Towards a **Sustainable Energy** Plan for *St. Kitts & Nevis*

"Long term electricity production cost assessment of electricity supply scenarios for promoting the introduction of Renewable Energy Technologies on Small Island Developing States in the Caribbean, the St. Kitts & Nevis experience"

ing. Kevin H. de Cuba
Department of Science, Technology & Society
Utrecht University
March 2006

sustainable development in energy resources

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Kevin H. De Cuba

Title page

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Author:	ing. Kevin H. De Cuba MSc. Sustainable Development Student Specialization: Energy and Resources Copernicus Institute: http://www.geo.uu.nl/20419main.html Dep. of Science, Technology and Society Utrecht University Heidelberglaan 2 3584 CS Utrecht The Netherlands Home address: Cambridgelaan 197 3584 DZ Utrecht The Netherlands Tel: 0031-620326869 Email: kevinhenry_decuba@yahoo.co.uk
Supervisor:	Dr. Wilfried G.J.H.M. van Sark Dep. of Science, Technology and Society (STS) Utrecht University The Netherlands e-mail: w.g.j.h.m.vansark@chem.uu.nl
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Hosting supervisors:	Sasha B. Gottlieb (until September 2005) Unit for SUSD and Environment Phone: +(202) 458-3964 Fax: +(202) 458-3560 e-mail: SGottlieb@oas.org Mark Lambrides Unit for SUSD and Environment Phone: +(202) 458-6261 Fax: +(202) 458-3560 e-mail: mlambrides@oas.org
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List of Acronyms

CARILEC	Association of Caribbean Utilities
CEIS	Caribbean Energy Information System
CDB	Caribbean Development Bank
CREDP	Caribbean Renewable Energy Development Program
CSES	Comparative Study of Electoral Systems
EC$	Eastern Caribbean Dollar (2.7 EC$ = 1 US$)
GDP	Gross Domestic Product
GEF	Global Environmental Facility
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (GmbH)
MSW	Municipal Solid Waste
NPV	Net Present Value
OAS	Organization of American States
OECS	Organization of Eastern Caribbean States
OLADE	Organisacion Latino Americano de Energia
OSDE	Office for Sustainable Development and Environment
O&M	Operation and Maintenance
PV	Photovoltaic
RDF	Refused Derived Fuel
RET	Renewable Energy Technology
SIDS	Small Island Developing States
UNDP	United Nations Development Program
UNEP	United Nations Environmental Program
UNF	United Nations Fund
UNIDO	United Nations Industrial Development Organization
USAID	United States Agency for International Development
US$	United States Dollar
UU	Utrecht University
UWI	University of West Indies
UWICED	University of West Indies Centre for Environment and Development

Executive summary

This thesis is the result of a co-operation between the Copernicus Institute of Utrecht University, the Netherlands and the Organization of American States (OAS) as part of the Global Sustainable Energy Islands Initiative project (GSEII). This is a project where the OAS and other international partners help Caribbean islands to develop Sustainable Energy Plans. Currently the OAS is helping three small islands states, namely Dominica, Saint Lucia and Grenada with the formulation of a Sustainable Energy Plan and St Kitts and Nevis will likely be added to this group.

The main goal of this research is to provide policy and energy planners related to the Caribbean island of St. Kitts and Nevis a long term (2005-2015) electricity cost assessment of different electricity supply scenarios including renewable energy technologies (RET) to meet future estimated electricity demands. Other related objectives are: 1) to promote a more varied mix of electricity production technologies or increase the contribution of renewable energy technologies to the electricity supply system to decrease the energy supply dependency of small island developing states (SIDS) in the Caribbean; 2) to set up a general methodology for SIDS using a combination of the HOMER (energy demand and supply match model) and the BOSDA (multi-criteria analysis model) model to facilitate and set more realistic targets to improve the introduction of renewable energy technologies when setting up a Sustainable Energy Plan.

Starting point / background

St. Kitts and Nevis' energy sector is run by two utilities: on St. Kitts the state owned St. Kitts Electricity Department and on Nevis the private/state owned Nevis Electricity Company Ltd. (NEVLEC). They both manage the production and distribution of the electricity.

The St. Kitts Electricity Department has 33.5 MW of installed capacity using 7 diesel fueled generators. The fuel that is used for electricity production is Diesel 45 Cetane 0.5% Sulfur fuel oil #2 also referred to as "Gasoil"[1]. The Needmust power plant of St. Kitts Electricity Department has a load factor of 0.73 and the overall power plant fuel efficiency is 40%[2]. Figure A-1 depicts the projected annual peak demand for St. Kitts in the period 2005 to 2015.

[1] A gas oil type distillate of lower volatility with distillation temperatures at the 90 percent boiling point between 540 and 640 ^{o}F. No. 2 distillate meets the specifications for No. 2 heating or fuel oil as defined in ASTM D396 and/or specifications for No. 2 diesel fuel as defined in ASTM Specification D975, source: T. Lidderdale, EIA, 1993

[2] From communication with representatives of St. Kitts Electricity Department, 2005

