,467 vs. 1,404 kW)

134) personal information, Ronald Bouma, Technical Team Leader Aruba, Vestas Central Europe, 8th of May 2011

Also, during night-time with nominal wind speeds, when the loads at Aruba are low, short-term reductions of the wind power output are sometimes necessary. Due to the contract arrangement it is guaranteed that always the maximum permissible wind power of the Vader Piet wind park is utilized.

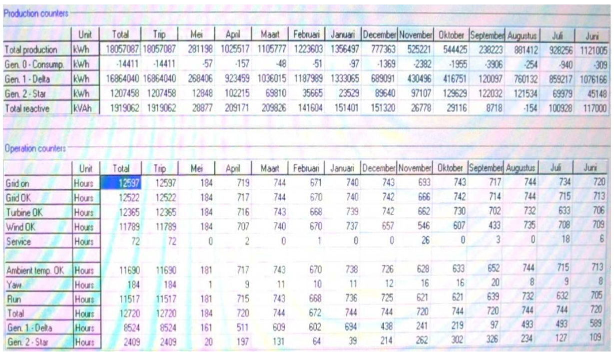
This is in stark contrast to the situation at Nevis, where the IPP contract limits the wind power production and does not constitute an incentive to increase the wind energy penetration rate on this island.[135]

2.14.5 Production Figures

Production figures of the wind park could not be obtained. In any case, the last year had above average rain fall in the Netherlands Antilles (as elsewhere in the Caribbean), therefore it is estimated that the wind speeds so far had been below average. This is confirmed by the plant manager of Vader Piet, Ronald Bouma, who reported that WEB Aruba has complained about getting less wind power generated electricity than anticipated.

Wind data were not available – however, the Vader Piet wind park features an independent meteorological tower with 80 m height about 200 m windward to the turbines (**Figure 2-162**).

Figure 2-161:
Screenshot of Production Figures WTG01



Production counters

	Unit	Total	Trip	Mei	April	Maart	Februari	Januari	December	November	Oktober	September	Augustus	Juli	Juni
Total production	kWh	18057087	18057087	281198	1025517	1105777	1223603	1356497	777363	525221	544425	238223	881412	928256	1121005
Gen. 0 - Consump.	kWh	-14411	-14411	-57	-157	-48	-51	-97	-1369	-2382	-1955	-3906	-254	-940	-309
Gen. 1 - Delta	kWh	16864040	16864040	268406	923459	1036015	1187989	1333065	689091	430496	416751	120097	760132	859217	1076166
Gen. 2 - Star	kWh	1207458	1207458	12848	102215	69810	35665	23529	89640	97107	129629	122032	121534	69979	45148
Total reactive	kVAh	1919062	1919062	28877	209171	209826	141604	151401	151320	26778	29116	8718	-154	100928	117000

Operation counters

	Unit	Total	Trip	Mei	April	Maart	Februari	Januari	December	November	Oktober	September	Augustus	Juli	Juni
Grid on	Hours	12597	12597	184	719	744	671	740	743	693	743	717	744	734	720
Grid OK	Hours	12522	12522	184	717	744	670	740	742	666	742	714	744	715	713
Turbine OK	Hours	12365	12365	184	716	743	668	739	742	662	730	702	732	633	706
Wind OK	Hours	11789	11789	184	707	740	670	737	657	546	607	433	735	708	709
Service	Hours	72	72	0	2	0	1	0	0	26	0	3	0	18	6
Ambient temp. OK	Hours	11690	11690	181	717	743	670	738	726	628	633	652	744	715	713
Yaw	Hours	184	184	1	9	11	10	11	12	16	16	20	8	9	8
Run	Hours	11517	11517	181	715	743	668	736	725	621	621	639	732	632	705
Total	Hours	12720	12720	184	720	744	672	744	744	720	744	720	744	744	720
Gen. 1 - Delta	Hours	8524	8524	161	511	609	602	694	438	241	219	97	493	493	589
Gen. 2 - Star	Hours	2409	2409	20	197	131	64	39	214	262	302	326	234	127	109

However, the SCADA screenshot of an individual turbine allows a tentative overview about the production of the wind park during the past 12 months. **Figure 2-161** shows the data for wind turbine 1 (WTG01). When evaluating these data we see that about 10 % of the total annual production is generated in star-connection of the generator (low wind speed situation), while the remaining production comes from a delta-connection. Total production of this turbine had been 10,019 MWh.

The own consumption (“**Cons**”) of the turbine is 1.14 % (11.5 MWh), resulting in an annual net production of 10,008 MWh.[136]

With this calculated production we arrive at a net capacity factor (“**CapFac**”) of 41.5 % - an excellent value with would indicate an annual average wind speed of between 8 and 8.5 m/s at hub height. Monthly capacity factors of more than 60 % show the outstanding wind resources of Aruba (**Figure 2-163**).

Figure 2-162:
Vader Piet - 80 m Meteorological Mast

Figure 2-163:
Evaluated Production Figures WTG01
(1st of June 2010 to 8th of May 2011)

	Delta	Star	Total	Cons	Net Prod	CapFac
Jan	1,333.0	23.5	1,356.5	0.1	1,356.5	60.8 %
Feb	1,188.0	35.7	1,223.7	0.1	1,223.7	60.7 %
Mar	1,036.0	69.8	1,105.8	0.1	1,105.8	49.5 %
Apr	923.4	102.2	1,025.6	0.2	1,025.4	47.5 %
May*	268.4	12.8	281.2	0.1	281.1	51.5 %
Jun	1,076.2	45.1	1,121.3	0.3	1,121.0	51.9 %
Jul	859.2	70.0	929.2	0.9	928.3	41.6 %
Aug	760.0	121.5	881.5	0.3	881.2	39.5 %
Sep	120.0	122.0	242.0	3.9	238.1	11.0 %
Oct	416.8	129.6	546.4	1.9	544.5	24.4 %
Nov	430.5	97.1	527.6	2.4	525.2	24.3 %
Dec	689.0	89.6	778.6	1.4	777.2	34.8 %
Avg	758.4	76.6	835.0	1.0	834.0	41.5 %
Total	**9,100.5**	**918.9**	**10,019.4**	**11.5**	**10,007.9**	

*) curent month, only 183 hours connected to the grid

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[135] see **Section 2.10.4 Production Figures Nevis**

[136] please note that the actual month May 2011 has only 8 days or 183 hours – thus the year misses 561 hours (6.4 %)

Assuming a similar performance of the other 9 turbines the annual production of the 30 MW wind park Vader Piet amounts to ~ 100 GWh/a.

This results in a wind energy penetration rate of ~ 14 % and is a very good value for a first wind park on the island.

2.15 Bonaire

The island of Bonaire has an area of 250 square km^2 and is located 80 km north of the Venezuelan coast. Together with Aruba and Curaçao it forms a group referred to as the ABC islands of the Leeward Antilles. During its long history, it has been used as a prison, a plantation island, and a salt production centre. Today the island's outstanding marine environment also attracts a growing number of tourists.

