Barbuda; A renewable resource Assessment

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Abstract

Barbuda is a small island in the Caribbean. Like most tropical islands the consistent trade winds, constant equatorial currents and plentiful sunshine provide a wealth of renewable energy potential.

At present the island relies on a poorly maintained diesel generator, provided by neighbouring Antigua Power and Utilities Authority, for an unreliable and expensive electricity service that suffers from inadequate power to cope with peak demand and frequent unscheduled stoppages.

This project assesses the renewable energy resources of the island and proposes a combination of renewable energy technologies to enable the island to install an autonomous power generating system of sufficient capacity to provide energy services to cater for the present need, and to be expandable for future developments.

The historical and political situation leading to Barbuda's independence from Britain and its relationship with the governing island of Antigua is discussed as this issue is fundamental to future decision making processes.

Acknowledgements

Mackenzie Frank, Secretary to the Council of Barbuda, and Claire Frank provided support and communication throughout the project. Keithly Meade of the Antigua Meteorological station provided unlimited access to his stations weather resources. Enercon UK for practical, experienced wind turbine advice. Malcolm Cook of IESD for continual advice and more time than could be expected. Catherine Bicknell without whom the project could not have started.

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1 Introduction

1.1 Barbuda; a renewable energy assessment

Barbuda is a small tropical island in the Caribbean Sea with a population of 1,500. The secretary to the Council of Barbuda, Mr. Mackenzie Frank, approached The Institute of Energy at DeMontfort University, Leicester, early in 2001. His discussions with Professor Fleming of the institute led to the proposal for a renewable energy assessment of the island to be undertaken by a MSc. student.

The motivation for the council to look at alternative electricity generating methods was twofold. Firstly, continual power cuts and secondly overpriced utilities, provided by APUA (Antigua Public Utilities Authority). As an ex student of De Montfort, Mr. Frank was aware of the potential of renewable energy and was keen to promote this as a possible solution. The ability to use the islands natural resources to generate electricity would enable the money paid currently for an inefficient and overpriced utility to be redirected to repay the loan necessary to install renewable technology.

Barbuda, in common with most tropical islands, has an abundance of natural renewable energy resources. They support a relatively small community with low individual power requirements, although these are increasing all the time. A combination of constant trade winds, plentiful sunshine, energy crops and continual oceanic currents provides a rich source of energy. Since there is no requirement for space heating, the by-product of traditional fuel burning generators, heat, cannot be used as in modern cogeneration plants.

1.2 Aims and objectives

The aim of this research therefore, is to provide an outline plan for introducing renewable energy technologies for the council of Barbuda with a view to assuming control and responsibility for their own domestic power supply.

The objectives of this research are:

- To establish the current and future energy demands of the island
- To assess the renewable energy resources of the island
- To propose a combination of renewable energy generating methods to supply sufficient power for the islands present needs.
- To propose a plan to increase the renewable generating capacity as the island develops in the future.

1.3 Methodology

Time and financial constraints allowed only a three-week visit to the island to obtain sufficient data to put together this assessment. With this in mind it was decided to concentrate on establishing firstly the islands energy requirement and secondly the most likely renewable resource to benefit the inhabitants.

The existing energy requirement was determined by a combination of survey data results, manual counting, and accessing available invoices and billing paperwork. The results were entered into a series of spreadsheets and analysed. A relatively accurate picture of electrical loads and times has been built up.

Assessment of available renewable resources was made by concentrating on the four most prolific available sources: wind, solar, biomass and hydroelectric. Background research prior to arrival and data gathered during the field trip, led to the conclusion that wind power would provide the most practicable, renewable energy source of these four.

1.4 Conclusions and recommendations

This research document therefore concentrates primarily on the case for installing a wind driven power system, whilst giving an outline to the benefits to be derived from solar, biomass and hydro technologies.

Wind energy has the advantages of rapid construction times, tried and proven technology and accurate financial predictions. In addition, turbines can be added in a modular manner allowing the quantity of generated energy to be increased and financed over time.

Solar energy does not coincide with peak electricity usage times, resulting in high energy storage costs, high initial investment and long payback periods. Hydroelectric energy does look extremely promising, but is a relatively "experimental" technology at this level and would be considered a poor financial risk by most financiers. Biomass as an option, still has great potential and in the future could provide a perfect back up/top up reserve but at present suffers from a combination of being a relatively new technology and requiring several years development of a harvesting strategy.

The technological problems of renewable energy resources have largely been overcome. Engineers are now familiar with extracting electrical energy from these four renewable resources in ever more efficient ways. In the majority of tropical islands, an abundance of these resources are available. Financially, savings in fuel can repay this technology over a relatively short period. The major problem is in breaking down the political and organizational barriers to implementing this beneficial change.

1.5 Layout of report

Chapter 2 of this report discusses the methodology used describing techniques and limitations of the research. Chapter 3 is an outline sketch to Barbuda's geographical, temporal, historical and political characteristics. Chapter 4 focuses on existing energy production and current energy demands with methods of reducing current energy demand included at the end of the chapter.

Chapter 5 summarises wind, solar, hydro and biomass potential on the island concluding that wind power is the most viable renewable resource at present. Chapter 6 then looks closely at the power available in the wind and the problems faced by wind turbines in a tropical climate. Chapter 7 takes into account difficulties experienced in communication, isolated dwellings and funding.

Conclusions and recommendations are drawn in chapter 8.

Chapter 10 contains an appendix of useful maps, charts and tables referred to throughout the text.

2 Methodology

This renewable energy assessment is broken into two broad categories. The first is an accurate quantitative assessment of the **energy used** on the island; the second an assessment of the most suitable **renewable energy type** available.

2.1 Data collection

2.1.1 Energy used

Energy used on Barbuda has to be broken down to hourly data so that peak times and loads can be established. It is not sufficient to simply gather monthly electricity bills and calculate the number of watts used per month since the power available in any renewable energy source varies over time within its natural cycles.

Options available for doing this, range between obtaining individual electricity bills for each building for the past year, individually counting every appliance in every household and applying estimated times of usage and conducting a survey amongst the local population to arrive at a reliable average.

2.1.2 Renewable energy available

Four types of renewable energy were considered, wind, solar, biomass and hydro with the power available from each outlined and the most favorable to be researched in greater depth. The most favorable energy type would be the renewable energy resource that could provide sufficient power to meet the present and future needs of Barbuda at least cost and constructed in the shortest time.

2.2 Rationale for choosing method

A combination of survey, hand counting/observation and invoice examination was decided upon. The APUA was not helpful in providing access to itemised bills, the reasons for which are discussed in *chapter 4.1*. The average household did not keep copies of its bills for longer than a month or two, and to manually enter this amount of information onto a spreadsheet would have created extensive work in a limited time. However access was available to two years of unopened bills from the Barbuda council for all of the buildings operated through the council's resources. For the majority of data, a simple domestic survey was completed in part by distribution through the local school and from the same surveys completed by house calls. Case studies survey results are shown in *chapter 4.5* with example surveys in *appendix 12*.

2.3 Techniques used

2.3.1 Energy used

Council buildings invoices: The council offices had bills from each of its buildings for the past two years. Details from these invoices were entered into a spreadsheet and quantity of electricity used averaged out over the councils working hours 8-4 Monday to Friday.

Surveys: A simple survey was compiled (*appendix12*). The objective of the survey was to establish both the living habits of the population and the number and type of electrical appliances used.

The survey was completed in three ways:

- A number of surveys were distributed amongst pupils of the local school following a short lesson describing the purpose behind the research and the effects of fossil fuels on the atmosphere plus the impacts of global warming on a small island.
- Interviewing people in and around the town provided a quick though less accurate method for completing the questionnaire. The advantage over accuracy was the ability to gather a "feel" for the lifestyle and living patterns of the local population. In addition, helpful comments emerged regarding thoughts about existing power supply and attitudes to possible future changes.
- A series of case studies on individual buildings revealed several important pieces of information. These were the most accurate surveys completed and gave indications as to the accuracy of the school survey and the interviewed survey. Power ratings of individual appliances were noted and these gave accurate figures to general appliances when entering values into consumption calculations. Old electricity bills were examined and estimates of monthly charges verified.

There were various elements to the islands electricity consumption that were simply not accounted for, so in the case of street lights and runway lights these were simply hand counted and multiplied by the number and wattage of bulbs used.

2.3.2 Renewable Energy Available

Quantifying the total renewable energy available to the island would require more time and resources than were available for a short field trip. It was decided to gather an overall impression of possible sources (wind, solar, biomass and hydro), identify key areas of the island with renewable potential and to quantify these in small manageable areas.

Exploration of the island was made by Jeep, bicycle and on foot to gain a better understanding of the local geography. Admiralty Charts provided accurate geographical features, hills, currents, reef shapes and depths. Pilot books gave details of unusual currents, wind anomalies and acceleration zones.

Weather data was collected from the meteorological station based at Antigua's international airport; Web based weather data programs, local books and travel guides.
Tidal charts gave heights and times of tidal changes directions and speeds of current. Diving on particular locations to measure depths and use improvised water flow measuring devices authenticated some of these figures.

Interviews with fishermen and farmers gave interesting background and clues to windiest sites, strongest currents, and best agricultural areas.

Local access to books, papers, articles, court cases and previous surveys plus information gathered from the University of Antigua all helped build up a picture of renewable sources available and some of the problems to be encountered in delivering them.

2.4 Limitations of research

2.4.1 Energy used

The quantity and time of energy usage changes every hour and every day, therefore at best the results of the survey can only be a mean over time. Here the "case studies" on individual buildings were quite accurate but limited in number, the "school surveys" less accurate with some information missing and the “interviewed surveys” less accurate still but being greater in quantity gave a better impression of times and trends.

Accuracy of meter readings both in terms of the meters themselves being accurately adjusted and figures being recorded properly is not verifiable. The information only provides monthly figures, and in calculations made in *chapter 4.4,* have been averaged out to give hourly rates.

2.4.2 Renewable energy available

Wind: Whilst the hourly wind data available is to the highest standard, local factors such as heights above sea level, effect of terrain, hills, wind sheer, surface roughness and barometric air pressure need to be taken into account. This requires the sighting and monitoring of individual anemometers for periods of a year or more.

Hydro: Tides and currents can be predicted with great accuracy infinitely into the future. Variations with the wind effect on current can be predicted with information available from reliable weather data sources. The effects of local geography that increase water speed through a venturi effect need closer and more detailed examination.

Biomass: Whilst it is possible to produce records showing the past success of plantation growth, and quantify the area available for cultivation, a further survey by qualified soil experts would be necessary to confirm the islands ability to produce sufficient energy crops to provide fuel for a biomass generator.

Solar: Accurate data is available as to daylight hours, average cloud cover and the angle of the sun’s path through the sky. It is therefore possible to calculate quite exactly the quantity of energy available from this source.

3 Barbuda an outline sketch

In order to complete a renewable assessment of a particular location it is essential to include the attitudes and beliefs of the indigenous population. Without including these a lot of time and money can be spent analysing the geography and climate of a site to find that whilst the location would be ideal to provide a renewable energy source, the practicalities in overcoming local political conditions are impossible.

In order to understand the current political situation within Barbuda a brief outline of the geographical and historical background to the island is included, as these are both essential to understanding the complex land assignment issues that directly effect any future plans to provide energy, and indeed any further construction work.