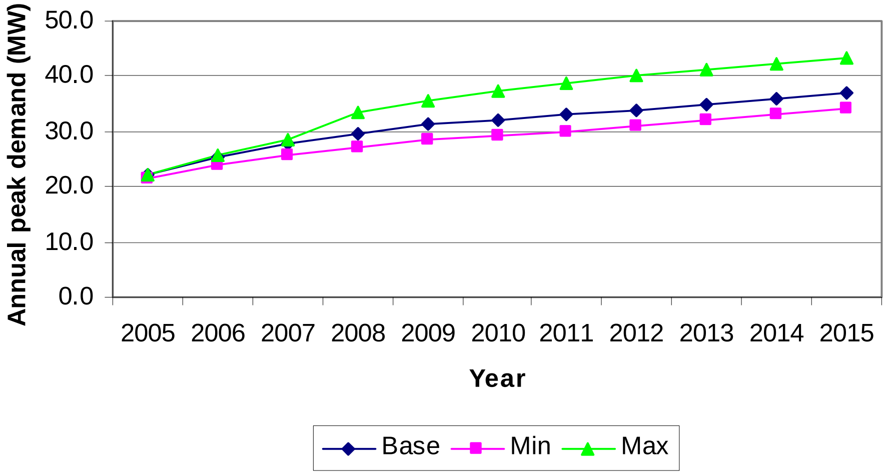

Figure A-1 Projection of the Annual peak demand for St. Kitts for the period 2005-2015[3]

Nevis Electricity Company has a total installed capacity of 13.7 MW using 7 diesel fueled generation units. The overall load factor is around 74% and the power plant has an overall fuel efficiency of 35%[4]. Figure A-2 depicts the projection of the annual peak demand on Nevis in the period 2005 to 2015.

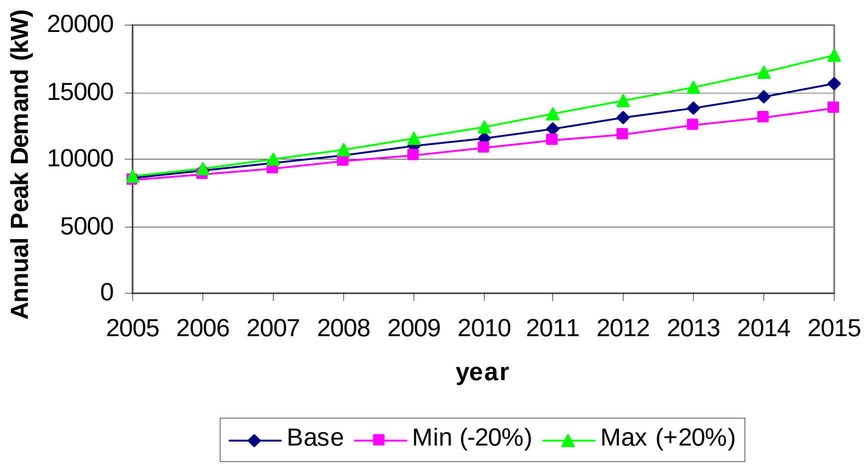

Figure A-2 Projections of the annual peak demand for Nevis for the period 2005-2015

Scenarios

Four scenarios for each island have been constructed, denoted with K or N for St. Kitts or Nevis, respectively. The Business as Usual (BAUK or BAUN) scenario projects the possible development in case no RET is introduced within the timeframe of this study, thus 2005 to 2015. Scenario K1/N1 is the best case scenario that represents the possible fast RET introduction in case there is a general consensus formed by the stakeholders involved in the energy development of St. Kitts and Nevis and without occurrences of set backs in the project procedure or development. Scenario K2/N2 is considered the intermediate scenario, where the assumption is made that the

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[3] Source: Generation Expansion Plan (2005-2015), St. Kitts Electricity Department (2005)

[4] From communications with representatives of NEVLEC, 2005

earliest a RET will start its operation will be in the year 2012. This is because no direct consensus is found on which RET to introduce and that there are cases of stagnation in the implementation procedure. Scenario K3/N3 is the worst case scenario and shows a possible development if no consensus is formed by the stakeholders and that causes time delay in feasibility studies or start up of operation up until 2015. See figures A-3 and A-4 for an overview.

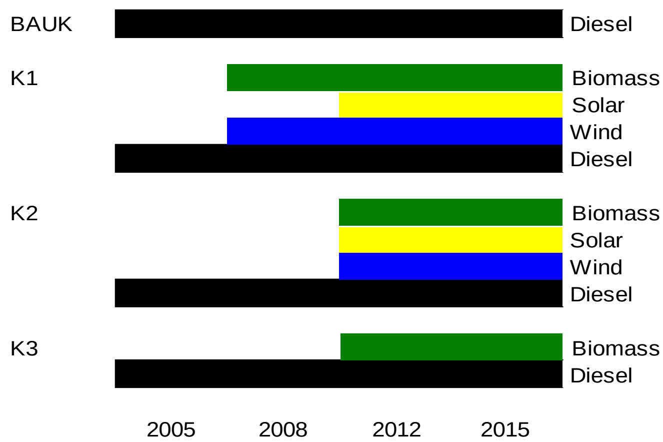

Figure A-3 Schematic overview of used scenarios for St. Kitts

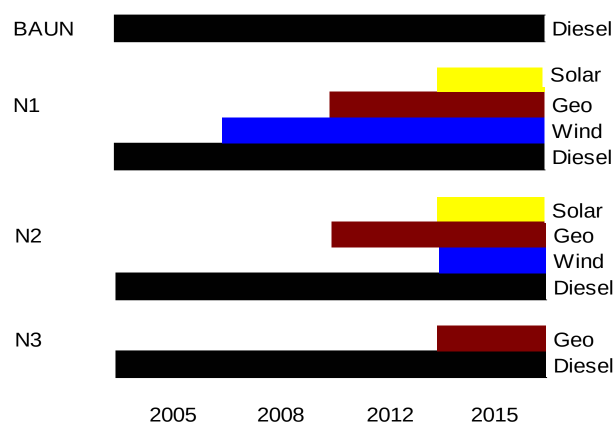

Figure A-4 Schematic overview of used scenarios for Nevis

In figures A-3 and A-4 one can see that the difference between the scenarios for St. Kitts and Nevis is that on St.Kitts, bio-energy is considered, while on Nevis the geothermal option is analyzed.