With a population of ~ 16,000, Bonaire's peak electricity demand is approximately 12 MW. Following the destructive fire in diesel power plant in 2004, the island was served by a set of rented container diesel generator systems that had a rated capacity of 12 MW and run on light-fuel diesel. In a typical year, Bonaire consumes 80,000 MWh of diesel-generated electricity.

After the fire in 2004, the island's government wanted not only to restore energy generation to the island, but also to generate that energy from 100 % renewable sources. The government began working with the local energy company Water en Energie Bedrijf Bonaire (WEB) to devise a plan to reach the 100 % renewable energy goal.

An international tender was launched requiring the bidder to simultaneously offer modern diesel power generators with biofuel abilities and wind turbines. The tender required a 50 % wind energy penetration after two years of operation. [137]

Eventually a consortium, EcoPower Bonaire BV, won the contract to develop the plan, which includes investment in research, wind turbines, and a facility that will produce bio diesel from algae.

The Water and Energy Company of Bonaire is a fully Government-owned company, responsible for the production and distribution of water and electricity on the island. The company signed an agreement with EcoPower Bonaire BV to purchase all electricity produced by the project.

With the new system, power consumers on Bonaire can expect **a 10 % – 20 % reduction** in their electricity bills.**[138]** This rate reduction was intended to go into effect the first day the project came online. This will also substantially reduce the island's dependence on oil, with its fluctuating and steadily rising prices, and increase the reliability of electricity. However, in May 2011, the reduction of electricity tariffs had not yet been implemented.

In the medium-term run, the combination of algae production, the wind turbine facilities, and the bio diesel plant are expected to create jobs and boost the island's employment. This project's island setting will act as a working, small-scale model of wind energy providing a significant portion of the energy in an overall electricity grid, and can later be scaled up for larger applications.

2.15.1 Wind/Diesel Project Implementation

As a result of the international tender, a Memorandum of Understanding (MOU) was signed between EcoPower Bonaire BV and WEB in September 2006. Originally, the total cost for the project was anticipated to be $75 million; US$60 million for generators and turbines, $15 million for network extension.[139] In May 2011, total investment costs were indicated to be US$60 million.[140]

In November 2007 EcoPower Bonaire BV signed a power purchase agreement (PPA) with WEB for the whole system.

From the onset of the project, it was planned to implement the 100 % RE system in two phases and gradually increase the RE penetration. This cautious approach has also been proposed by CREDP for the implementation of wind power projects in St. Vincent and St. Lucia – i.e. from standard grid-parallel and high-penetration wind park operation until the introduction of energy storage and eventually diesel-off mode.[141]

As part of Phase 1, EcoPower installed a 330 kW Enercon E33 wind turbine at Sorobon in

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[137] this and the information of the following sections are taken from http://www.edinenergy.org/bonaire.html?print and http://www.powergenworldwide.com/index/display/articledisplay/8319915025/articles/power-engineering-international/volume-18/Issue_5/features/Bonaire_Island_of_green_dreams.html

[138] according to Dirk Berkhout, a board member of EcoPower partner Econcern, see http://www.geni.org/globalenergy/library/technical-articles/generation/small-island-nations/bonaire-set-to-become-caribbeans-first-island-with-100%25-renewable-energy/index.shtml

[139] http://www.tourismbonaire.com/en/over-bonaire/news/bonaire-to-be-powered-by-50-sustainable-energy-for-early-2010

[140] Vincent Kooij, Managing Director, Ecopower Bonaire, “World’s largest hybrid wind-diesel power plant”, presentation at “Sustainable Energy in the Caribbean”, Jamaica, 3rd and 4th of May, 2011

[141] see **Box 3 – Operation Modes for Wind Parks and Diesel Generators**

2007. This area is on the southeast coast of Bonaire, where the average wind speed is about 9 m/s. It is estimated that the manufacturer Enercon wanted to get more information about the behaviour of the their machines in the grid of Bonaire and also get practical experience with the meteorological conditions of the island (cooling system layout under high ambient temperatures and high average wind speeds).[142]

Phase 2 involved the construction of a wind park consisting of 12 turbines Enercon E44 with 900 kW each and a 14 MW diesel power plant. There is also 3 MW of battery storage integrated to optimize the wind contribution and to improve the grid quality.

2.15.2 Current Status

In May 2010, the new diesel power station with five units 2.8 MW (MAN Type 9L27/38) started test operation.

Figure 2-164:
MAN 2.8 MW Diesel/Biofuel Generators

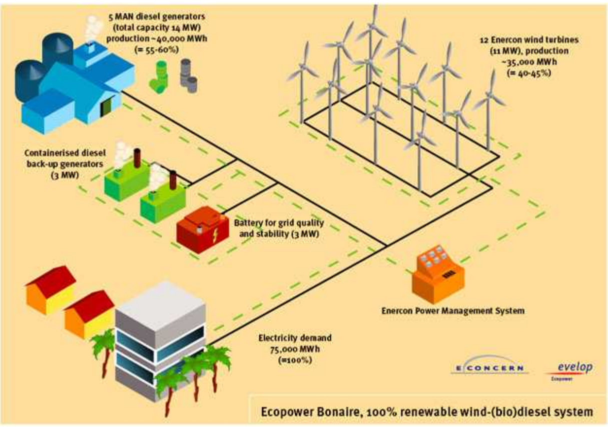
Photo: B. Jargstorf, May 2011

At present, the diesel power plant is using "conventional" heavy fuel, however, the plant is prepared to be converted to burn biofuel from algae. The production of biofuel has not yet begun – currently only heavy fuel is used in Bonaire.[143]

In the next several years, the project will start producing bio diesel from algae to run the diesel generators. The consortium expects that at least 3 to 5 years of research and development are needed for this technology to be viable in the island's energy plant. Eventually, the consortium will need about 10,000 metric tons of algae each year to run the power plant.

In order to optimize the parallel operation of wind and diesel generators, a relatively small unit size for the diesels of 2.8 MW was chosen. The installation of the 10.8 MW wind park was completed in October 2010. The turbines were manufactured and installed by Wobben Windpower Brazil, a 100 % subsidiary of Enercon from Germany.[144]

Figure 2-165:
Wind/Diesel System Bonaire - Schematic



Source: http://www.edinenergy.org/bonaire.html?print

2.15.3 Technical Concept

According to the schema of the wind/Diesel system in **Figure 2-165** the functioning of the individual components of the is described in the following:

- **5 MAN diesel generators** (main diesel running on heavy fuel oil HFO) with a total installed capacity of 14 MW: supply of base-load electricity;
- **3 containerized diesel generators** with 1 MW each (back-up diesel running on light diesel fuel): needed for a cold-start of the diesel generators, and also as a back-up for the main HFO diesels, in case these are unavailable due to maintenance and repair (to fully replace one main diesel generator. all three back-up diesels are needed);
- **3 MW of battery storage** (NiCad) with a inverter/converter system, to bridge over the time which is needed to start the diesels in case of sudden loss of wind power. EcoPower Bonaire has opted for 3 MW