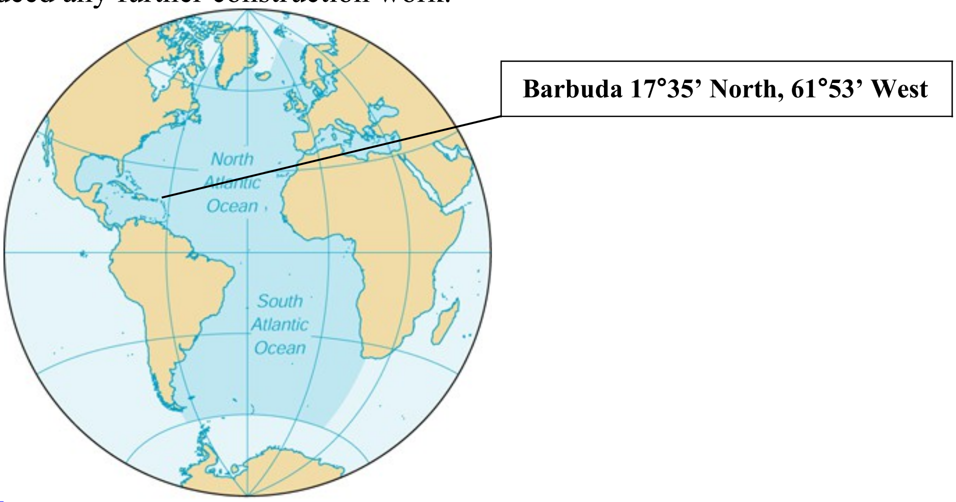


Figure 1 Atlantic Ocean & Barbuda (COL, 2002)

These outlines of Barbuda draw reference from a wide source of reading found variously in libraries (London and Antigua), the art café in Barbuda, Internet sites and travel guides including: Caribline, 2002; CIA, 2002; Commonwealth Secretariat, 2000; Coram.R 1989; Court of Justice. 2001; Court of appeal, 2001; Craton 1978 Lowenthal,D and C.G.Clarke C.G, 1977; Mather,J 1971; Vaitlingham.A 1995. Watters, D 1980. Marine charts and pilot books give detailed heights depths wind acceleration zones and currents. (Cunliffe. T, 1989; Imray-Lolaire 2002; Norie,J. 1836; Reed, 1999; Street 1998).

3.1 Geographical outline

Barbuda lies 25 miles north of Antigua (latitude17°35'North, longitude 61°53West) in the leeward islands of the West Indies (*figure2*), a chain of islands that separate the Caribbean Sea from the Atlantic Ocean. (Imray-lolaire, 2002)

Figure 2 Antigua and Barbuda (CIA, 2002)

The population of 1,500 live in Codrington, the only village on the island, situated on the east side of the lagoon. The only industry is fishing, on a small scale, and the three hotels that open six months of the year on the southwest beach.

The major part of the islands interior is scrubland existing on shallow boulder strewn rock. It has not been conscientiously cultivated since the mid 1800's and the emancipation of slaves (Craton, M 1978). To the northwest a large lagoon provides calm waters and abundant local lobster fishing and is home to a rare colony of frigate birds. A shallow creek provides access to the Caribbean Sea at the very north of the lagoon.

A detailed map of Barbuda is shown in *Appendix 10.1*.

3.2 Historical outline

First sighted in 1493 by Columbus, the islands were inhabited by nomadic Arawak and Carib Indians prior to the first settlements in the seventeenth century. Recorded history of Barbuda started in 1632 (Commonwealth Secretariat, 2000) when the English, who imported African slaves to the island to grow tobacco, and then sugar, colonized Antigua. From the mid 18^{th} century to mid 19^{th} century Antigua also served as a major naval dockyard for the British fleet in the eastern Caribbean. In 1685 until 1898 the crown leased the island of Barbuda to the Codrington family (Edwards, B 1966).

It is widely believed that the Codrington family used the island as a stock farm for its sugar plantations on Antigua, the slaves enjoyed a far easier life on Barbuda raising cattle and goats than their counterparts further south (D.Lowenthal, 1977). Maps of the island drawn in the mid 1700's show a civilized network of houses, fortresses and cultivation connected by a road system (*appendix 10.3*).

There are remains today of the Codrington's "highland house", a castle on Castle Hill Bay and some of the original walls still exist in Codrington the village. A semi- reformed fortress now known as the Martello tower is open to visits near the commercial jetty.

A plantation existed in the middle of the island, with cattle watering pens located at numerous points around the island. Some time later North South division of the island was created where a fence was incorporated across the island to separate livestock from vegetation. This point becomes crucial in the ongoing battle with Antigua for the assignation of property rights between the two islands.

In 1858 the Antiguan legislature allowed the British monarch to declare that the island of Barbuda be made a dependency of Antigua, and beginning 1871 Antigua and its dependency Barbuda were administered as part of the colony of the Leeward isles. In 1956 they were included in the federation established under the “British Caribbean Federation Act”. The federation was soon dissolved and Antigua became an “associated state” under the West Indies act of 1966, this act allowed the state to terminate its association at any time and by 1976 agreed that they would seek independence (Court of Appeal, 2001).

It is generally agreed by the people of Barbuda that they had not agreed to dis-association at this time, and so, when independence was given to Antigua and Barbuda in 1981, the Barbudan people had not readily agreed to become an integral part of the now independent state.

3.3 Political outline and the “land issue”

The relevance of the historical background to the history of the island is integral to the legal claim of land within the islands shores. It is a complicated issue, which has been in and out of court between London, capitals throughout the Leeward island chain and subject to an impartial commonwealth review under an Australian judge during the course of the last sixteen years.

To summarise the situation, the Antiguan government believe that they have governance over the island since they were granted independence in 1981 as Antigua and Barbuda. The democratically elected government feel, therefore that they are entitled to use the islands natural resources as it sees fit in terms of governing Antigua and Barbuda.

This immediately gives rise to the issue of property rights. The Barbudan’s have historically self governed themselves and their land in a cooperative manner, they did not wish to be granted independence under the governance of Antigua and do not wish to divulge property to that administration.

For the purposes of the land issue in relation to the installation of renewable energy it is sufficient to summarise that as long as the council of Barbuda wishes to introduce a new building or construction on the island, and it is financially able to do so then there will be little in the way of obstruction within the shores of Barbuda. If on the other hand the Antiguans wish to construct something it will inevitably be torn down and its components dumped in the sea. This has happened on several occasions including a hotel project on Spanish point and a desalination plant next to the lagoon in Codrington.

An obstacle that does exist is the Antiguan insistence that Barbuda does not have a port of entry. All shipping and goods must be cleared by customs at Antigua. Releasing goods from Antigua is subject to an almost arbitrary level of duty. Therefore if the Antiguan government wishes to stop a project on Barbuda it can simply make the level of duty on the materials necessary exorbitantly expensive. This makes budgeting an engineering exercise very nearly impossible.
To secure a financial contract, engage an engineering company and ship components to Barbuda would require the total agreement in principle and practice of both parties. At present rate of progress this settlement is some years away.

3.4 Weather patterns

Barbuda has a typical tropical climate, hot and sunny all year with a constant trade wind with an annual average wind speed of 6.4m/s (NASA 2002). Annual average temperature is 25.4°C. *Figure 3* shows a compilation of annual averages taken between1960 and 1995 (full details *appendix10.5*).

BARBUDA: SUMMARISED CLIMATOLOGICAL DATA													
Particulars		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
Normal Daily Temp.	°C	25.5	25.2	25.8	26.8	26.8	27.8	27.9	27.7	27.4	27.4	26.3	25.7
Avg. Monthly Rainfall	mm	56.9	37.6	46.7	67.6	112.5	49.5	86.6	100.6	140.5	130.8	134.9	87.4
1960 - 1995	mm	20.1	9.9	14.5	12.2	5.8	5.8	14.2	24.1	27.7	12.4	22.6	12.2
Avg. Relative Humidity	%	81	81	81	81	82	82	83	83	84	85	85	83
wind speed	KNOTS	12.8	12.4	12.1	11.9	12.0	13.4	14.2	13.0	10.8	9.6	10.5	11.7
Prevailing Wind Direction	DEGS.	090°	090°	090°	100°	110°	100°	090°	090°	090°	100°	090°	090°
Cloud cover	Tenths	3.7	4.1	4	4.5	5.1	4.9	4.5	4.6	4.8	4.9	4.4	4.2
Pressure sea-level	mb	1016	1016	1016	1015	1015	1016	1016	1015	1014	1011	1013	1015

Figure 3 Summarised weather data Barbuda (CWS, 2002)

The idyllic weather pattern can be disrupted during the hurricane season, which lasts from June to November. These cyclonic winds form in the mid Atlantic Ocean just above the equator and increase in power as they weave an unpredictable path up the Caribbean island chain towards the USA. A table of Hurricane frequency and islands affected is shown in *appendix 10.5*.

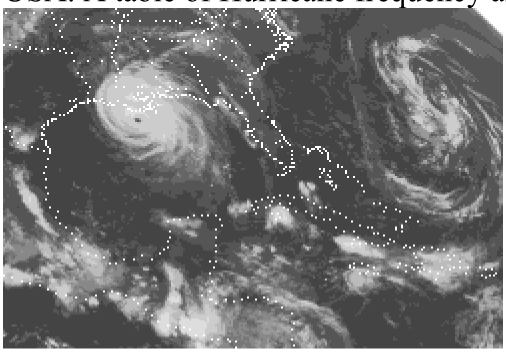


Figure 4 Hurricane Andrew veers west along the Gulf of Mexico (Storm watch, 2002)

Hurricanes generate wind speeds in excess of 150 mph. This is double the destructive wind speed factored into most European wind turbine manufacture (Enercon, 2002). Gusts are powerful enough to pull off roofs and knock down walls. Sea levels can rise by many meters in a short period of time causing flooding.

Barbuda is particularly low-lying and therefore vulnerable to hurricane damage. Any form of renewable energy will have to include in its calculations both protection for the technology and a method to generate power during and immediately after the cyclone.

4 Existing Energy on Barbuda

Electricity on Barbuda is supplied through Antigua Power and Utilities Authority (APUA). This is a government owned company based in Antigua. It is responsible for the generation and distribution of power and water to the village of Codrington.
The first objective of this dissertation is to establish the current and future energy demands of the island. This is achieved through a combination of surveying energy use, examining the existing system and predicting future developments. This enables quantity of energy to be generated by renewable techniques to be established, when it is needed and what it will need to provide in the future.
Chapter 4.8 describes methods that can be used to reduce the amount of electricity used. This would make economic sense to do ***now*** regardless of future energy plans both to reduce individual electricity bills and to ease the peak loading of the generating plant.

4.1 Generating station

The generating station comprises a fenced off area of 150m x 200m enclosing a brick built office and two generating "houses". At present, out of four complete and several incomplete generators within the confines of the station only one is in operation. There are several problems.

Figure 5 The generating station at Codrington

4.1.1 Maintenance.

The existing generating plant is a Caterpillar D0398 generating plant developing 650kVa. Twice a week the generator has to be stopped for essential routine maintenance. A longer more in depth stop is scheduled once a month. In practice these stops are more frequent than twice a week, they are longer than the scheduled 40 minutes, and the community is not advised in advance as to when they will be.

4.1.2 Fuel consumption and cost

Costs are all given in US dollars (US$) based on the fixed exchange rate of 2.7 where information has been sourced in local Eastern Caribbean dollars (EC$). ($US1 = $EC2.7)

At 650kVa the existing generator is just sufficient to cope with the peak demand between 19:00 and 22:00 (*see chapter4.4*). Between these peaks the generator is performing at just 20% capacity for 12 hours per day (*see figure 9*). This leads to excessive fuel consumption and shortens the life of the generator plant.

Operation of a smaller 250kVA generator for non-peak loads would lead to instant fuel savings, combined with a 680kVA plant for peak loads. Fuel and cost savings can be compared on the table below.