Comparative results of scenarios

Four main indicators are used for the evaluation of the scenarios, the levelized cost of electricity production (COE), the net present cost (NPC), the CO_2 emissions and the renewable fraction.

The levelized electricity production cost (COE) is the average cost for electricity production for a single or an integration of electricity production systems, including renewable energy production systems. In this cost calculation the main parameters are the generation capital investment costs, the generation operation and maintenance costs, the replacement costs and the fuel costs. Figure A-5 depicts the COE for each scenario related to St. Kitts. See figure A-6 for the COE of the scenario related to Nevis. It is clear that for all four scenarios there is a decreasing tendency of the COE over the period 2005 to 2015.

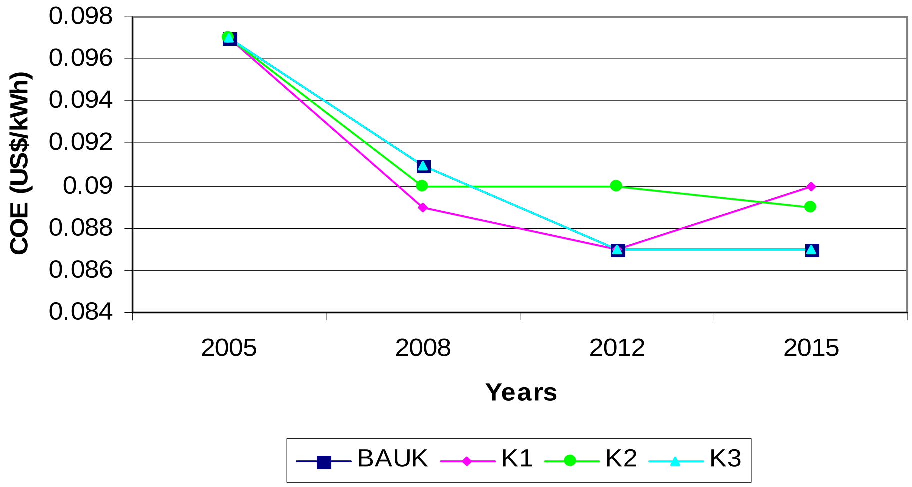

Figure A-5 Levelized cost of electricity per scenario for St. Kitts

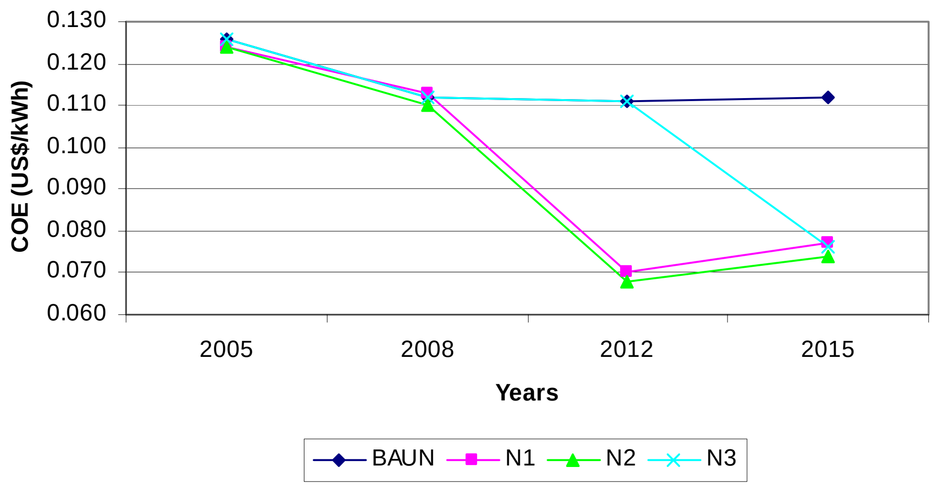

Figure A-6 Levelized cost of electricity per scenario for Nevis

The net present cost (NPC) is calculated based on the capital recovery factor and the project lifetime and includes all the costs and revenues that occur within the project lifetime into one lump sum in today's dollars, with future cash flows discounted back to the present using the discount rate. All costs provided in the results are real costs, thus constant dollars of the year 2005. Figures A-7 and A-8 show the net present costs of each scenario for St Kitts and for Nevis.