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142) under European climate conditions, the strong wind season is simultaneously the season with low ambient temperatures (autumn and winter). In summer, with temperatures between 20° and 30° C, generally average wind speeds are below 6 m/s. Under Caribbean conditions, however, high ambient temperatures > 30° C are combined with high wind resources – all throughout the year … (see **Section 2.13.3 Technical Issues at Playa Kanoa**)

143) there is a similar approach on the Galápagos Islands. Here biofuel from Jatropha shall be used. See, for more details, http://www.ergal.org/cms.php?c=1272 (Biocombustibiles)

144) see http://www.wobben.com.br/

Nickel-Cadmium battery storage from Saft Batteries of France[145]. The essential role of the energy storage system is threefold:

(1) to provide **backup power** to ensure that the main frequency of the Bonaire grid remains under constant control at the steady 50 Hz required for grid stability;

(2) to **bridge time** until a diesel can be started: in case of a sudden increase in load or a loss of generation (wind speeds drop) the battery will supply just over 3 MW for up to 2 minutes. This will allow sufficient time for one or more of the main diesels to be started and brought on-line;

(3) to act as a **dump load**: the supervisory system keeps the battery always at a 90 % state-of-charge (SOC), therefore, should a sudden loss of load occur – caused for example by a line fault – the battery can absorb energy for a short time, but this energy is dissipated not stored.[146]

Figure 2-166:
MAN Diesel Power Station Bonaire

Photo: Vincent Kooij, “World’s largest hybrid wind-diesel power plant”, op. cit., slide 47

The Bonaire project is the first to use Saft's new nickel-based SMRX block battery design that combines the high power capability of its well proven SRX cells with the compact, lightweight construction pioneered with its MRX batteries. The battery fits into three standard transportation containers for ease of installation and commissioning (**Figure 2-167**). The fourth container holds the power conditioning modules (inverters).

The use of the SMRX batteries has enabled Saft to design a high performance 640 V battery with a nominal capacity of 1,320 Ah (640 V x 1,320 Ah = 844.8 kWh).[147] This is a capacity of 50,640 kW-minutes. Of this, about 50 % is practicably usable ~ 25,000 kW-minutes. With a peak load at Bonaire of 12,000 kW, the battery is sufficient to supply stand-by power for about 2 minutes.[148]

Figure 2-167:
NiCad Battery Storage with Power Converter

Photo: B. Jargstorf, May 2011

- **11 MW of wind power** (12 x 900 kW Enercon E44), given the excellent wind conditions at Bonaire (~ 9.2 m/s annual average wind speed in 55 m hub height), this wind park could produce about 50,000 MWh if it were installed in parallel to a larger electric grid with constantly more than ~ 11 MW of demand. Due to the need to curtail (= pitch away) some of the wind energy during time of insufficient demand, the annual production of the wind park is expected to be 35,000 MWh. This results in about 30 % lost production, part of which can be utilized to charge the battery storage;
- **Power Management System** – the supervisory control of the wind/diesel system, integrates wind and diesel power with the battery storage (developed by Enercon).

Figure 2-168:
Transporting the Turbine Parts to the Wind Park Site

Photo: Tarossel, October 2010 (accessed via GOOGLE EARTH)

In **Figure 2-169** an extreme example of a loss of wind power is shown, and how the Enercon supervisory system reacted. First of all, within 13 seconds the wind power production (**green line**) goes from a stable 5.7 MW to “0” – thus, practically 68 % of the energy supply became unavailable within 13 seconds. Such a loss of production must be considered as a situation a “standard” power system based on diesel generators alone could not cope with.

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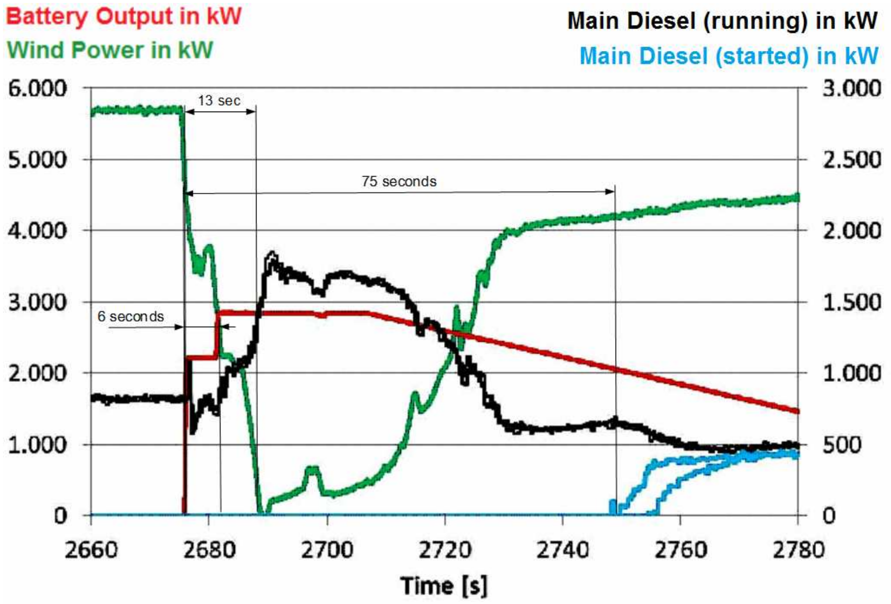
[145] see http://www.saftbatteries.com/

[146] personal information Vincent Kooij in his email from 29-05-11

[147] compare this capacity to a typical car battery with 0.8 kWh, an electric car with 15 to 25 kWh, and a fly wheel with typically 5 to 25 kWh

[148] Vincent Kooij, “World’s largest hybrid wind-diesel power plant”, op. cit.

Figure 2-169:
Bonaire: 5.7 MW Wind Power Loss in 13 Seconds



Source: Vincent Kooij, op. cit., slide 37, *modified*

Immediately, the battery supplies 2.2 MW and goes up within 6 seconds to the maximum value of 2.9 MW (**red line**).[149] Simultaneously, the three main diesel generators, operating at ~ 900 kW each, go up to 1,800 kW each within 15 seconds (**black lines**).

It took 75 and 80 seconds to bring the other main diesels on-grid (**blue lines**). Both take over about 500 kW of the load immediately after starting. By then, the wind power has been restored to ~ 4 MW and the starting of the diesels would not have been necessary anymore. In the opposite, the starting of the two new HFO diesels forces all five units into an extreme low-load operation of ~ 500 kW or 18 % nominal load. This is a load situation diesels running on heavy fuel should avoid – as a rule, long-term part load operation of more than 50 % is required for such machines.

Also, one can see that the battery power is slowly going down on a ramp from 2.9 to 1.5 MW. Such a gradual reduction of battery load allows the diesels a gradual take-over of load; and is also expected to have a life-prolonging effect of the battery itself.

The battery – due to it’s short reaction time, bridges over the time until – after ~ 50 seconds – the wind power came back and helped to stabilize the system (see **Figure 2-170** for details of load sharing).