Generator	Fuel consumption (gph)		gals/day	gals ($US) per year
Existing 650kVA	18		432	155,520
			Cost	$311,040
New 680kVA	21	(6 hours/day)	126	45,360
				$90,720
New 25kVA	8	(18 hours/day)	144	51,840
				$103,680
			Total fuel	97,200 gals
			Cost	$194,400
Total saving in fuel per year				58,320 gals
Total saving per year				$116,640

Figure 6 Generator Fuel costs and savings (fuel costs @ $US 2 per gallon)

The purchase costs of new, ready to run Generator sets from Caterpillar (Caterpillar, 2002) are:

250kVA	$37,500
680kVA	$82,500
Total	$120,000

There are shipping and installation costs to be added to these basic figures, but clearly the savings in fuel alone would repay the capital cost within two years.

The price that APUA pays for fuel is not known, however (Commonwealth Secretariat, (2000) Agenda item 1.G; *See appendix 8*) it reports a total diesel fuel bill of $879,933EC. This figure agrees with the calculated fuel consumption of this sized generating plant (Caterpillar, 2001), operating 24 hours per day, if fuel costs are $US 2 per gallon.

The Government of Antigua has access to duty free fuel. The duty free, delivered price of diesel is 80 cents per gallon (EIA, 2002). Apart from using 60,000 gallons per year more than necessary APUA is charging the Barbudan's US$186,624 per year in inflated fuel prices. This same practice exists on a much larger scale in Antigua.

In addition to distortion in fuel prices the total annual cost accounted to the people of Antigua and Barbuda comes to US$662,868 (APUA comparative analysis *appendix 8*) This includes items such as uniforms and protective clothing US$5,721: lubricating oil US$9,007 (This equates to 2 complete oil changes per day of 15 gallons each. The manufacturer recommends oil change every 500 hours or 20 days in this case).

Clearly the real cost of providing electricity to the people of Barbuda is much lower than the budget created by APUA. The government "subsidizes" this budget from the tax revenue generated in Antigua. The government publicly declares this subsidy, causing friction between the people of the two islands. The actual distribution of this unseen profit is unknown.

4.1.3 Workload.

Diesel generators should ideally work at 75-90% load (Caterpillar,2002). In this case the 650kVa installation is either working at 100% capacity during the peak period of 7.00pm to 10.00 pm or being under worked in off peak periods at 25% or less. This puts an uneven strain on the system resulting in shortened life, excessive fuel consumption and increased pollution. Whilst it is impossible to calculate the exact shortening in life of a generator by over and under loading, it is clear that in addition to the savings in fuel, if the larger peak load generator works only 6 hours per day instead of 24 its life expectancy will be increased at least fourfold.

4.1.4 Location.

The generating station is located at the edge of the Lagoon in Codrington. The benefits are that it is open to the cooling trade winds and close to the grid system of the village.
The disadvantages being that the noise and smoke from the generators blow through that part of the village. The location is one of the most attractive parts of the village and close enough to the port that the generator can be heard. Being close to the waters edge it is in a flood zone should the tide rise on the back of a hurricane.

It seems that it would make sense in any major redevelopment of the power system to move the site to the leeward side of the village.

4.2 Distribution system

A grid of overhead cables to individual end-users distributes generated electricity. From the generating station it is transformed up to 4,000 volts. Boxes at cable height (*figure 8*) on telegraph poles transform back to either 220volts or 110volts prior to redistribution to individual dwellings. At each building there is a meter before the fuse box. This is of the magnetized disc type and gives digital reading. Calibration and verification of these meters is uncertain (*figure 7*).

The mixture of 110 volts and 220volts at the user end causes some problems and inefficiencies. Equipment such as TVs purchased in Europe are designed to run at 50Hz, 220v and products from the US at 60Hz, 110v. This leads to a considerable number of transformers being installed in buildings to provide the correct voltage. Devices that rely on electronic timers do not work accurately if connected to a supply at the wrong frequency and these transformers permanently consume electricity.

Figure 7 typical electricity meter

Figure 8 local transformer 4,000v-220v

Should the generating station be moved inland away from the village the existing distribution scheme could still be used. Whilst this is a distinct economic advantage in the capital cost of introducing a renewable scheme, there are complicated implications in purchasing the grid from the APUA should the decision be made to create an independent power supply company.

4.3 Billing system

Each building in Codrington is supplied with a meter between the grid and the house. These meters are read monthly, entered into APUA's records and an invoice issued. The disproportionate size of these bills in relation to income is substantial. The average income for an islander is around $1200ec per month ($US440), with an average electricity bill of between $150 ec. This represents 12.5% of income. The international measure for fuel poor families is set at 10% of income, and this includes heating. Given that these families are not even heating their water and rely on far fewer electrical appliances shows the disparity in the billing system.

The Barbudan's are given a "discounted" rate of 50 EC cents (18.5cents US) per unit. (Antiguans pay 65EC cents per unit). The political spin on this arrangement is such that the Antiguan population feel that they are subsidising the Barbudans *see 4.1*.

The reality is that if the generating station was run efficiently then the cost of running it would come down, the price charged could be reduced, the amount of oil burnt could be more than halved, power cuts would be rare, quality of supply increased and the company running it would be in profit.

4.4 Quantity and time of energy used

As discussed in *chapter 3* a survey was carried out in three phases to establish the times and loads of electricity used in Codrington. The results of the survey combined with an analysis of bills made available from the council of Barbuda provided a power usage chart as shown in *figure 9***.**

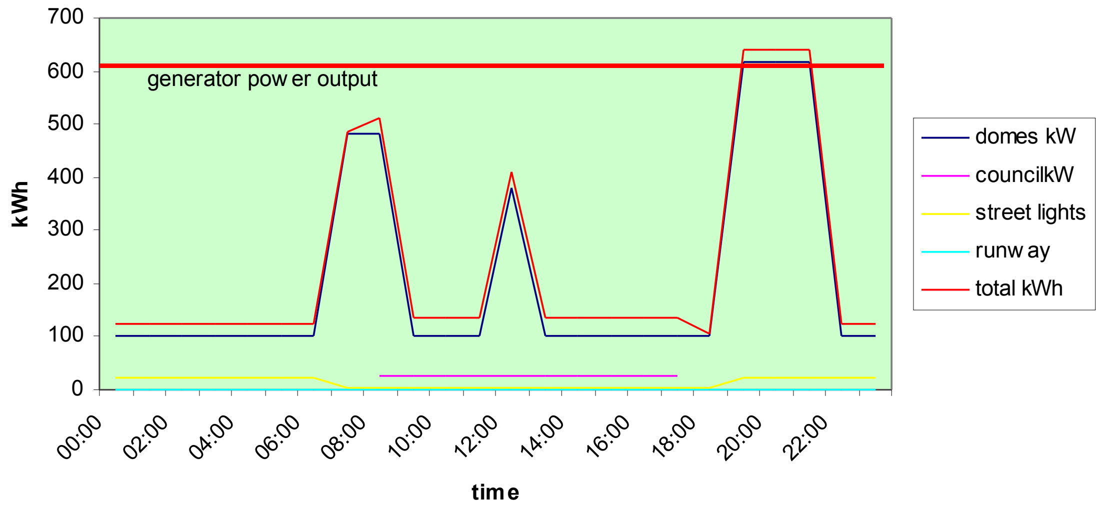


Figure 9 Total energy used in Codrington over 24 hrs

Figure 6 demonstrates that the peak loading is at 100% of the generators capacity (red line) for three hours in the evening, but that outside of that time it is only working at 20% capacity.

The total quantity of energy consumed is 5,627kWh per day.
2,053,855kWh per year.

4.5 Survey Results

A total of 98 surveys were completed from a possible 718 individual dwellings (APUA,2002). 45 surveys were those done individually by students from the Holy Trinity School the remaining 53 were completed by the author from house visits, case studies and roadside interviews. (*Sample survey appendix 10.12*)

Domestic	Watts	House A	House B	House C
TV stereo	400	1	1	0
Washing machine	800	1	1	0
Satellite tv	300	1	0	0
Electric fan	200	3	2	1
Computer	200	1	0	0
Electric hot water	1500	1	0	0
Water pump	750	1	1	0
Refrigerator/freezer	250	3	1	1
Lights	60	20	12	6

Figure 10 Domestic appliances and house types.

Individual case studies of houses checking the electrical data plates of different appliances revealed average power figures for appliances as above. To make the calculations manageable the types of houses were split into three broad categories; A, B and C. The number and types of appliances are shown in *figure10. 7*. The number of each type of house was arrived at through a combination of counting by hand estimated from an external viewing and data drawn from a council utilities map of the area (*appendix 10.7*)
The estimated numbers of each are

House type A	70
House type B	150
House type C	498

These electrical appliances were then entered into a spreadsheet usage column derived from the times of usage suggested in the survey results. Percentage usage factors per household again derived from survey information were then added giving a measurable peak-loading chart.

4.6 Desalination

Provision of clean drinking water is an essential ingredient of the islands sustainable development policy. Irrigation is vital if eadible crops are to be grown rather than imported. The energy required to produce desalinated water needs to be factored into the future power requirements of the island.

Figure 11 Example of private water well (left) and pumping station for Codrington (right)

The existing system is in need of total overhaul in terms of provision and distribution. The fact that drinking water is delivered by boat or by boiling and chlorinating existing brackish supply is uneconomic. The council has set a target of 30,000 gallons per day for the village of Codrington. This equates to 20 gallons per person per day, which seems a reasonable target given that this includes some irrigation of gardens, bathing, cooking cleaning and drinking.

An example of a solution to this problem could be found by installing a Reverse osmosis desalination plant (CDC, 2002). A typical plant comes ready to connect in a 20 ft sea container. The power required to produce 66, 000 gpd (gallons per day) is 62 kWh. This is the power requirement of 2 high-pressure multistage centrifugal pumps and a booster pump channelling water through the RO membranes (HOH-USA & Carib Ltd, 2002). The chart in *figure 9* shows how easily 60kWh could be provided in 18 off peak hours per day. If the desalination plant were to run 60% of the time then 36,000 gallons of fresh water would be produced for no electrical cost. The cost of a unit such as this is US$ 204,000 (SeaRO-20ERS, 2002).

Producing different water production quality ratings could make reductions in the power requirements of the desalination plant. For example it would be possible to produce drinking quality water, which could then be bottled in re-useable containers, and at other hours water produced at a level that is desalinated to an acceptable level in which to shower, cook, clean and irrigate. This water would be fed into the existing piped water system. The piped water could be produced at a far greater volume for les energy than producing drinking water.

It would be important to ensure that the piped system was well maintained and leak free. Ideally the water would be pumped to a head of some 50m. This would allow the entire village to have consistent water pressure without the need to run expensive and energy sapping individual water pumps. Water surplus to domestic requirements could be used to provide irrigation to crops.

4.7 Proposed building projects

Whilst there are many new buildings that the council would like to build, including schools, sports facilities and hotels, the land issues and financial implications set out in *chapter 3.3* indicate that the decisions on any of these going ahead will not be made for some time.

Any new energy scheme is therefore reliant on making an estimate of the likely increase in electricity consumption as a percentage of the existing quantity without referral to proposed plans.

It will be suggested therefore that future distribution schemes (cable between generators and the grid at Codrington) are connected in such a way that they will be able to handle large increases in current and are buried to prevent hurricane damage. The ideal wind turbine site (*chapter 6)* is 5km from Codrington. Consultation with AEI Cables Ltd. produced a recommendation for 11kV 185mm armoured cable at a cost of $26, 565 per kilometre.

One of the attractions of a renewable scheme is that it can be added to in a modular fashion as the island develops and finance is secured, unlike a traditional generating plant that will either be too big and running inefficiently or will rapidly become undersized and require replacement.