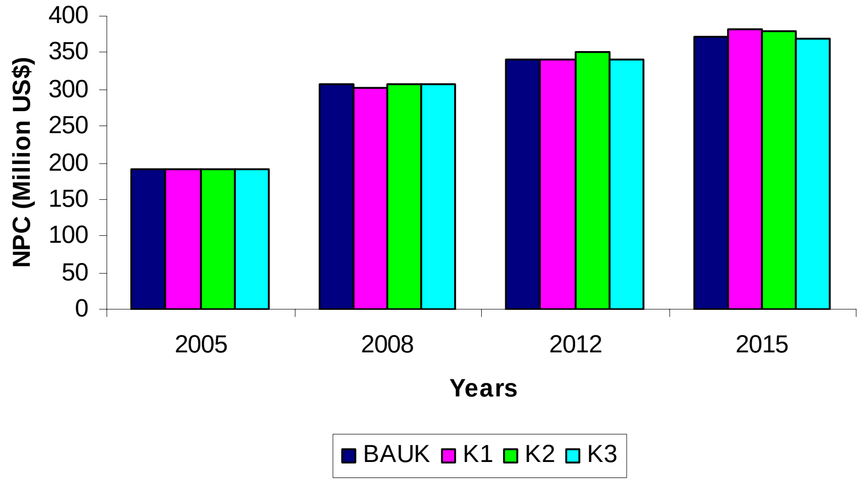

Figure A-7 Net Present Cost per scenario for St. Kitts

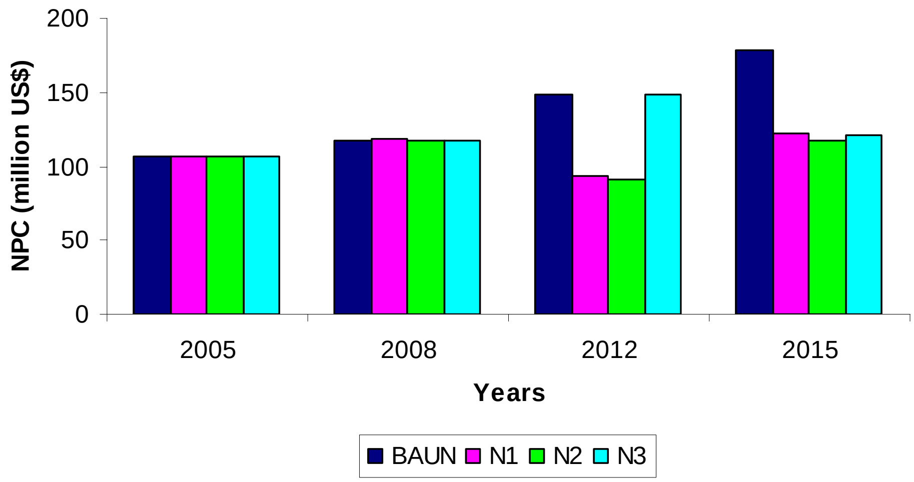

Figure A-8 Net present costs per scenario for Nevis

The third indicator is the CO2 emission of each scenario. When the CO_2 emissions related to each scenario are compared to the business as usual scenarios (BAUK and BAUN scenarios), an estimation can be made of the CO_2 emission reduction and this will be quantified in money value. This is because since the ratification of the Kyoto Protocol by Russia[5] to combat the global warming, the Carbon credit market has become official. It is a booming market and it is important for savings in investment costs for projects within the Clean Development Mechanism (CDM) or Joint Implementation (JI) schemes for which St. Kitts and Nevis is entitled to. Figures A-9 and A-10 show that for both islands it is the best case scenario K1/N1 that scores best on the carbon credit value.

[5] The Kyoto Protocol took effect in February 16, 2005, source: UNFCC website http://unfccc.int/2860.php/