As such, the example given by Ecopower in **Figure 2-169** unfortunately does not prove the basic function of the Enercon Power System, i.e. to cope with a sudden and complete loss of several MW of wind power.[150] This example only demonstrates how a temporary (i.e. 50 second loss) of about 4 MW is bridged over by the battery. It does not show how the system would behaved if the loss of wind power had pertained.

In any case, one can see in **Figure 2-169** that the system has at least two instants of reserve power potential:

(1) the running main diesel could go up to a value close to their nominal power (~ 2.500 kW);

(2) the main diesels could also go up higher than the current 500 kW, indicated in the graph.

Figure 2-170:
Instantaneous Wind Energy Penetration Rate

Source of Energy	before	during	after Power Loss
Wind	5,700		4,400 kW
Main Diesel 1	900	1,833	500 kW
Main Diesel 2	900	1,833	500 kW
Main Diesel 3	900	1,834	500 kW
Battery		2,900	1,500 kW
Main Diesel 4			500 kW
Main Diesel 5			500 kW
Wind Penetration	67.9 %	0 %	52.4 %
Total	8,400	8,400	8,400 kW

When the situation shown in **Figure 2-169** occurred, EcoPower operated the wind/diesel system under a special test situation, as there had been three main diesels in operation when the wind

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[149] please note that in smaller wind-diesel systems the task of supplying instant reserve power would have been taking by a flywheel. The Enercon flywheel has a capacity of 5 kWh and 300 kW of peak power – thus, for the power demand ~ 10 flywheels would have to be installed. However, this would have only provided ~ 50 kWh or 300 kW-minutes – by far a too small a capacity to bridge over the time until the back-up diesels come on-grid. Besides, flywheels have to held spinning always, thus they have considerable energy losses. Under this situation the use of a battery was mandatory in Bonaire.

[150] this incident has been the most serious incident during the operation of the wind/diesel system, a complete, and long-term loss of wind power has not been experienced so far (personal information Vincent Kooij in an email from 29-05-11)

power loss occurred, whereas the total diesel load of 2.7 MW could have been managed comfortably by two engines with 2.85 MW rated power each.[151]

The consultant estimates that the Enercon supervisory control system has been programmed with a n+1 rule for the main diesel generators. Thus, when a certain instantaneous wind penetration rate has been achieved - for example more than 40 %, which would typically represent a power demand of more than 3 MW in the grid - there is always one main diesel more on-grid than would be needed without wind power: As 3 MW is the maximum battery power, a sudden loss of more than 3 MW could make the system unstable.

As a rule, one can say that the dimensioning of a wind park using the Enercon power management system requires a battery backup of the same magnitude as the unit size of the main diesels (~ 3 MW), and also the same capacity as back-up diesels (~ 3 MW). Of course, this is just a first estimation of a dimensioning rule. Also, the fine tuning of the supervisory system is still underway – after all, the wind/diesel system Bonaire is only in operation since 9 months, with the complete wind park on-grid only since October 2010.

Figure 2-171:
Wind Park Bonaire with 12 units Enercon E-44 (900 kW)

Photo: B. Jargstorf, May 2011

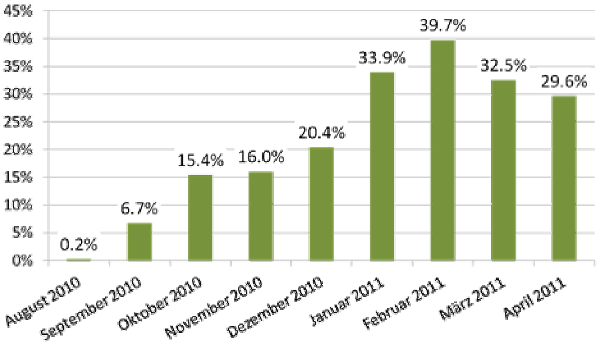
2.15.4 Summary

Since implementation, there has been good political support from the government of Bonaire. The most difficult parts of the project were the contracting phase and securing financing. Contracting took place in 2007 and 2008 when – due to the then wind energy boom – wind turbine prices were at an all-time high.

In 2009, due to the credit crunch, Econcern — the main shareholder — went bankrupt. Rabobank decided to take over the project and made sure it was completed. In addition, local permit procedures were inadequate to support such a complex project. Despite these hurdles, however, the project was completed. To finance the project, Rabobank of the Netherlands provided non-recourse financing; 20 per cent equity and 80 per cent debt. The cost to build the new wind-diesel system had been 60 million US$,[152] with an anticipated return of US$ 16 million a year. This figure is based on the sale of ~ 80,000 MWh/a and a tariff of 0.20 US$/kWh.[153] Part of this investment is also expected to be recouped through carbon credits.

The new thermal power plant has been in operation since 20th of August 2010 and is performing well. The wind farm has been phased in gradually, but the highest instantaneous wind share has already been more than 70 %. Average monthly wind energy penetration rates have been slowly increased and reached 35 % in 2011 (**Figure 2-172**). The targeted annual average wind share of 40 % – 45 % will most likely be met. A more accurate estimate will be available by the end of 2011.

Figure 2-172:
Monthly Wind Energy Penetration Rates



Source: Vincent Kooij, op. cit., slide 19

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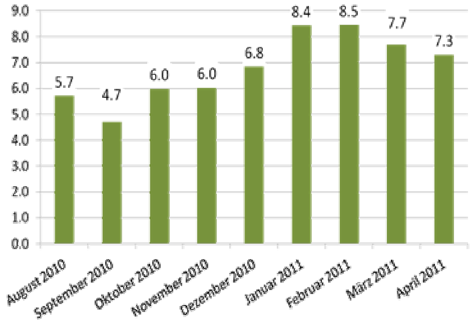
[151] theoretically, a single diesel would have been sufficient for the load of 2.7 MW (P_{nomial} = 2.85 MW) , but no power plant operator would go up to the nominal power output – even without wind power in the grid there are load fluctuations which have to be accounted for.

[152] during the planning phase, investment costs had been estimated between US$ 55 and 75 million.

[153] Vincent Kooij, “World’s largest hybrid wind-diesel power plant”, op. cit., slide 41

It looks that the wind speeds so far have been below the average indicated in the web articles on the Bonaire project. There, annual average wind speeds of over 9 m/s had been mentioned for the wind park site.[154] The monthly wind data since August 2010 as published by Ecopower, calculate far below this value. As shown in **Figure 2-173**, these values are in the range between 4.7 m/s and 8.5 m/s an give an average of 6.8 m/s over the last 9 months. It is not indicated how these wind data have been measured – but it is assumed that the data have been recorded at the hub height of the turbines and come from the nacelle anemometers of the wind turbines.