For the immediate future then it is possible to concentrate on a renewable energy system that has enough capacity to cover existing needs with a “comfort” factor of 10%. The distribution system to the village should be sized in such a way that it will be able to handle a three-fold increase in power demand. Energy saving measure described in *chapter 4.8* will give sufficient surplus capacity to cope with increased demand.

4.8 Methods of reducing current energy demand

The existing peak energy demand (7.00pm to 10.00pm) stretches the capacity of a 650kVA generator. Whilst it is possible to increase this capacity the most economical strategy would be to reduce demand. This can be done in a number of ways that do not require the consumers to reduce use of appliances. Not only will this save residents money now and provide a more stable supply of electricity at peak times, a comprehensive energy saving program would reduce the size and therefore investment of any renewable technology to be installed.

- Low energy lights: Installation of compact fluorescent bulbs reduces power consumption by 80%.
- Timers on refrigerators: Refrigerator motors have a high start up rate, every time the compressor kicks in a large draw (up too three times the motors rated output) is made on the grid. With 700 refrigerators cycling on and off all day this has a large effect on the stability and quality of current supplied, especially during peak hours. A simple solution would be to install timers on refrigerators to turn them off at peak hours. This would have little effect on operating temperatures but a large effect on reducing the peak loading levels on the grid.
- Water pumps: Similarly to electric motors on refrigerators, start up loads on water pumps are very high. The majority of houses have a pressure pump feeding into a pressure tank. This often results in the cycling on and off all day of the pump. A reliable water distribution system incorporated into a high head water tank would solve this problem, making electricity bills cheaper and eliminating the need to purchase expensive individual pumps.
- Solar switches: Streetlights have solar switches incorporated to turn them off during the day. In the majority of cases they are now not working. This should be rectified and a similar solution found for the runway lights that burn 24 hours per day. (The airstrip lights are on 24 hours a day due to damp in the circuits, it has been found that once turned off numerous bulbs blow upon reconnection).
- Solar Hot water heaters: Installation of these devises will make significant savings to peak electricity usage for those that do have electric water heating and for the majority of homes that do not have hot water, simple solar hot water heaters can be made for less than $US500. The pre made US and European models are not necessary in this climate and are prohibitively expensive.

Figure 12 shows the drop in electricity consumption if these energy saving measures are adopted by 70% of the population. The resulting consumption levels were achieved by introducing new columns to the survey result spreadsheet for each of the three house types. Percentage use factors and consequent power savings were then calculated. The resultant line (green) was the laid over the existing consumption chart *figure12*.

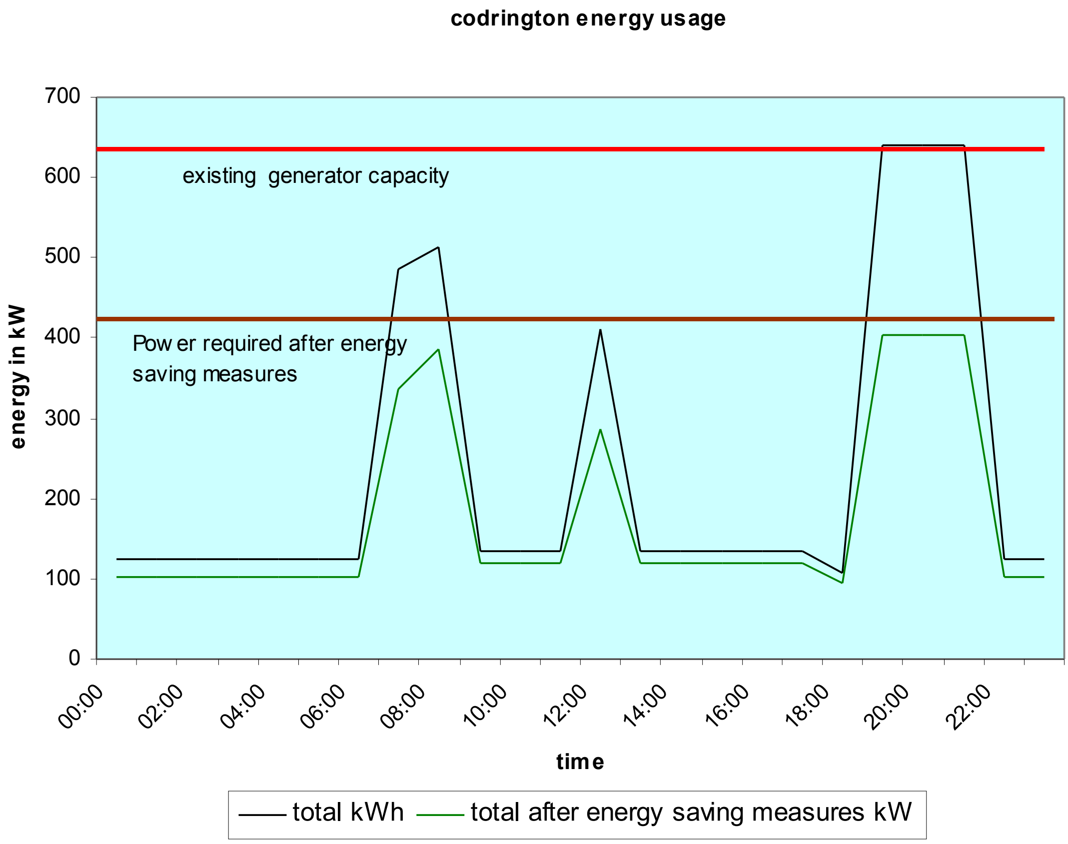


Figure 12 Energy requirement of Codrington with energy saving measures in place.

Reduction in power consumption to the level indicated by the green line in *figure 12* results in a peak load of less than 400kW. Fuel consumption figures would be significantly reduced as a smaller generator could be run. Calculations for renewable energy schemes could be revised to incorporate far lower start up investment capital as smaller generators could be considered.

5 Renewable resources Barbuda

5.1 Selecting a renewable energy source

A superficial look at the renewable resources of Barbuda concludes that a small island in the Caribbean benefits from plenty of sunshine, a steady trade wind, the constant currents set up by the Atlantic fetch of these winds and a historical association with growing fine energy crops, namely sugar cane and tamarind.

A comprehensive renewable energy programme would combine some or all of these assets to produce an uninterrupted supply of electricity at least cost. Due to time constraints it was considered advisable to concentrate on a single renewable energy source for this project, however in choosing that it was necessary to outline the possibilities and disadvantages of the four energy types considered.

- Wind
- Solar
- Hydro
- Biomass

5.2 Wind Energy

Barbuda lies in the trade wind belt of the Atlantic Ocean. Trade winds are a result of pressure differentials across the earth's surface. In its simplest form this is the result of air at the equator being hotter than at the poles, this sets up a circular current of air that at surface level travels from north to south. The Corriolis effect of the earth's rotation gives the resultant wind an easterly direction in the Northern hemisphere. These are known as geospheric winds.

The average annual windspeed for this region is 6.4 m/s (NASA, 2000). The minimum average annual windspeed considered appropriate for the generation of high voltage electricity is 5.8 m/s (AWEA, 2002). The computer generated immages *(figure 13)* show in white the areas of high wind speeds around the globe. It is interesting to note that whilst Barbuda lies at the lower end of the ideal wind speed, the wind is constant both on an hourly basis throughout the day and on a monthly basis throughout the year (*see chapter 6 wind turbine installation*)

In effect this means that if the energy in the wind can be harnessed effectively the energy supply will not have to be backed up regularly as is common with Northern European wind sites when periods of calm are experienced during high pressure weather systems.

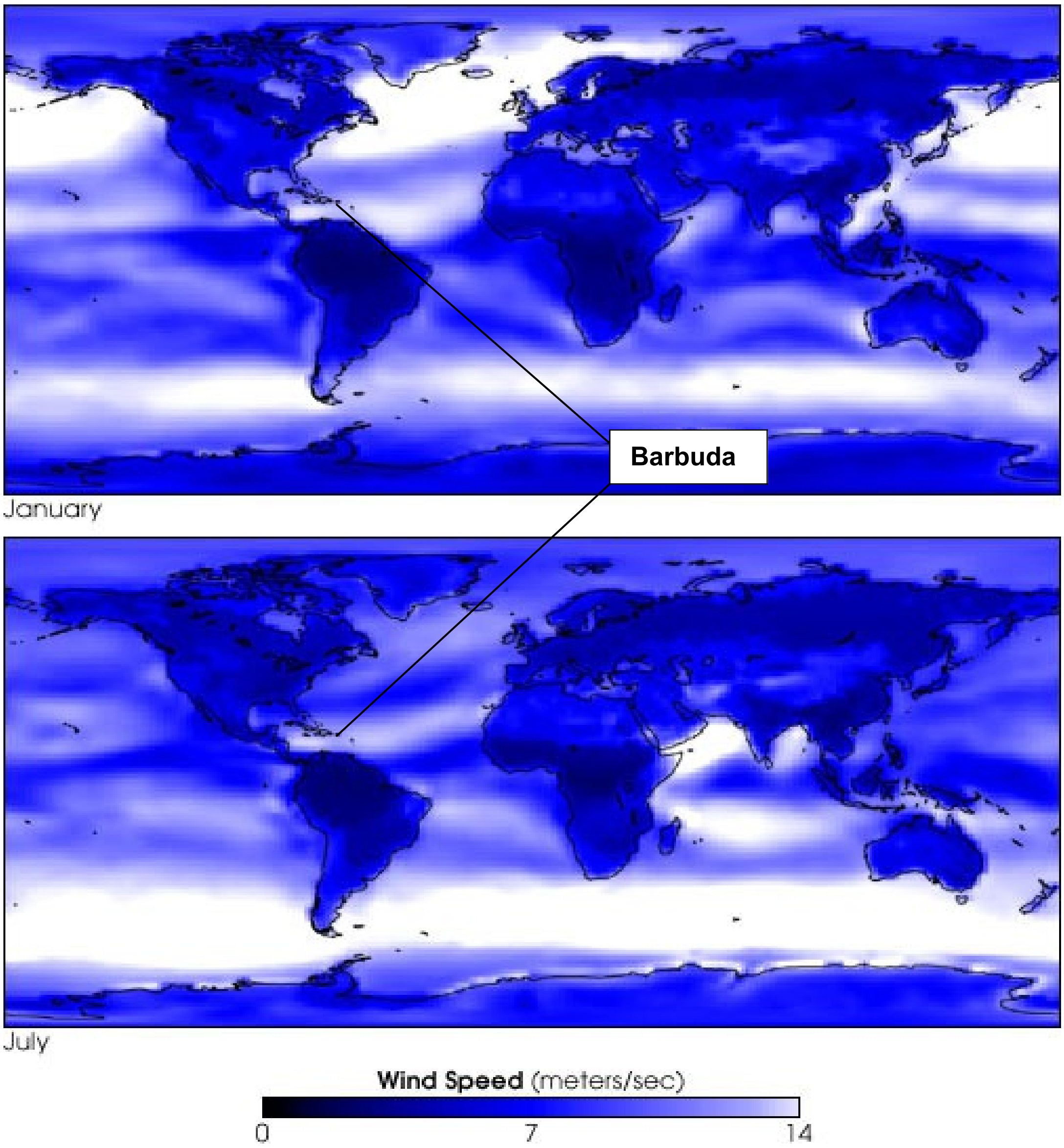


Figure 13 Global average wind speeds. (Source; Earth observatory, 2002)

Certain locations on the island exaggerate this wind speed and combined with relatively good access, lack of planning constraints and an existing distribution system the basic economics of wind power look very promising. The technology is proven, financing is accurate, visual and audible pollution should not prove a difficult issue due to the proposed location (*see chapter 6*).