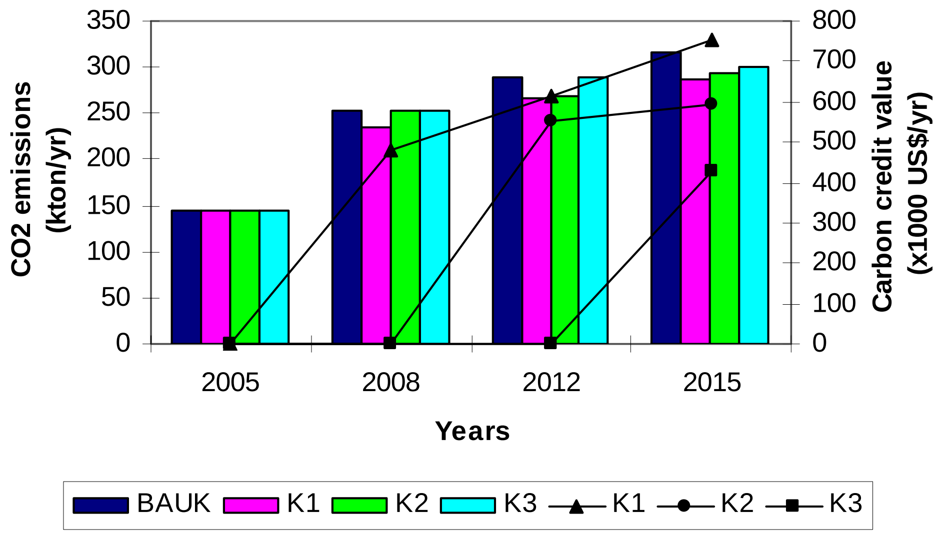

Figure A-9 CO2 emissions and carbon credit of scenario for St. Kitts

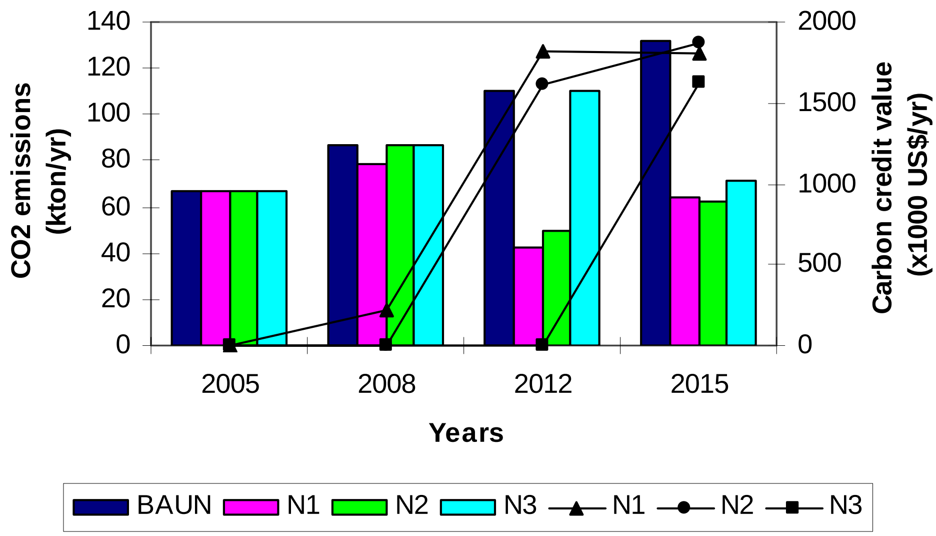

Figure A-10 CO2 emissions and carbon credits of scenarios for Nevis

As indicator for social impact, the renewable fraction is used; this is because the larger the contribution of renewable energy the less dependent the economy of St. Kitts and Nevis will be to external diesel fuel price developments. Also, continuation of the renewable energy projects can create diversified employment. Figures A-11 and A-12 show an overview of the renewable fraction results.

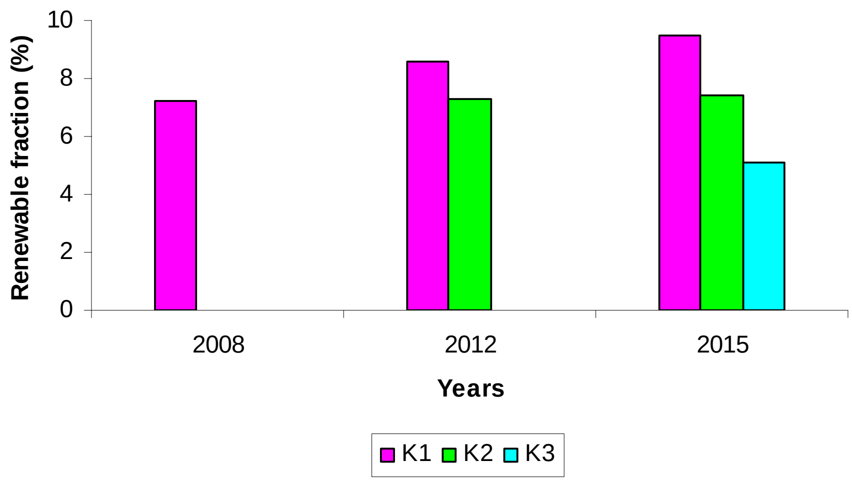

Figure A-11 Renewable fraction in each scenario for St. Kitts

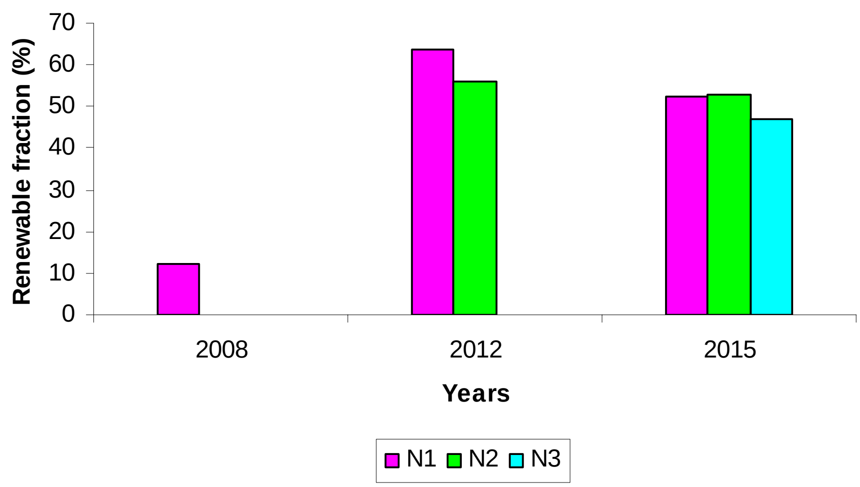

Figure A-12 Renewable fraction in each scenario for Nevis

Multi criteria analysis

A multi criteria analysis is performed to select the best scenarios for each island. The weighing of values of the four indicators used is subjective. In order to limit the subjectivity in the results, it is chosen to take two perspectives in account, the economical and the socio-environmental perspective. In the case of the economical perspective a higher weighing value is set on the cost reduction or cost effectiveness of the electricity production system, thus the COE and NPC, where for instance the lower the COE, the better. In case of the socio-environmental perspective attention is set on the decrease of environmental impact, as the CO_2 emission reduction. As social impact, the renewable fraction is highly valued, this is because the larger the contribution of renewable energy the less dependent the economy will be to external diesel fuel price developments.This means higher weighing values are set on the CO_2 emissions and the renewable fraction.

From the multi criteria analysis it resulted that for St. Kitts, the scenario K1 scored best on all the four indicators using both the economical and the socio-environmental view point. In the case of

Nevis, the N2 scenario scored best from the economical perspective and scenario N1 scored best from the socio-environmental view point.

Details best scenarios

Figure A-13 shows the optimal capacity expansion plan for St. Kitts, where the system architecture for the period 2008-2015 is: 4 x 800kW Nordex wind turbines, 2.9 MW Bio energy plant, an inverter/rectifier capacity of 3.5 MW and an increasing diesel capacity over the years from 50.6 to 63.4 MW in period 2005-2015. In a later stage a 5.4 MW Solar PV capacity is added to the energy production mix. This means less diesel is required compared to the business as usual scenario, and thus less fuel usage, a lower COE and lower CO_2 emissions. Note that the total installed capacity (diesel + RET capacity) is the minimal required installed capacity in order to have a 0% capacity shortage.