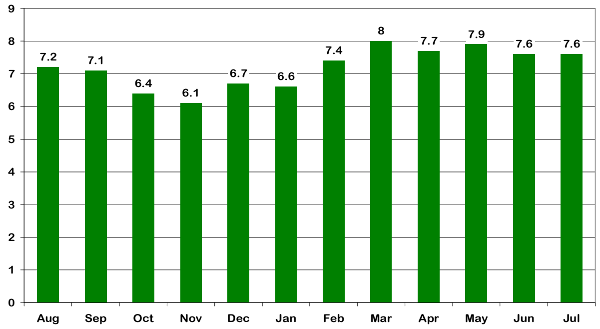
Figure 2-173:
Bonaire Wind Park
Monthly Wind Speeds in m/s



Source: Vincent Kooij, op. cit., slide 20

As such, the measured wind speeds so far are more in line with wind measurements undertaken by FAPE in 1996 in Rincon, a village about 4 km away from the wind park (**Figure 2-174**).[155]

Figure 2-174:
Rincon 1996 - Monthly Wind Speeds in m/s



Source: Fundashon Antiyano Pa Energia (Margo H. Guda), "Bonaire Wind Resource Assessment", 1997, p. 25

According to Ecopower, the power management system and the battery have been performing above expectations. Power quality and grid stability are reportedly good. This has been confirmed by the grid operator WEB in a telephone conversion on 9th of May, 2011.

The turbine supplier has guaranteed the fuel savings, and the system is reducing Bonaire's electricity costs. Moreover, the island now has a strong hedge against future fossil energy price hikes and is on track to achieving 100 % sustainability through its algae/biofuel option.

However, the reduction of the retail tariffs for electricity on Bonaire – as announced at the onset of the project in 2008 - has not been implemented by WEB so far. Currently, the average end used tariff for electricity is 0.37 US$ per kWh. With generation costs of 0.20 US$ it is estimated that this tariff allows the grid operator WEB sufficient head room to operate profitably.

In summing up, this project shows that the operation of a diesel power plant in direct combination with a wind park allows the safe operation in high-penetration mode. It seems realistic that wind energy penetration rates of 50 % can be reached with the technical concept as used by Ecopower in Bonaire. As such, this technical concept is regarded as a model case for several other islands of the Caribbean with similar wind resources and electricity demand.

2.15.5 Energy Efficiency Improvements

Only with regard to energy efficiency, however, some improvements could be made: First of all, before engaging into such a high-penetration wind energy project, the energy efficiency potential on the island, in particular in the hospitality sector should have been properly assessed and addressed. It does not seem logical to produce electricity with high technical efforts from renewable energies, and then allow it to be consumed with a low efficiency (air conditioning, illumination with incandescent lamps, refrigerators etc.).

Also, the desalination plant of WEB – formerly being integrated into the old power plant through using the dissipation energy of the diesels – now operates in a suboptimal mode using only heat from fossil fuel boilers. At the same time, considerable dissipation heat at the Ecopower thermal power plant is being wasted – assuming a diesel generator efficiency factor of ~ 40 % for the

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154) http://www.powergenworldwide.com/index/display/articledisplay/8319915025/articles/power-engineering-international/volume-18/Issue_5/features/Bonaire_Island_of_green_dreams.html

155) But it is also possible that the general wind speeds in 2010/2011 so far have been far beyond the long-term average. This has been the observation of the operator of the wind park in Vader Piet (Aruba), see **Section 2.14 Aruba**

heavy fuel MAN diesels, the cooling energy dissipated would be about 200,000 MWh. With a typical energy consumption of 23 - 27 kWh/m^3 for a multi-stage flash distillation process, just using half of the cooling energy from the new power plant would allow the production of between 3.7 and 4.3 million m^3 freshwater per year.[156] The current annual water demand in Bonaire is estimated at about 1.2 million m^3 – thus, the cooling energy is more than enough to generated all the water needed.

Figure 2-175:
Temperature of Cooling Water

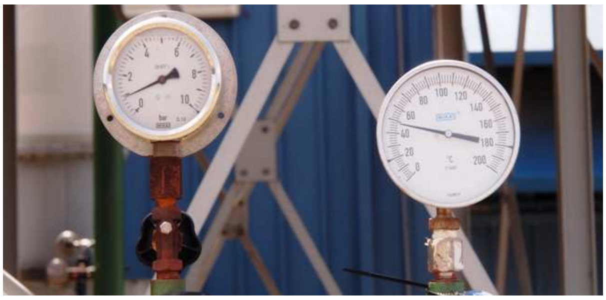


Photo: B. Jargstorf, May 2011

The WEB contact during the visit at Bonaire gave the impression that the new wind/diesel system caused no technical, but some economic problems for WEB. It is estimated that this refers to the considerably higher desalination costs WEB if facing with the operation of its seawater desalination plants without the dissipation energy from the thermal power plant.

Figure 2-176:
Heating Elements in the Fuel Tanks

Photo: B. Jargstorf, May 2011

A smaller energy efficiency issue concerns the preheating of the heavy fuel tanks at the new power plant. Here heating elements of 4 x 65 kW are installed to guarantee a fuel temperature of over 50°C, while simultaneously the cooling water of the diesel generators is sent to the outside radiators of the power plant with the same temperature.

Figure 2-176:
Separate Generation of Electricity and Heat

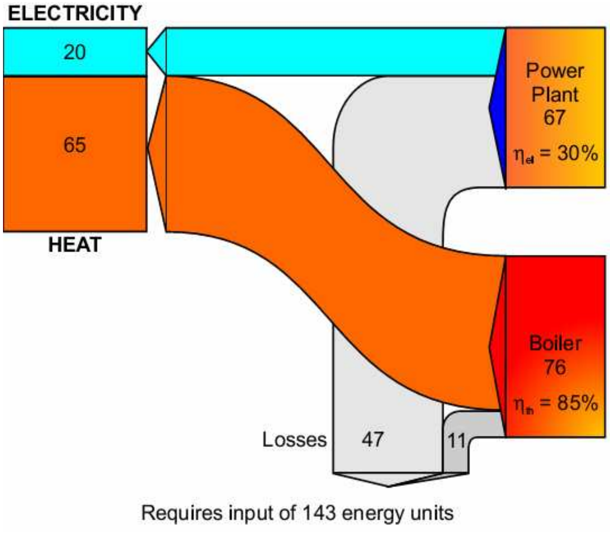
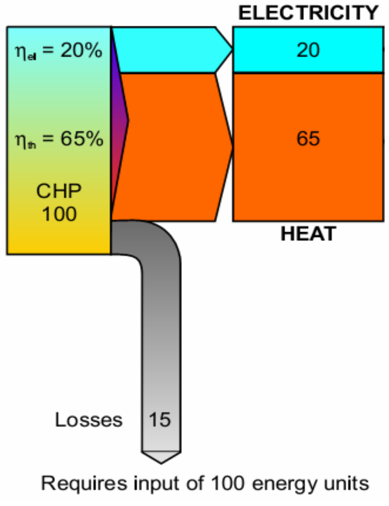


Figure 2-177:
Cogeneration of Electricity and Heat



Source: “COMBINED HEAT AND POWER”, brochure published by the Indo–German Energy Programme IGEN (GTZ), see www.energymanagertraining.com/CHP

Under the assumption that the heating elements are used ~ 25 % of the time, about 0.5 million kWh could be saved per year. This would be the equivalent of ~ 125,000 litres of heavy fuel or, with 20 US$cents per kWh a value of 110,000 USD per year. Therefore, using a heat exchanger and the dissipation heat from the main diesel generators is expected to have a short payback period and increase the overall efficiency of the plant.