From June to September the area is subject to hurricanes. These are powerful cyclones that can produce wind speeds in excess of 150 mph (*see chapter 3.4*). Whilst they are very well documented and understood they have so far proved impossible to predict accurately as to track and power. On average Antigua and Barbuda are effected every 5 to 7 years (*appendix 10.5*). Due to the nature of hurricanes it is impossible to calculate an exact maximum wind speed and duration. The problems created by hurricanes and possible solutions are dealt with in more detail in chapter 6.5.

The Trade winds on the high ground of the East coast of Barbuda provide a potential energy in excess of 500,000 kW. 700 times present peak consumption in Codrington of 650kW. (*See details chapter 6*)

5.3 Solar Energy

There is no doubt that sufficient sunshine falls on Caribbean islands to convert to a significant source of electricity. Its latitude of 17°North gives it regular sunlight of 12 hours per day. Up to an hour more in the summer and an hour less in the winter. Additionally at low latitudes the sun rises in an arc directly overhead giving a more direct source of light and less need for movement of solar panels.

An average of 5.82 kWh/m ^{2} /day (NASA, 2002) falls on Barbuda *figure 14*. A 100m² solar panel array would receive 58,200 kWh per day. At an efficiency of 20% that is over 11,640kWh per day. Present consumption is 5,627 kWh per day (*chapter4.4*) without energy saving measures.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Av.
5.29	6.27	7.22	7.71	6.78	5.08	4.63	4.51	5.12	6.52	5.68	5.05	5.82

Figure 14 Average daily radiation on a horizontal surface (kWh/m ^{2} /day) (Ref; NASA, 2002)

Whilst data has been collected on cloud cover and uninterrupted sunshine levels (*appendix 10.4*) the major problem with solar energy production is that it does not coincide with the peak load times of 19:00 to 22:00.

This results in the need for storage either via batteries or transfer of water head. It is the storage element that makes the payback period increase to an unrealistic level. Of the three types of renewable energy photovoltaic panels are the most expensive to install on a $ per kWh basis (Kackadorian, 1998).

The photovoltaic array would have to be installed in a hurricane proof manner to eliminate the loss of power after high winds and in a location removed from the possibility of flooding.

Whilst perhaps inappropriate for supplying the village of Codrington, small p-v systems could be perfect for powering remote locations where the noise and susceptibility to severe winds discourage the use of small wind turbines (*chapter 7*). Battery storage is small enough to be economic and voltage runs can be either kept short in dc voltage or small-scale inverters used to provide ac domestic voltage. On a small scale it is easy to make a solar installation hurricane proof, or to remove the panels on warning of approaching high winds.

5.4 Hydro

The great advantage of hydroelectric generation is that it is largely predictable and very efficient. The disadvantages being that it can be very expensive to install, impact on the local environment and is often remote from the point of use, often implying that the people to suffer its environmental consequences are not those that benefit from its use.

A combination of studying admiralty charts, exploration of the North East coast of the island and consultation with local fishermen led to the view that there is a constant current flowing SE to NW along the east coast of Barbuda (Imray-Lolaire, 2002). At two-foot bay just off Gun shop cliff there is a natural Venturi effect where the Atlantic driven current is forced through a narrowing channel created by a reef some 300 meters from shore. This has the effect of increasing the velocity of the water passing on the landside of the reef.

The distance from shore to the outlying reef is between 260 and 320 meters. The depth varies depending upon tide and barometric pressure, however approximated to a low tide the depth of the channel varies between 0.5 and 2.5 meters.

The stretch of water is shown is illustrated in the photograph in *figure 19.*

The current is made up of three components.

- Tide
- Wind driven current
- Equatorial current.

The wind driven current provides a SE to NW set, the speed of this flow being variable depending on general weather patterns. Typically in January this will be around 1 to 1.5 knots (Reed, 1999 & British Admiralty Charts, 2001).

The thermal equatorial current runs east to west varying between 0.8 and1.5 knots (Reed, 2000).

The times and strengths of the tidal component of the current are totally predictable and can be calculated accurately far into the future with the use of almanacs and tables. Generally they set east and west, the exact magnitudes being the result of some quite complex calculations (Cunliffe 1989; Reed, 2000; NASA, 2002).

A simplified "sailors" rule of thumb is as follows. The tide starts running to the east soon after moonrise, continuing to run east until an hour after the moon has reached its zenith then runs westward reinforcing the westerly current (Cornell, 2000).

Typically there will be a 1.8 to 3 knot tide continually SE to NW as a result of wind and equatorial components. This will be added to or subtracted from by the tidal component of 0.5 to 1 knot. This gives an average range of 1.3 to 4 knots. The tidal effect around Barbuda is diurnal that is once per day, giving a 2.3 to 4 knot tide for twelve hours reducing to 0.8 to 2.5 knots for the remaining twelve. Using almanacs and tables accurate forecasts can be made on an hourly basis for years in advance

The speed of this combined current is amplified by the Venturi effect of the reef. In an attempt to quantify this effect a simple experiment to gauge the actual velocity of the current was undertaken.

The speed of water in the channel was measured in an approximate manner by throwing a series of wood logs (the original meaning behind a ships "log") into the stream. A distance of 100 meters having been pre measured. The logs where then timed on two separate days at different times. The results are shown in *appendix 13*. The speeds recorded were then compared to expected currents calculated from existing tables (Reed, 1999)

Whist not conclusive in any way, these figures do suggest that there is an increase of water velocity in this area of around 0.5 to 1.5 knots in comparison to the surrounding tidal body of water passing further offshore around Barbuda (Street 1989; Reed, 1999). For use in measuring the potential power available in the stream a detailed series of measurements would need to be recorded over a full year.

The technology used to most effectively harness this power is known as tidal stream (Twidell, 1986). Unlike normal hydroelectric plants where the generators take advantage of the kinetic energy of a head of water falling through a given height, tidal stream technology converts the moving mass of water in a horizontal plane in a similar manner to that of a wind turbine.

The power available is expressed as a function of the flow or volume of water passing

$$P(kW) = 10\eta QH \qquad \text{(ETSU, 1993)}$$

Where; P = power in kW
η =Efficiency of plant
Q =Quantity of water in m^3
H = Head of water

Here there is no head of water so the total energy available from two-foot bay given an average depth of 2 metres, width of 300 metres and average flow rate (mean flow plus venturi velocity) of 1.9m/s (3.7 knots), is very approximately.

10 x 1.9 x 600 = 11,400kW

If just 10% of that energy could be harnessed it would provide double the present required electrical supply of Codrington if energy saving measures were put in place.

5.5 Biomass

The previous forms of renewable energy suffer from the possibility of not producing electricity at certain times due to lack of sun or wind. This requires a back up supply, which is conventionally supplied using a fossil fuel burning plant. There have however been large steps forward in the production of energy through burning energy crops. Energy crops are those that grow prolifically in a given local climate to produce a material that burns effectively. Under managed harvesting these crops are considered to produce Co2 neutral energy, that is, the amount of carbon released into the atmosphere is the same as that absorbed during growth.

The energy contained in these crops is then stored effectively ready to be burned in a generating system as required. The energy can be stored as cut piled wood; turned into bio-gas (methane) or ethanol (liquid fuel) this could provide a viable backup to a wind turbine or solar generating system when required.

Several types of biomass generation are available from units that burn in cogeneration schemes that in northerly latitudes are used to generate heat in addition to electricity making them a very viable alternative energy source; in Barbados steam is used in the production process for making sugar (Boyle, 2000). In Barbuda however heat generation would not be necessary reducing the overall efficiency of a plant generating electricity unless a heat intensive process was developed as a by product.

At present Barbuda uses 7,500 gallons of regular gasoline (petrol) per month (90,000 gallons per year) and 7,200 gallons of propane (86,400gallons per year) In addition to the diesel fuel used by the generating station (figures from consultation with Thomas J. proprietor of Barbuda's only fuel station). Petrol is used primarily for cars and fishing boat engines. Propane is used for cooking.

Ethanol from sugar cane is a well-developed energy crop. With a well-managed harvest sufficient energy could be stored both to run a back up generator when needed and conceivably fuel the cars and boats on the island on the island. Experiments are well documented on renewable energy projects taking place on the French Islands of Guadeloupe (Jensen, 1998). In Brazil more than 4,000,000 cars run on pure ethanol made from sugar cane (Carpentieri, 1993; ABA, 2002).

Precise yields are difficult to estimate since each year is dependent upon variable factors such as weather, soil degradation and fertilisation, 2000–2800 litres per hectare (Tropical Crop Coefficients, 2002) is the typical variation. If we take the low figure of 2000 litres per hectare per year, a field $20km^2$ square would be required to provide sufficient fuel for the cars alone. Obviously if the yield could be increased the size of plantation could be reduced.

Although there is certainly uncultivated land in Barbuda's interior that could support this scale of harvesting, present local feeling on the island is that the land is of poor quality, and not suitable for harvesting, with continual droughts, shallow topsoil and regular rock outcrops hindering the use of mechanical farming equipment (Berkeant, 1978).

The measurability of energy crops is subjective and figures supporting the potential for its use on Barbuda would require much further detailed research by agricultural specialists. In addition the political issues surrounding the assignation of property rights (*chapter3.3*) would have to be overcome before utilising this potential resource.

6 Case study of wind Turbine installation.

It was decided to explore the potential of wind energy in some depth as the most feasible renewable energy resource to supply power to Barbuda (*chapter 5.2*). The specifics of deciding exactly which type of turbine placed exactly where are to be considered the "next stage" in completing a renewable power system and would be best addressed by a turbine manufacturing company. Here it is intended to explore the overall potential and problems of installing wind turbines in a small tropical island.

There are many factors to take into consideration when examining utilization of wind as a resource and in compiling this chapter reference was made to a wide range of information in the form of written text, manufacturers and renewable project management companies (Boyle, 2000; Enercon, 2002; Vergnet Wind Turbines, 2002; G.E. Wind Energy, 2002; AWEA, 2002; Bishop, 1994; CWS, 2002; Chadwick, 1996; Lammings, 1982)

The chapter is sectioned:

- Power in the wind
- Variations in wind speed
- Location
- Feasibility
- Special Needs of the Caribbean.

6.1 Power in the wind

In its most basic from the power available in the wind is represented as.

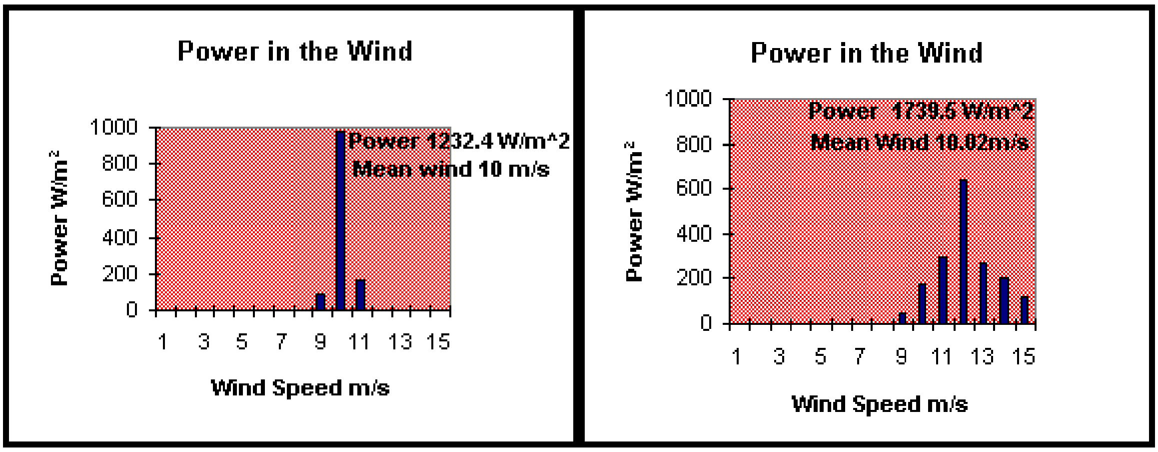
$$P = \frac{1}{2}\rho A V^3$$

Where; P = Power in the wind in Watts, which equals the kinetic energy in the wind
ρ = Density of the air
V = Velocity
A = Area through which wind is passing. (Twidell,1986)

At sea level the density of the air is universally close to 1.225kg/m ^{3} . Changes to this figure are caused by air pressure, temperature and altitude. In Barbuda all three elements are nearly constant all year (*appendix 10.4*). The area through which the wind is passing will be the swept area of the turbines blades.