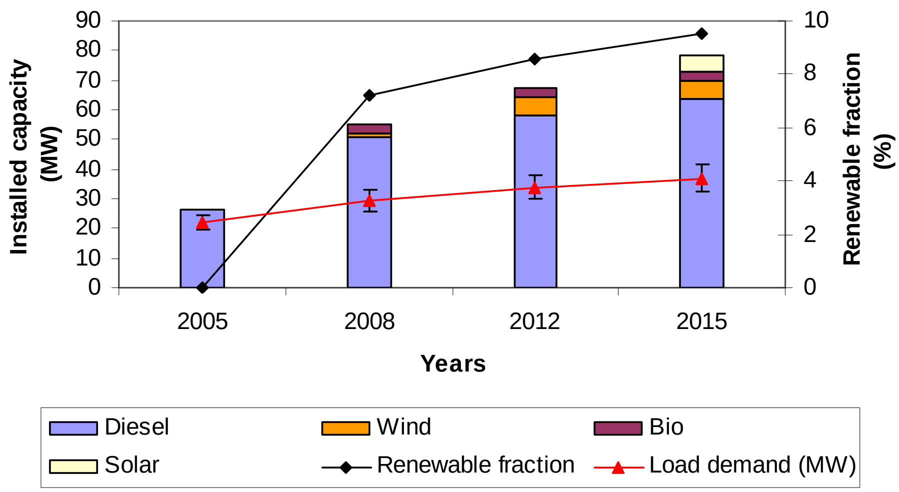

Figure A-13 Optimal capacity expansion for St. Kitts (K1 scenario)

In the case of Nevis, the N1 scenario (with fast and high contribution of RETs) that scored best on the socio-environmental perspective, the system configuration consists of diesel capacity, 10 MW geothermal capacity and 6 x 800 kW Nordex turbines as wind energy (see Figure A-14). In the case of the N2 scenario a 10 MW geothermal technology development will be in operation in 2012, while in the wind option is introduced in a later stage (See Figure A-15). As in scenario N1, here the geothermal technology has a great impact on the fuel usage and thus also the COE, next to this the CO_2 emissions are reduced considerably.

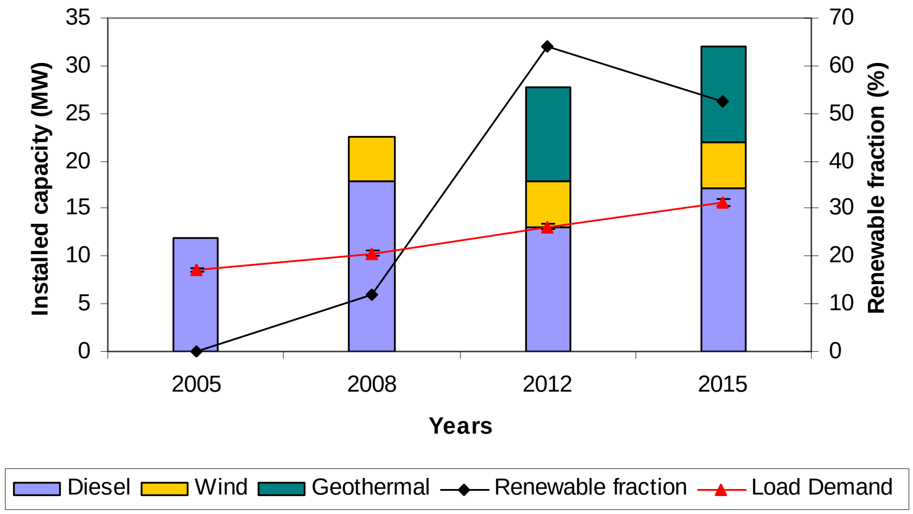

Figure A-14 Overview of results of the N1 scenario for Nevis

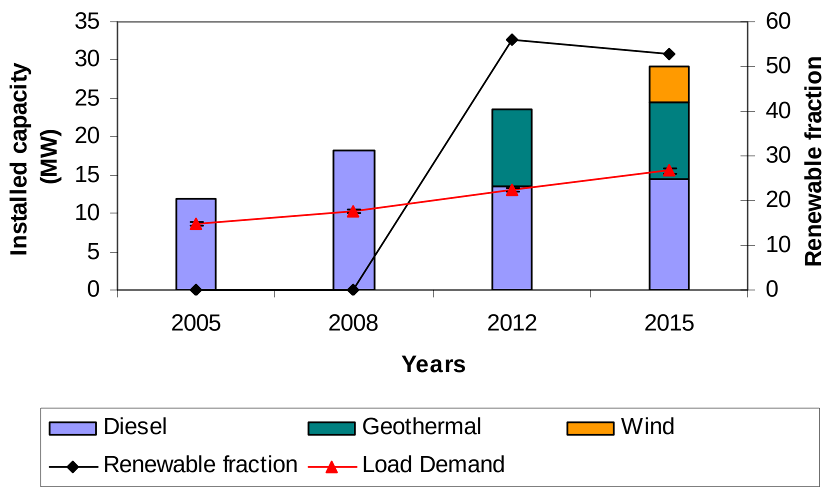

Figure A-15 Overview of results of the N2 scenario for Nevis

Sensitivity analysis

A sensitivity analysis is performed to identify the input data that has the highest influence on the main performance indicator, the levelized cost of electricity production (COE). By entering several values covering a range of input data one can see how the results vary across that range. Figure A-16 shows the sensitivity results for the biomass feedstock price, fuel price, capital investment in converter and interest rate. These are input data collected with high uncertainty or which are own estimates.