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156) see http://www.iags.org/n0813043.htm

When comparing the separate utilization of heat and power with cogeneration one can see that the primary energy efficiency can be increased considerably. The typical efficiency for separate generation is

$$\eta_{separate} = \frac{85}{143} = 59.4\ \%,$$

while the cogeneration increases this value to

$$\eta_{cogeneration} = \frac{85}{100} = 85\ \%.$$

Under consideration of the considerable fossil fuel consumption for seawater desalination in Bonaire it is recommended that ways are found to use the dissipation energy from the new diesel power plant of Ecopower. This would require a new IPP contract and the direct cooperation between WEB and Ecopower.

But the technical complexity of a cogeneration project seems considerably less than that of a bio fuel production facility intended by Ecopower. Even though the location of the new power plant is far away from the coast line, it is proposed that the use of the cooling energy for desalination should have priority before the bio fuel production.

Independently from the energy efficiency issue, there seem to be problems in the interpretation of the IPP contract between Ecopower and WEB. This has led to reduced revenues of Ecopower and a situation, when they could not fully pay their fuel bills. These developments happened during the time of the consultant’s visit and were only discovered during report writing (see **Figure 2-178**). Ecopower has not answered the consultant’s request for comments on this situation.

In spite of this, and in a final analysis, the wind/ diesel system in Bonaire must be regarded as an excellent example of the integration of renewable energy into a new thermal power plant.

It demonstrates that high wind energy penetration rates are possible without reducing power quality and without the need to increase electricity tariffs. As such, it seems a possible way to reduce the dependency on imported fossil fuel and the ever-increasing fuel bills and, consequently, the fuel surcharge on the Caribbean islands.

Figure 2-178:
Bonaire Power System – Current Discussions

WEB fulfils obligation regarding electricity supply

Friday, 06 May 2011 12:49

KRALENDIJK — Through a concession from the Board of Governors of Bonaire, Water and Energy Company Bonaire (WEB) has the right as well as the obligation to supply electricity within the island territory of Bonaire. This concession guarantees the electricity supply on Bonaire, the Dutch Minister of Economic Affairs, Agriculture and Innovation, Maxime Verhagen states, answering questions from GroenLinks Lower Chamber member Ineke van Gent.

After it became known that due to problems surrounding the company Ecopower and the bankruptcy of major shareholder Econcern, there’s the possibility that the energy supply on Bonaire could get into difficulties, Van Gent states, expressing her concern, wanting to know from the Minister what the state of the electricity supply is on Bonaire.

According to Verhagen, due to interpretation differences between WEB and Ecopower regarding the explanation of the agreements between both parties, the revenues of Ecopower are lower than the expenditures. Those expenditures have gone up amongst others due to the increased fuel costs.

“Ecopower has an overdue debt with the fuel supplier and the latter ceased the fuel supply several times during the past weeks. The conversations between WEB and Ecopower are a civil affair, in which the government does not have any formal position at all. Ecopower, WEB, the curator and the financer are now seeking a structural solution for the current situation. WEB has a supply obligation and has demonstrated they want and can fulfill such,” says Verhagen.

“I trust the parties in question will assume their responsibility with regard to the supply guarantee and prevent any stoppage of supply. I am currently considering if and how a regulating framework can be drawn up.”

Price

Van Gent also wants to know how high the risk is that due to the financial problems of Ecopower, the electricity price will rise on Bonaire instead of the intended decrease. Verhagen states that the solution of the conflict between the parties will be of influence on the tariffs. “In principle, the new wind/diesel installation of Ecopower can supply 40-50 percent wind energy, which is also a cost advantage because wind energy saves on (expensive) fuel costs (oil). Wind energy on Bonaire is practically profitable, on the one hand because there’s a constant wind, on the other hand because the costs for supply of fossil fuel are relatively high on an island. For that matter, a contribution of 40-50 percent in the total electricity production on Bonaire appears to be the maximum in connection with maintaining the balance of the electricity net. Finally, the new diesel generator produces more efficiently than the old (temporary) installation, which was installed after the fire in 2005 on Bonaire.”

Source: http://www.amigoe.com/index.php?option=com_content&view=article&id=7080%3Aweb-fulfils-obligation-regarding-electricity-supply&Itemid=136

3. Summary

3.1 General Observations

3.1.1 Geographic Particularities

This evaluation of wind energy projects in the Caribbean covered 12 projects in 11 CARICOM countries, which were visited by CREDP's consultant in February 2011. In addition, three islands from the former Netherlands Antilles – Curaçao, Aruba and Bonaire – have been included in the evaluation.

In general, the results are not encouraging: in consideration of the extremely high generation costs from (typically) diesel generators in the Caribbean region and the proven excellent wind resources of the region, progress with wind energy based electricity generation has been slow during the past 7 years.

On a first glance, the principal reasons for this retarded development seems to lie in the high competition for the space needed for wind parks – mainly from actual or expected tourist development projects.

In fact, existing projects presented in this round-up – especially Nevis and Bonaire – seem to be on islands with a less-than-average pressure on land resources. But then, Aruba and Curaçao – two countries with considerable wind energy development – feature considerably above-average population densities, in the case of Aruba more than twice the average value of all evaluated countries (see **Figure 3-1**)

Thus, a closer look at the population densities, does not fully support the 'lack of land'-explanation. Obviously, just dividing the population by the available land area is not automatically an indication of the amount of potential area for wind development. This becomes clear in the case of Dominica, which has one of the lowest population densities in the Caribbean – but poses, due to its topography, at the same time extreme problems for wind park site selection.

However, when looking at other countries – such as the leading wind energy countries Denmark and Germany, a relatively high population density is not necessarily an obstacle to wind development – there exists no simple correlation between the population density and wind development.

Figure 3-1:
Population Density of Selected Countries[157]

Country	**Persons/km^2**
Barbados	603
Aruba	**554**
Curaçao	**446**
Saint Vincent	354
Grenada	285
Saint Lucia	252
Jamaica	**245**
Netherlands Antilles	216
Trinidad and Tobago	215
Saint Kitts and Nevis	159
Antigua and Barbuda	146
Nevis	**124**
Dominica	87
Bonaire	**46**
Average	**267**
for comparison	
Germany	235
Denmark	126
United States	30
World	14
but also:	
Bangladesh	949
Hong Kong	6,571

For example, assuming the same relative wind installation for Jamaica per inhabitant as in Germany (0.32 kW), we could expect 890 MW wind installa-

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157) http://www.photius.com/wfb1999/rankings/population_density_0.html

tion in Jamaica. In the same way, transferring Germany's installed wind capacity per km^2 (73 kW) to the land area of Jamaica, one would get 800 MW installed wind capacity in Jamaica.

With currently 42 MW installed, this would mean a long way to go for Jamaica. Please note, that 800 MW wind capacity in Jamaica, with a capacity factor of 30 %, would produce 2,100 GWh of electricity or about 1/3 of Jamaica's current demand of 6,300 GWh. Conversely, in Germany, the current wind installation gives just 12 % of electricity demand, on account of the higher per capita electricity consumption and the lower wind resources in Germany (average capacity factor ~ 22 %).