It can be seen from this equation that the velocity of the wind has a cubed effect on the total power available to be converted. A small increase in the wind speed will have a disproportionately large effect on the power available. For example an increase in wind speed from 14 mph to 16mph will give an increase in power output of 50% (AWEA, 2002).

It is this exponential rise in power with the velocity of the wind that gives rise to a difference in power available from wind over time. Two sites with the same mean wind speed over the course of a year may have very different power availability as shown in *figure15*.



Site A **Site B**

Figure 15 Power available from two sights with the same mean wind speed. (Chadwick H, 1996)

The example here is typical of a region with a consistent wind speed on site A and a fluctuating wind speed on site B; a disproportionate amount of power is derived from site B during periods of higher than average wind realising a greater amount of power over time.

The Caribbean falls into the category of site A. with a mean wind speed of 6.4m/s (12.5 knots) with little variation. This has the advantage of providing power constantly throughout the day therefore requiring little back up for periods of calm, but the disadvantage over time of producing less power.

Detailed weather information was gathered from the Meteorological office situated at V.C.Bird International airport in Antigua. This information was taken from hourly records kept from 01/01/01 until 01/06/02. In addition much information was available through the Caribbean weather station, an inter-island organization designed to provide information amongst then eastern Caribbean (CWS, 2002). Other weather statistics and averages were accessed through Marine charts and pilot books (Cornell 2000, Reeds 1999, and Hammick, 1994)

The wind speed information available was fed into a data base and charts created to show average wind speeds and variations in both direction and magnitude. Some problems were encountered in the utilization of data supplied by the Meteorological office.

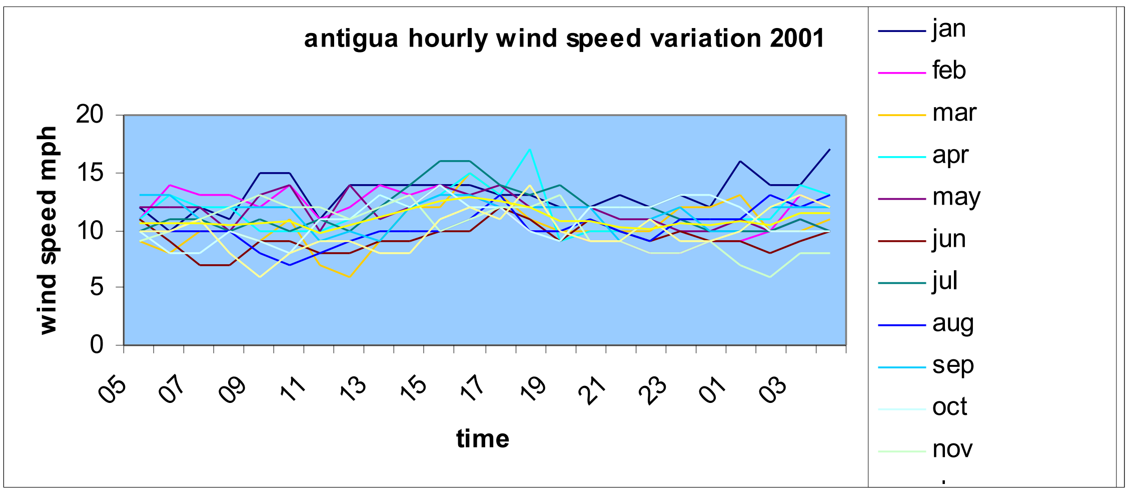


Figure 18a. Hourly wind speed data. (Detailed view appendix 10.11)

The data recorded was available in excel format. Unfortunately the layout contained a gap between each line, although over the 8,760 rows of information not each and every line had the same space and in some cases the space was omitted. This arbitrary variation precluded the use of programming techniques to remove the gap. To simplify the task, seven days of hourly samples were manually taken from each month of the year. These were then entered into a new excel spreadsheet to generate charts and figures.

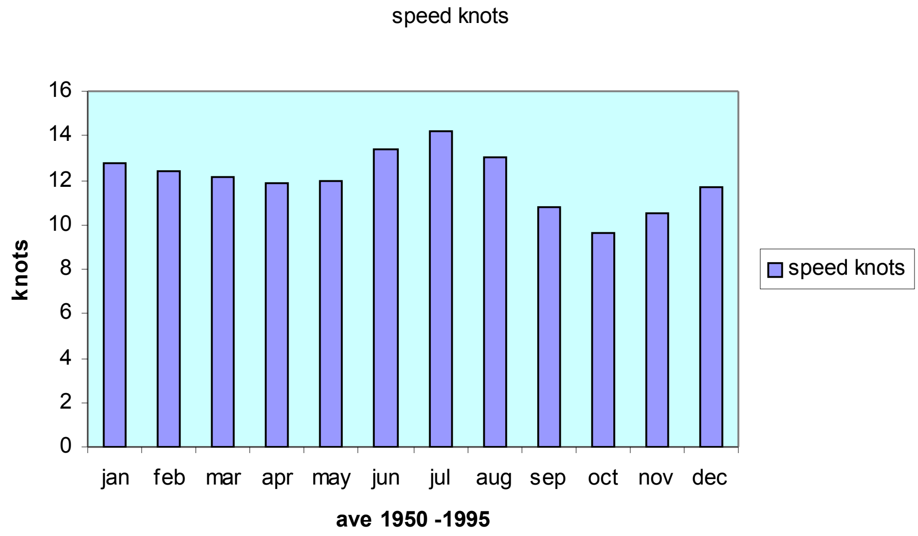
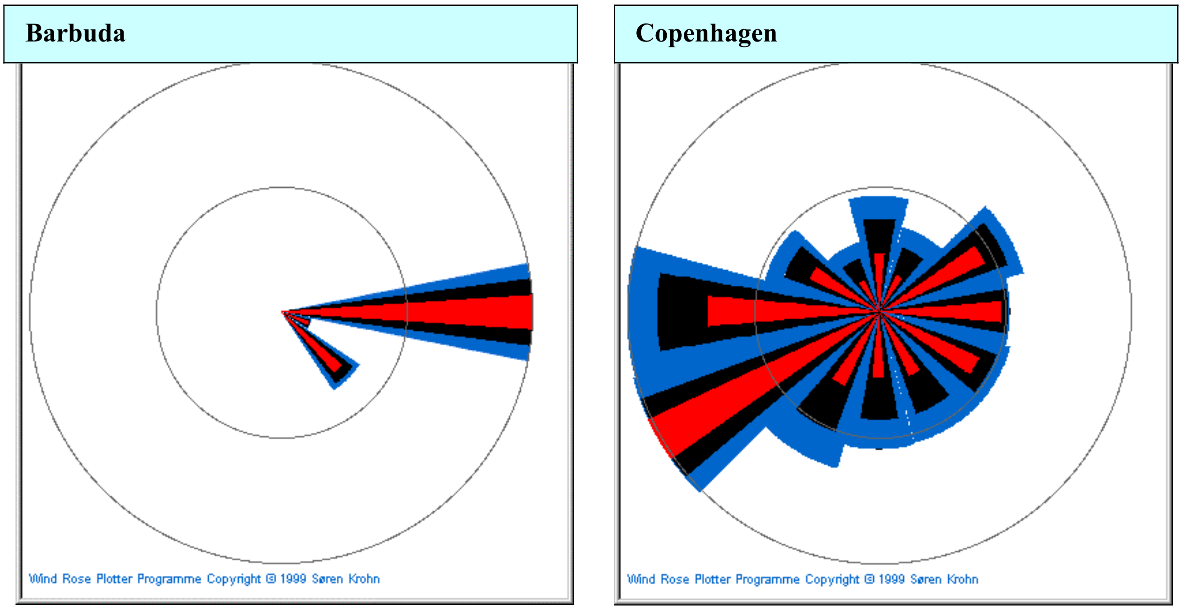


Figure 16 Average monthly wind speeds over 45 years (CWS, 2002)

Figure 16 shows a reasonably constant average wind speed throughout the year with fluctuations in the summer due to variances in frequency of cyclones taken over a 45-year period (*appendix 10.6*). A better breakdown of wind information is necessary for accurate sighting of wind turbines, some of which are described here.

The wind rose is a form of presentation widely used to display wind information in a format that clearly shows the direction in which the majority of power will arrive. *Figure 17* shows a comparison between Barbuda and Copenhagen. A software programme developed by Danish Wind Power has been used. Data taken from hourly information supplied by the Antigua meteorological station was fed into the programme with the following results (windpower, 2000)



1. Barbuda annual wind pattern **2. Copenhagen annual wind pattern**

For each of the sectors the outermost (blue) wedges show the wind frequency distribution.

The middle (black) wedges show the distribution of the product of the two columns, i.e. the wind speeds times their frequency.

The innermost (red) wedges show the distribution of the wind speeds cubed (i.e. the energies) multiplied by their frequencies.

Figure 17 Wind rose comparing wind power and direction between Barbuda and Copenhagen. (Windpower, 2002)

The red innermost wedges are those most relevant to sighting a wind turbine as they show the comparative power in the wind, its cubed function of average wind speed. As predicted this is almost entirely easterly. Having established that an average wind speed of 6.4 m/s (12.5 knots) over the year exists, the next stage was to break this down to hourly averages. It is important that sufficient wind speed coincides with peak evening power loads.

Figure18 shows the annual mean hourly wind speed curve found by dividing the hourly data available from Antigua Meteorological station into monthly segments (details *appendix 10.11*). The general trend shows an increase in wind speed at midday with a slight dip during the evening. This trend is only taken from data on one year and for accurate estimation longer term records need to be analysed.

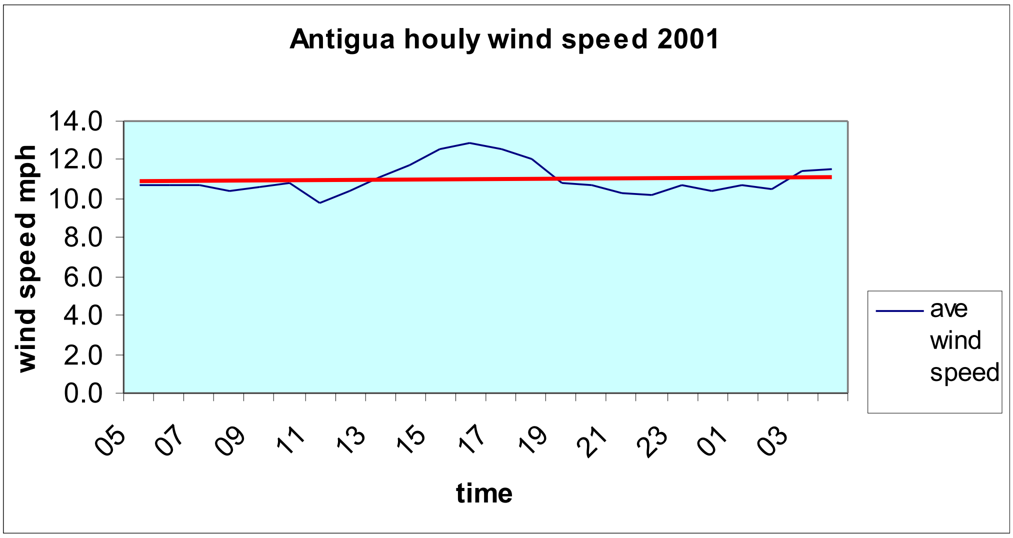


Figure 18 Annual mean hourly wind speed for 2001. (Data provided by AMS, 2002)

6.2 Barbuda: Variations in wind speed

Physical exploration of the island quite clearly showed that the wind speed on the highlands on the East coast of Barbuda were significantly higher than elsewhere. The particular area of Gun Shop point was explored since this site has a road already built to the foot of the hill and lay closest to Codrington.