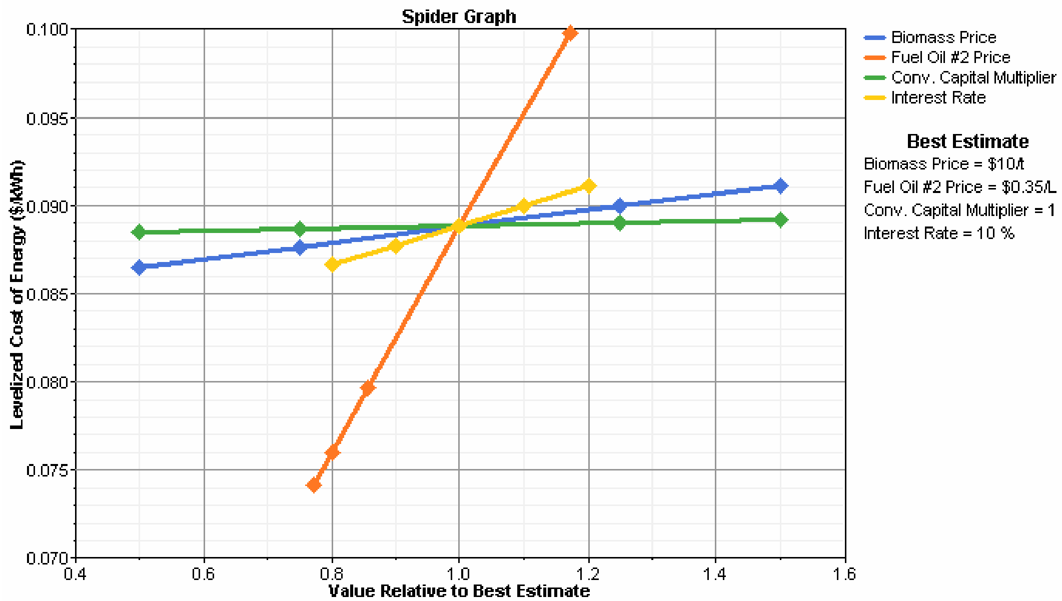

Figure A-16 Sensitivity of COE for variations in biomass price, fuel oil price, conversion investment costs, and interest rate for the K1 scenario

From figure A-16 one can see that the diesel fuel price has the highest influence on the change of the COE. For the fuel cost, the possible fuel price development is based on different scenarios from the US energy information administration (EIA), including possible price development due to the new energy supply agreement "PetroCaribe" for the Caribbean, that St. Kitts and Nevis in 2005 has signed with Venezuela. The fuel price can range between 0.28-0.41 US$/L. The lowest fuel price of 0.28 US$/L represents the possible future Petrocaribe price, the high fuel price of 0.41 US$/L is the case of the high diesel fuel price development as projected by the EIA and will cause a change in the COE of 0.089±0.014 US$/kWh for the best case scenario (K1 scenario) for St. Kitts.

Figures A-17 and A-18 show the maximum range the COE can deviate during the period 2005 to 2015 for the best case scenarios K1 for St. Kitts and N1 for Nevis.

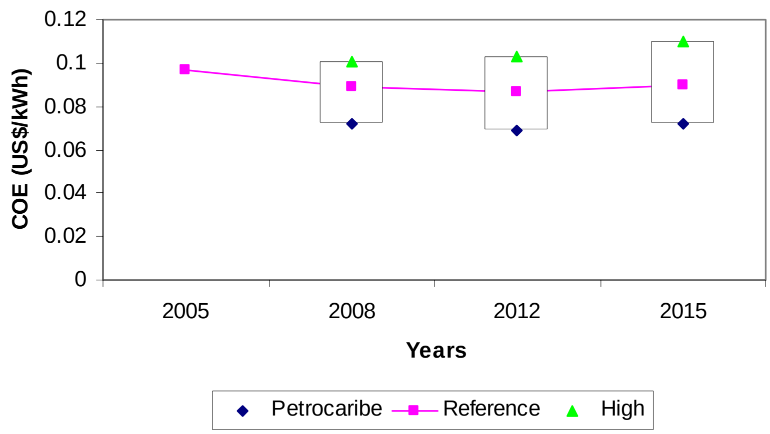

Figure A-17 Maximum cost of electricity production deviation for scenario K1 over the period 2005-2015

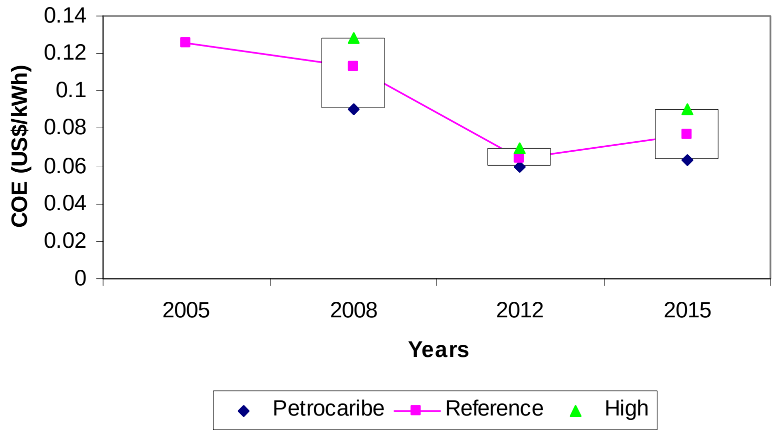

Figure A-18 Maximum cost of electricity production deviation for scenario N1 over the period 2005-2015

In figure A-18 one can see that in 2012 the fuel price has less influence on the COE, this is because a 10 MW geothermal system is added to the electricity production mix, that causes for less needs of diesel generators, thus less fuel imports.