Therefore, not only with regard to the much better wind resource, but also with regard to the specifically lower electricity consumption an accelerated wind development in Jamaica has a much more positive effect on overall sustainable development than in Germany.[158]

3.1.2 Political/Economical Issues

But geographical and statistical observations do not seem to help very much when evaluating the different pace in wind development in the region. Also a discrimination between public and private developers does no show a clear picture, which ownership relation is better for wind energy development. Whereas we have a private developer in Nevis and two on the Netherlands Antilles, the two wind parks in Jamaica have been developed by public companies.

The most important constraint to wind development in the Caribbean seems to be the combination of (a lack of) energy policy and the existing electricity supply acts which guarantee the utilities a rate of return on investment. Or, in other words, the fuel surcharge, which caused the region to produce some of the highest electricity tariffs in the world.

Combined with the dependency on tourist development (the tourists often don't care to pay higher electricity rates – its only for a few weeks per year anyway) the fuel surcharge has created the paradoxical situation, that the utilities are not really interested in electricity supply alternatives – even though they know by now that these are less expensive than diesel.

There should not be the smallest doubt about the economics of wind power in the Caribbean: with excellent wind conditions (= capacity factors between 30 and 50 %), extremely high generation costs and one of the highest retail prices for electricity in the world, introduction wind energy to the grid is an economical favourable venture, which also reduces the dependency from imported fuel. As a rule of thumb, even under consideration of above-average investment costs for smaller projects (transportation, crane costs) a kWh from wind is cheaper than from a diesel generator with oil prices higher than ~ 70 USD per barrel.[159]

Under this favourable economic situation for wind power other reasons must be hold responsible for the lack of wind energy development in the region. One is definitely the aversion of utilities to non-dispatchable forms of energy. However, given the extremely stable trade wind conditions in the Caribbean (in some areas with a Weibull k-factor of 5.0) guarantees a much smoother power output than elsewhere in the world. This could be a felt problem for the utilities – but it is not a real problem.

A more important constraint to wind energy development seems to be the energy policy in many countries of the Caribbean, in particular the fuel-surcharge. The introduction of the fuel surcharge has created a situation, in which the utilities do not need to really look for cheaper alternatives to diesel-based electricity generation: They are getting their revenues independently of the oil price anyhow. With other words: knowing that for each kWh the utilities themselves generate from a non-fossil energy source they will not receive the fuel surcharge (which is, at times, several times the base rate) utilities have no economic stimulus to do something new, i.e. wind instead of diesel. The same holds true for the introduction of energy efficiency measures, which would directly reduce the revenue of the utilities.

As a consequence, utilities seem to expect the same "revenue safety net" for wind energy as for diesel power generation – and this, of course, is politically out of question.

Everywhere in the world, utilities are conservative in thinking – and this is generally a good thing, as this guarantees a safety of supply, always enough spinning reserve and an overall preparedness to quickly do repair in case of line faults etc.

Here in the Caribbean, however, the 'conservative thinking' of utilities – combined with the guaran-

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158) in any case, it is not recommended for Jamaica to opt for nuclear energy, as obviously Mr. Zia Mian, director general of the Office of Utilities Regulation (OUR) did in an Article from December 2010, see http://jamaica-gleaner.com/gleaner/20101226/focus/focus2.html

159) see **Section 2.9 Saint Vincent**

teed revenue they get for fossil-based electricity generation – has created a barrier for innovation, for the use of renewable energies and for energy efficiency measures. At the same time, when elsewhere in the world wind power and other RE power installations are growing much faster than conventional ones, the Caribbean still installs predominantly new diesel generators.

For example, in 2009, the installation of new wind power capacity in the EU outstripped any other electricity-generating technology. According to figures published by the European Wind Energy Association (EWEA) in February 2010, 39 % of all new capacity installed in 2009 was wind power, followed by gas (26 %) and solar photovoltaic (16 %). In the same period, Europe decommissioned more coal and nuclear capacity than new capacity came on-grid. Taken together, renewable energy technologies accounted for 61 % of new power generating capacity installed in 2009 (up from 43 % in 2008). [160]

With oil prices of more than 100 US$ per barrel and no imaginable scenario that they will fall in the long run, it is absolutely clear that, the higher the wind energy penetration in a diesel-driven grid, the lower the average specific energy cost will be.

Thus, it should not only be a medium or long-term target for the countries in the Caribbean to introduce wind energy, but part of an immediate action plan instead, with high priority right now.[161]

Figure 3-2:
Oil Price per Barrel (Brent Oil Spot)[162]

The cases of the Netherlands Antilles - might teach us that a combination of a clear political will with a suitable technical concept can achieve a considerable RE penetration in an island's grid, in a relatively short period of time.

Therefore, the major barrier to wind energy development is the wrong economic signal given to the utilities through electricity supply acts and the fuel surcharge. In effect, this disconnects the utilities' revenue from the generation costs and does not provide an incentive to go for new forms of electricity generation, for which they have no previous experiences.

As the keeping of electricity supply acts is a political decision, the unsatisfactory pace of wind energy development in the Caribbean must be attributed, in a final analysis, to a failure of the (energy) politics in the Caribbean.

Obviously it is not the lack of technical expertise or knowledge, which is very often cited in the literature as a major constraint for the development of renewable energies. This evaluation has extensively documented all the consultancy CREDP has given to the interested utilities, But not a single "client" of CREDP has managed to come closer to the realization of an intended wind park, during the past six years of project execution.

In particular, the Wigton Windfarm in Jamaica was planned and commissioned before CREDP started, and both the Nevis wind park and the Munro wind park were implemented without any technical input from CREDP. Also the project on Barbados which seems close to realization, has been planned exclusively with technical support from (private) consultants.

For a political scientist this would only prove the primacy of politics over technical issues, but for the development expert the result of this evaluation must be a disappointment.

In a final analysis, one has to ask the question, whether the principles of "good governance" are not infringed upon through the current political practice of keeping electricity supply acts,[163] known to not only hinder the development of renewable energies but also being a constraint to energy efficiency. After all: the more kWh are produced from diesel oil, the higher the fuel surcharge – why should one reduce production?

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160) European Wind Energy Association EWEA 04.02.2010, see http://co2-handel.de/article340_13606.html

161) this argument, naturally, goes also for hydro or solar and for energy efficiency, for that matter

162) http://boersen.manager-magazin.de/, accessed 06-04-11

163) some countries, however, are currently re-negotiating their electricity supply acts and entering new paths in energy politics – f.i. Dominica

3.1.3 Technical Issues

The successful integration of wind power into (small) isolated electric networks constitutes quite a different task than standard grid-parallel operation.