Figure 19 Gun Shop Point; “the highlands”

The Wind data gathered is from anemometer readings taken from V.C.Bird international airport in Antigua. Whilst very accurate for this location they need to be adjusted for accuracy for use on the east coast of Barbuda. There are two main considerations

- Height
- Shielding

Surfaces of land create friction and reduce wind speed. The rougher the landscape or vegetation the more friction is created. Therefore the higher the anemometer from the ground the higher will be the recorded wind speed.

Hills and cliffs slow down or speed up the airflow. Gently rolling hills can funnel wind through a valley and increase it’s speed, turbulence at the top of a cliff may slow local wind.

The wind data obtained from the Antiguan meteorological office is shown to be an average of 2 m/s slower than an unsheltered point on the east coast of the island (Lamming S, 1982). With the topography of the land to the windward side of the airport consisting of several small islands and hills (Imray-Lolaire, 2002). See also wind chart *appendix 10.10*.

In addition these measurements are made at a standard height of 10m above sea level. The proposed site at gun shop point stands 50 metres above an unobstructed sea level, the hub height of any proposed turbine adding another 50 meters.

These two factors together theoretically provide an increased average wind speed at the proposed site of 2.5m/s (Windpower, 2002 & Lamming 1982) increasing the average annual wind speed to 8.9m/s (17 knots). This adheres more closely to the impression of wind speeds observed on several visits to the site (see visual indications of wind speed *appendix10.6*).

The exact location of maximum average wind speed within an area of 1 kilometre would need to be assessed in greater detail with the use of accurately recorded anemometer readings taken over a year. Turbulence close to the edge of the cliffs will reduce wind speed; various geographical anomalies such as gullies in the hill face may accelerate the wind. These small differences make a large contribution to the final power obtained.

6.3 Converting the wind to electricity

The small changes in wind speed between 6 and 12 m/s are critical in calculating the conversion of wind to electricity. Figure 20 shows the power curve of an Enercon E-66 turbine rated at

1800kW. This power curve is typical of European wind turbines designed to convert the maximum power out of the wind on an annual basis (*figure15*).

The rated energy of a wind turbine is the maximum power that that wind turbine will produce at a given wind speed. Most European turbines are optimized for wind speeds in excess of 12m/s (24 knots) as shown in section 6.1 this provides the maximum return over a year for a variable climate.

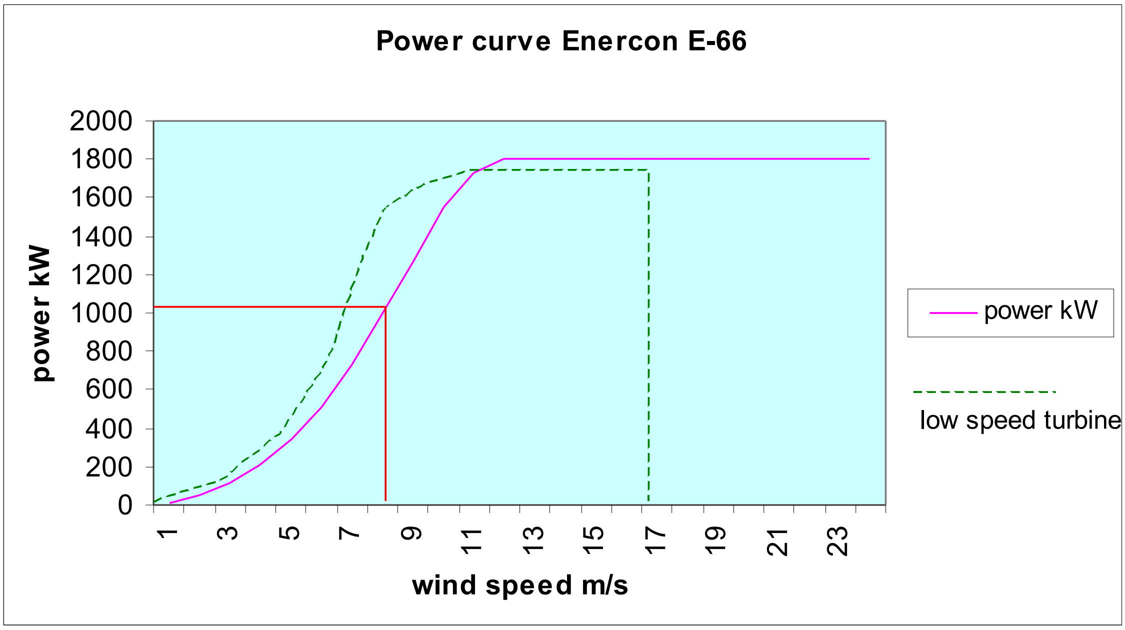


Figure 20 Power curve of typical European 1800kW wind turbine with low speed turbine approximation in green.

The consistent but comparatively light trade winds of the tropics need a turbine optimized for a mean wind speed of 8m/s (16 knots). This requires a lighter structure and finer pitch of rotor, which consequently has to be shut down earlier to avoid damage. With wind speeds historically never exceeding 35 knots (18m/s) outside hurricane season this should not pose a problem. During hurricane season precautions as described in *chapter 6.6* have to be taken. The green line in *figure 20* represents the type of power curve required where the rated output is reached at much lower wind speeds.

6.4 Feasibility

The Easterly prevailing wind and the height of the highlands on the east cost of the island make the area around Gun shop point (*see map appendix 10.1*) ideally suited for the location of a wind turbine. The area is three miles from the existing grid system of Codrington, which whilst incurring some expense is in fact a good distance in terms of reducing any visual or acoustic pollution. It would be recommended to bury the lines along the road side in armoured cable to avoid possible hurricane damage. The existing generator could then be moved away from the lagoon to the turbine sight as a back up system at no investment cost and reducing noise and pollution within Codrington.

There is already a road to within 300 meters of Gun shop point. The road is directly linked to the main jetty on River road. Some consolidation of road integrity would have to be undertaken to allow transfer of heavy materials, however this is already one of the priorities of the council.

The land issue is dealt with in detail in *chapter 3* and is of fundamental importance to the whole concept of a renewable energy strategy. Any investment body would need a cast iron agreement that the entire renewable energy project could be completed with no recourse to land disputes, property rights issues or other contentious subjects between the government of Antigua and the people of Barbuda. Repayments on the loan would have to be guaranteed and these should be generated through an efficient, fair pricing and invoicing structure within the island.

The costs of putting together a project of this magnitude needs to be assessed accurately by a wind turbine manufacturing company or experienced wind farm project management team. However some rough figures help to visualise the feasibility of the concept.

	$US
1800kW wind turbine	1,500,000
Shipping	100,000
Installation	150,000
Cabling	150,000
Road works	200,000
Desalination plant	204,000
Miscellaneous expenses	200,000
Total	2,504,000

These figures were arrived at after consulting with Enercon UK with regard to generator price, annual maintenance, shipping and installation. AEI Cables for price per Km of 11kVA armoured cable, SeaRO Ltd., installation of desalination plant, and a generous miscellaneous figure given to account for unforeseen complications.

A good proportion of the expense occurring in European wind farms is associated with the legal and planning issues involved in gaining permission to start a project. Of the civil engineering works it should be remembered that labour is relatively cheap and the main component of concrete, sand, exists within a few hundred metres.

Figure 21 shows the repayment schedule of a $2.5 million loan at 5% interest if initial repayments are kept to $300,000 pa for the first five years rising to $400,000 thereafter.

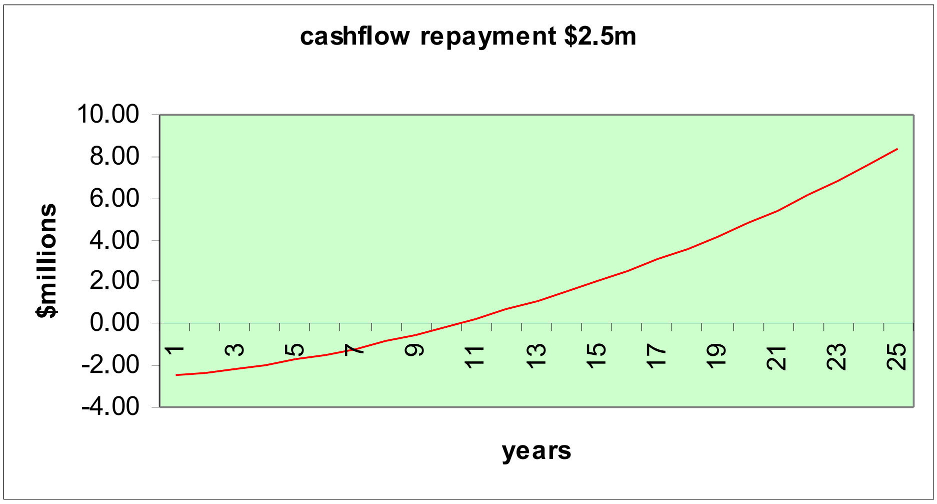


Figure 21 Cost breakdown and repayment schedule

At present the Barbudan consumers pay a total of $US 484,130 per year to APUA. This does not include drinking water. The loan should be comfortably be paid off within ten years when surplus funds can be used to upgrade the system.

6.5 Special needs of the Caribbean

Whilst turbine costs are dropping and efficiencies are improving a major factor in the cost effective use of wind power is ensuring maximum availability of the plant. This is very much dependent on a professional maintenance programme ensuring that the turbines are running efficiently at all times.

A maintenance crew would ideally service thirteen 1.5mW wind turbines in a small area for maximum economy (Vestas, 2002). Without professional maintenance very serious damage could be expected within a short space of time.

Hurricane damage plays a significant part in calculating maintenance and power availability costs. The destructive damage limitations at Enercon (Enercon, 2002) are set at 70mph for all their large wind turbines. With the hurricane season lasting from June to September and difficulty in predicting exact times of their arrival a suitable system needs to be developed in order to ensure damage is avoided. Methods that can be employed range from removing blades, to tilting towers to ground level on smaller scale turbines.

The consistent but relatively low wind speeds of the Caribbean indicate a need to build turbines optimised for winds of 8m/s. This is 4m/s slower than their European counterparts. They will be lighter and more vulnerable to high wind speeds. It may make sense to plan to install several smaller more manageable turbines with pre-constructed gantries to remove blades in advance of predicted hurricanes.

The best way to achieve these economies of scale would be for a number of Caribbean islands within close proximity to agree to incorporate the same system. A group of engineers could then secure a permanent posting to maintain the turbines and educate a core of local engineers. Manufacture of optimised low wind speed generators could then be scaled up to improve economy.

The next stage of this research project would be to work closely with a wind turbine manufacturer using the data and local knowledge built up during this research to develop solutions to the problems posed by tropical wind speeds and cyclones. From here it would be possible to make a more accurate assessment of costs involved.

7 Communication, Isolated dwellings and Funding

7.1 Communication

From the earliest times access to Barbuda has been difficult. Unlike Antigua with its safe harbors and comparatively easy approaches, a ring of coral reefs with difficult navigational approaches surrounds Barbuda. These are difficult today with satellite navigation systems and engines. In the seventeenth century this had to be negotiated under sail, with boats that could not sail into the wind.

Today there is still no ferry service to neighboring islands and the small airport only operates an 18-seat plane twice a day.

There is a substantial jetty on the west coast of the island from which cargo is unloaded and sand removed and a small jetty within the lagoon for shallow draught vessels able to negotiate the creek.

At present all goods must be sent via the port of entry in Antigua. This adds significant time and cost to shipping but more importantly leaves goods open to the vagaries of Antiguan duty, which can be more than 100%.

Much of the research involved in putting together a renewable resource assessment could be undertaken from a distance if it was possible to communicate regularly with an interested and knowledgeable individual based on the island. Since renewable technologies are relatively new, that level of knowledge is not generally available, not only does this restrict a two-way flow of information in the data gathering stages, it is likely to prevent its initiation in other tropical islands.

The Internet combined with satellite and radiophone has bought instant communication to most of these islands, although to a large extent the reliability and low cost experienced in Europe is not available. In general the beauty and charm of these islands lies in their being a long way from the grey maritime climates where the majority of renewable technology companies are based. This leads to increased survey costs, increased shipping costs and increased maintenance costs.

7.2 Isolated dwellings

The existing Power station on Barbuda has been built only to supply Codrington. The grid system has been slowly expanded along the main roads, highland road and river road leading out of the village as inhabitants take up their options to build on parcels of land surrounding the town (*appendix 7*). There are however quite a number of isolated buildings at various locations around the island that at present rely on their own generating systems.

- Hotels
- Private houses
- Sand company

7.2.1 Hotels

There are three hotels on the island Cocoa Point, K club, and Palmetto Point. Varying in size these three complexes all operate in a similar manner. They are open only six months per year, are isolated from the existing grid. Palmetto Point the closest is 5 miles from Codrington. The cost of installing transmission cables would be prohibitive, the existing power station in Codrington could not supply the increased capacity required and the hotel management is not confident in the regularity of supply provided by APUA. In addition the tariffs charged by APUA are so high that it is cheaper to provide power for themselves using diesel generators.

The hotels were closed for the season during the field trip so information as to power usage was unavailable. Access to an unconfirmed report held at the offices of the council of Barbuda indicate that Co-Co point hotel is powered by three 250kVA Caterpillar Generating sets.

Being only open for six months and requiring high peak loads after sunset it is unlikely that a renewable energy system could be installed to work competitively with a short payback period. The land within the grounds are defined and utilised for golf courses, swimming pools and shaded gardens, the area required for solar panels or a wind turbine would be too close to guests paying upward of $1500 a night. In addition this level of investment in a renewable technology requires a twenty-year plan, which is outside the remit of most hotel operators, especially given the political issues surrounding the hotel leases (*chapter3.3*).

7.2.2 Houses

There are around twenty isolated houses dotted around the island. At present these are either uninhabited or used occasionally as holiday homes powered by small generators. In all of these cases power could be supplied using small-scale photovoltaic arrays connected to battery storage and transformed to domestic voltage. The direct sunshine levels available (*see chapter 5.3*) are ideal to supply power at a typical domestic level.

A case study was made of a small beach dwelling on the islands North beach. Inaccessible by road this group of three wooden cottages is run as a small hotel. At present it is powered by a small generator. In order to keep the domestic standard refrigerators and freezers running the generator has to be kept running 24 hrs a day. This leads to exorbitant fuel costs and unwanted noise pollution.

The fresh water at present is supplied from a brackish well and is not fit to shower in. Drinking water is bottled, boiled or chlorinated. The 7,5kW generator generates 180kWh per day. The average power used is less than 20kWh. Fuel costs alone are over $US 10,000 per year not including shipping and transfer by boat, oil and maintenance. $US 25,000 would purchase a formidable photovoltaic array, desalination unit, and battery storage bank and inverter system. Pay back would be less than less than three years. (Details of north beach power supply *appendix 18*).

7.2.3 Sand Company.

The only isolated industry on the island; in fact the only industry other than local fishing, is the sand mining company. This is now based opposite the main landing jetty on the south west coast. Access was not granted to the site although from a distance it was observed to have a diesel generating plant running continuously to power the offices, whilst most of the operation was carried out by self propelled machinery such as conveyors, backhoes and tractors.

The intense sand mining operation has now reached the end of its life having mined the islands resources to its maximum potential. It is therefore not a relevant consideration in the islands future power plan.

7.2.4 Back up supply

There are a number of institutions on the island that suffer from the disruptions caused during power cuts. The hospital and school in particular suffer when electricity supply is cut with no notice. Firstly, it should be possible for APUA to schedule service stops for times of minimal interruption and allow people to prepare for this.

There are a number of solar powered back up devices on the market that could be employed. These consist basically of a battery, charged all day by a solar panel or the mains that on detection of a voltage drop activates and supplies ac voltage through an inverter instantly. The battery is sized to allow the relevant number of computers or machines to run for three or four hours during the power cut.

The government building and radio mast for the mobile phone company, have back up generators that come on immediately there is a voltage drop. This is not quick enough to save computers crashing at the power drop. Again an instant solar powered back up system could be employed.

7.3 Funding

All renewable energy technologies are capital intensive. In Europe, projects are funded by banks and other financial institutions on purely commercial grounds, in the knowledge that all electricity generated can be sold into the grid at a measurable rate. Repayments are made through a recognised company and the land and generating plant can be held as security against the outstanding balance.

Tropical islands cannot provide this financial security since by their nature they are remote; the ownership of land is not as structured and basic laws governing financial arrangements are not subject to the same rigorous standards of implementation.

A major problem for most tropical island governments is providing security in terms of repayment. The governments are often family based dynasties with a history of corruption. Large amounts of money are already tied up in existing power generating systems that whilst inefficient, expensive and environmentally damaging, provide a rich source of income to a few powerful people. Hence the decision makers within the political network have no real incentive to change the existing system.

The established pay back figures from wind farm examples in Europe can be quite accurately considered with figures taken from existing examples. Income is derived from a reliable and reputable source where all energy produced is sold directly to a third party in the form of a power supply company. On a tropical island income is derived from a generally poor local population, which may be considered not as reliable a source of repayment.

Insurance and maintenance are important considerations. In order to generate income the renewable energy source must be operational at all times. Hurricane damage may disrupt supply for considerable periods and is quite unpredictable, a poor maintenance programme could result in expensive damage to equipment. These factors will inevitably lead to higher insurance premiums and running costs again reducing the financial benefits of the project.

A good renewable energy project would initially concentrate on reducing the quantity of energy consumed with a series of energy saving measures. If the price of electricity is kept the same per unit this in turn reduces the income for the power generating company. This loss in income reduces the finance available to invest in the new technology.

The system can only work if the energy generating company is owned and operated by and for the inhabitants. Finance needs to be arranged through a trust fund or other international monitory body whose goals are environmental, social and developmental rather than purely profit oriented.

With careful planning there is every reason why a wind turbine driven generating plant could supply the energy needs of Barbuda at less cost than the existing system supplied by APUA.

8 Conclusions and recommendations

8.1 Conclusions

The first objective of this research was to establish the current and future energy demands of the island. *Chapter four* demonstrates that the existing diesel powered generating plant operated by APUA provides a poor quality service at an exceptionally high cost. The peak loads in the early evening already reach the generators maximum capacity. Any new developments requiring additional electricity will require finding extra capacity. The location of the generating plant next to the lagoon and upwind of a large proportion of inhabitants is unhealthy and prone to flooding.

Energy savings measures could be introduced within weeks that could reduce peak loads by 50%. These measures would benefit the consumers by reducing their monthly bills increasing the quality of supply at peak times and reducing the number of power cuts. The initiative in funding these measures has to come from the council.

There is no incentive for APUA to introduce energy saving measures since the more electricity used the larger their income.

Solar energy it was discovered, that whilst plentiful, did not coincide with peak load times of the early evening. This necessitated an energy storage system, which is both expensive and inefficient. Solar energy in the form of photovoltaic panels and batteries could be very useful in isolated dwellings. Large solar collection systems could be severely damaged by hurricanes.

Hydroelectric generation was explored and the potential energy in the wind, tide and equatorial currents passing the north east coast of Barbuda found to be substantial. The technology for converting this tidal stream energy to electricity is relatively new and hence any system installed would be developmental rather than practical. Financing such a project would therefore be difficult and the quality of energy services provided unpredictable at the moment.

Biomass potentially could produce ethanol and methane to power vehicles, generators and cooking. The political situation surrounding the “land issue” would first have to be settled permanently with Antigua. The cultivation and harvesting of large tracts of land would have to be undertaken and would certainly prove unpopular. It would be a good idea to cultivate a small area now for experimental purposes for future reference.

Wind energy was considered the most appropriate form of renewable energy to take forward to the next stage of research. Analysis of wind data taken from Antigua showed that whilst at the low end of necessary mean wind speed the consistency of the trade winds provided power throughout the day and year. Optimisation of existing wind turbines to suit the tropical breeze need to be made and procedures need developing for maintenance and emergency shut down at short notice during the hurricane season. Wind turbines are an established, proven technology that can be installed quickly to the correct level of performance and be added to in a modular fashion as the island develops and finance is secured.

8.2 Recommendations

There are energy saving measures that could be taken immediately to improve the energy supply situation in Barbuda. Longer term planning could lead to an entirely new renewable energy generating system that gives Barbuda its own independent power and water supply. Measures to be considered are laid out here in short, medium and long term goals.

- **Short-term measures**
  ☐Introduce energy saving measures (*chapter* 4.8)
  ☐Install 250kVA off peak generator (*chapter4.12*)
  ☐Begin negotiations with Antigua and APUA to create independent power generating company run by a benevolent Barbudan company.
  ☐Upgrade existing utilities distribution within Codrington; Reduce leakage in water supply and standardise transformation to single low voltage and frequency.

- **Medium term measures**
  ☐Involve wind turbine manufacturers in completing annual wind assessment for gun shop point.
  ☐Complete building of river road and highland road.
  ☐Survey power usage following introduction of energy saving measures.
  ☐Consult with banks and funding bodies to establish viability of long-term finance package for renewable energy scheme.
  ☐Raise interest and awareness levels of neighbouring islands to benefits of renewable energy with a view to maximising economies of scale on purchase, development and maintenance costs.

- **Long term measures**
  If financial backing can be raised and the people of Barbuda wish to be powered by the wind then the following outline plan could be followed:

  ☐Install wind turbines as appropriate at Gun Shop Point following detailed survey and cost analysis. Identifying system and type of turbines most suitable for tropical weather pattern. Technical and financial input from a wind turbine manufacturer and an independent energy project management company are essential.

  ☐Bury armoured high voltage cable and water pipe along Highland Road to Codrington. Move existing generating station to Gun Shop Point as back up, install transformers and connect to Codrington grid.

  ☐Install desalination plant at turbine site drawing seawater from Two-Foot Bay. Use off peak energy surplus to desalinate water and pump to 50 metre head on highlands. Surplus desalinated water can be used to irrigate crops.

There are tens of thousands of tropical islands stretching around the globe at these latitudes. Most of them are powered in a similar manner to Barbuda with an inefficient diesel generator system providing expensive and environmentally damaging electricity (Jensen 1998). Whether or not profits are made from these systems, they are paid for by some of the world's poorest people and money burned in imported diesel fuel could be invested in clean, renewable generating technology.

Small islands throughout the world are the most vulnerable to the effects of climate change. Rising sea levels and severe winds have a devastating effect on low-lying islands open on all sides to the weather. On an individual level, contributions to the planets Co2 levels are small, multiplied by thousands the introduction of renewable energy to islands could be significant. The development of a renewable energy generator and desalination unit on Barbuda could provide a blueprint for other islands and the incentive for their governments to pursue autonomous energy supply.

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