Figure 3-3:
Variation of Power Factor (AC-DC-AC)

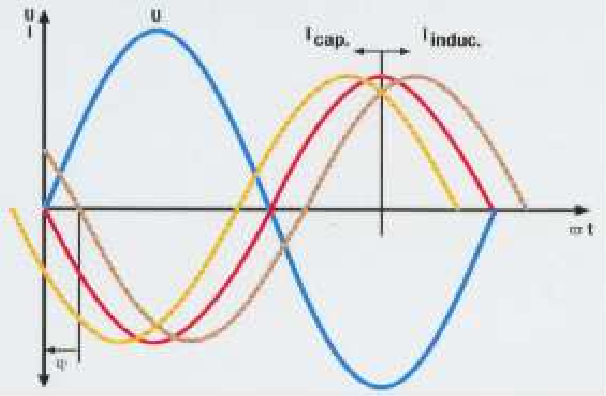
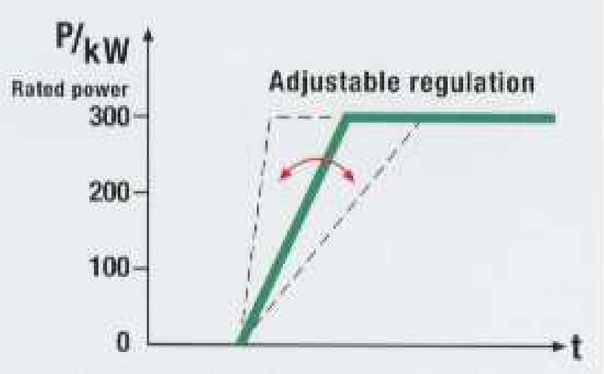


Figure 3-4:
Adjustable Power Gradient



Source: Company brochure Enercon

Connecting wind turbines to the distribution grid requires a careful analysis, to avoid negative influences on grid stability. Modern wind turbines with variable speed operation and an indirectly grid coupling through AC-DC-AC links offer considerable advantages over directly coupled fixed speed systems. To ensure grid stability, the dynamic power factor variation of modern AC-DC-AC systems can be utilized and allow quite higher wind power installations than would be possible with directly coupled induction generators (**Figure 3-3**).

Pitch-controlled turbines are a pre-requisite for projects in the Caribbean – now, new software features, like power limitations for the complete wind park (instead of individual turbines) are an important improvement for high-penetration operation.

Also, indirectly coupled wind turbines with pitch control allow the variation of the power gradient[164] in a way, as to allow the diesel generator more time to react. Thus, in case of a sudden increase of wind power, the output power increase of the wind turbine is retarded (**Figure 3-4**). In doing so, output fluctuations of the wind park are reduced and operation of the diesel generators are improved.

3.2 Special Observations

3.2.1 Existing Projects

The existing projects fall into two categories: in Jamaica we have public project sponsors and in Nevis a private project sponsor of a local company, being majority-owned by an overseas investor.

The privately owned project in Nevis is an absolutely untypical wind energy project in that only a fraction of the installed power has a guarantee to be fed into the grid. Also it seems that the investor had no particular practical experience with the special situation of electricity generation and distribution in a small island grid. In the same way, most likely, he relied too much on advice from the wind turbine manufacturer, especially with regard to the micro-siting of the turbines.

The two wind parks by public project sponsors in Jamaica are not plagued by similar problems as the project in Nevis. The 39 MW wind park of Wigton Windfarm Ltd. has been a very successful project from the start. One might say, it was so successful that it brought the public utility Jamaica Public Service Company to start their own wind park.

But also the Munro wind park must be regarded as a success (even with the current transformer problems) as its implementation time has been extremely short and as it stayed well within the budget. However, all three projects only save a few percent of fossil fuel consumptions – as such, their success in terms of sustainability of electricity generation is only limited.

This seems to be different for the wind energy project on Bonaire, where currently more than 30 % fuel savings are achieved and more than 40 is targeted. The private project sponsor announced a reduction of end user tariff between 10 to 20 %, should the project come on-line. This reduction has not been introduced, but an oil price increase of 50 % when compared to the project planning has not lead to an increase of the fuel surcharge. Thus,

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164) also called Ramp Rate, see **Section 2.14.3 Vestas V90 – Technical Features**

the high wind penetration has indeed caused a reduction of the end-user tariffs.[165]

Considering that many Caribbean countries are in the process of, or already have decided upon National Energy Plans (NEP) and/or sustainable energy strategies or similar, the things that actual happen in the working area of its utilities are un utter disappointment.

One does not need to process prophetic properties to predict that none of the RE targets will be met – not the currently discussed 20 % of all domestic energy use in Grenada by 2020[166] and not the 30 % RE, originally planned in St. Lucia for 2010.

In practice, it seems, that it does not make much of a difference to have such National Energy Plans or not – the RE politics of countries with ratified NEPs does not seem to differ substantially from countries without.

3.2.2 Planned Projects

The wind park Lamberts in Barbados has received a building permission and seems close to implementation. Even though the land owners ask for high leasing fees, the utility seems to be ready and in a position to pay it.

While a prognosis for some islands is difficult on account of lack of concrete decisions of the concerned utilities (St. Lucia, St. Vincent), other islands (Grenada) treated their information confidential and did not reveal them. Judging from this evaluation of 11 CARICOM countries, however, it does not seem likely that a wind park will come online any time soon in the Caribbean.

This situation is obviously different for the former Netherlands Antilles, where two projects with 15 MW each are planned to come on-grid next year in Curaçao. Also Jamaica plans two new projects.

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165) see http://amigoe.com/index.php?option=com_content&view=article&id=7385:energieprijzen-stabiel-door-windenergie&catid=109:artikelen-antillen&Itemid=201 and http://www.amigoe.com/index.php?option=com_content&view=article&id=7080%3Aweb-fulfils-obligation-regarding-electricity-supply&Itemid=136

166) The DRAFT National Energy Policy of Grenada, A Low Carbon Development Strategy For Grenada, Carriacou and Petite Martinique, August 2010

Annexes

Annex 1: CAWEI Tender Documents - Instruction to Tenderers / CAWEI Flyer

Annex 2: Summary of Results – Jamaica, February 2008

Annex 3: Summary of Results – Antigua and Barbuda, April 2010

Annex 4: **“**Navigating the Murky Waters of ‘Clean Energy’” – Antigua Sun, 13th of April 2010

Annex 5: Wind Energy in Suriname – Presentation from 16th of February 2011

Annex 6: Draft Request for Proposal, MEEA - February 2011

Annex 7: Building Permission Lamberts Wind Park, Barbados, December 2010

Annex 8: Summaries of Results – Grenada, March and October 2007

Annex 9: Summary of Results – Dominica, June 2006

Annex 10: VINLEC – Development of Ribishi Point Wind Park, St. Vincent (6MW-8MW) Request for Proposal, December 2008

Annex 11: Summary of Results – Nevis, June 2006

Annex 12: To IPP or not to IPP – Options for the Organizational Structure of Wind Park Operation in (small) Island Grids

Annex 13: Summary of Results – St. Kitts, July 2006

Annex 14: North Star Development Article – 29th October 2010 www.rechargenews.com

Annex 15: Hurricanes in the Caribbean

Annex 16: Summary of Results – St. Lucia, August 2005