Conclusions

For the islands of St. Kitts and Nevis this study pointed out that the scenarios that result to have the greatest economical and socio-environmental benefits are scenario K1 for St. Kitts and scenarios N1/N2 for Nevis. On St. Kitts the two renewable energy technologies that are recommended to introduce into the electricity production system over the period 2005 to 2015 are bio-energy and wind energy. For Nevis the recommended renewable technologies are the geothermal option and wind energy.

Since in this study a brief natural resource assessment is done and the theoretical energy production potential of each renewable technology is estimated, it is recommended to use the results of this study as a guideline for policy making towards a sustainable energy plan for the federation of St. Kitts and Nevis. More detailed studies are needed to quantify the real energy production capacity of each renewable energy technology.

1. Introduction

1.1 Background and Problem description

The Caribbean region consists of many diverse small islands and countries. For small island developing states (SIDS) it is a challenge to develop in a sustainable manner and introduce renewable energy technologies (RETs). The islands have to deal with limited resources, limited spatial area, and limited availability of technologies and also have to cope with natural disasters. On the other hand looking from a different perspective, these small islands states also have beneficial circumstances as excessive sunlight, constant warm temperatures, and easy access to sea, wind and have small treatment areas. These circumstances create the prospects for good returns in investment in some renewable energy technologies (Haraksingh)[6].

From a study done by Jensen (2000)[7] it results that on the majority of the islands worldwide, expensive and environmentally damaging fossil fuels are still the only energy source utilized. In general these fossil fuels are imported from external markets where geo-political developments have influence on the fluctuating prices. This puts high pressure on and brings uncertainty to the islands security of energy supply and also creates unnecessary financial burden on the islands governments' budget (Weisser, 2003)[8]. Small developing islands cope with another problem which is the rapid increase in population size and economic activities. The population growth leads to higher electricity demand and puts pressure on the energy supply system. Next to this it is of great importance that stable and environmentally responsible electricity is supplied for a healthy and sustainable economical development, this can be considered as a part of a Sustainable Energy Plan that is based on the Sustainable Development ideology.

In 1987 the Brundtland Report, also known as *Our Common Future*, alerted the world to the urgency of making progress toward economic development that could be sustained without depleting natural resources or harming the environment. Published by an international group of politicians, civil servants and experts on the environment and development, the report provided a key statement on sustainable development, defining it as:

"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs"(Brundtland Report, 1987).

Considering all the above named problems related to the import of primary fuels while the Caribbean region has great amount of solar, wind, geothermal or other renewable energy sources available, the question arises as to why such resources remain largely untapped?

When introducing a renewable energy technology it is important that the technologies are next to compatible with the technology capacity on an island, also economical feasible and corresponding to the socio-economic situation of the state and region on the long term as well as environmentally responsible.

There are several problems with the implementation and management of RETs on small islands. The International Energy Agency[9] (IEA, 2000) considers the economics of renewable energy as

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[6] Haraksingh, I., The State of the Art of Renewables in the Caribbean, Department of Physics, The University of the West Indies, St. Augustine, Trinidad & Tobago
[7] Jensen, T.L., Renewable energy on small islands, Second edition, August 2000
[8] Weisser, D., Costing electricity supply scenarios: A case study of promoting renewable energy technologies on Rodriguez, Mauritius, June 2003
[9] International Energy Agency (IEA), Energy Technology and Climate Change, A call for action, OECD/IEA, 2000

the largest barrier to renewable technology penetration. This is because most fossil fuel based electricity technologies have been developed over the last decades with large public support and have a technological advantage over renewable technologies, as the direct electricity production costs are in general lower. Others as Jensen (2000)[7] say that the lack of knowledge transfer, lack of maturation of the RETs and the organizational models used for planning are the main limitations.

Haraksingh[6] sums the following restrictions to the implementation of RETs for small island states:

- Lack of capital
- Shortage of hard currency
- Policy framework – lack of subsidies or tax exemptions
- Utility resource acquisition procedures that favor conventional technologies
- Lack of trained manpower
- Lack of community and private sector involvement
- Transfer technology limitations

Resolving these limitations of introduction and implementation of RETs is of great importance for the feasibility and credibility of future Sustainable Energy Plans. Policy makers depend on such plans to create or adapt energy policies for long term responsible and stable electricity production. The combined effect of high transport costs for fossil fuel imports, a limited demand for fuels domestically and diseconomies of scale in power production, makes electricity generation not only extremely expensive but also bears financial risks in the long term (Weisser, 2004)[10].

The proliferation of RETs can offer social and environmental benefits, as well as enhancing the security of energy supply, in comparison to fossil fuel based energy systems (Weisser, 2004)[11]. Alternatives to fossil fuel generators are rarely examined analytically. Even where commercialization and privatization has been exercised, direct and indirect subsidies still exist for conventional power generation technologies giving them a head start over RETs . Subsidized electricity prices not only encourage wasteful consumption but also discourage demand for efficient electric appliances. While reforming the power sector, socio-environmental considerations are often ignored, either because decision makers perceive priorities elsewhere, or because they presume that reform will automatically lead to environmental improvement (Weisser, 2004).

Other reasons that limit the introduction of RETs in the Caribbean are: 1) the inadequate policy frameworks that govern the way a country’s energy economy and electricity tariffs are structured and organized, and 2) the inherent interests of senior officials of public/private utilities or electricity boards to promote energy technologies that lie within their own area of expertise, traditionally conventional engineering or similar.

It has been stressed by the World Bank that in order to maintain control of the reform process that the pace at which this is pursued should be directly related to the stakeholders´ ability to adapt to

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[10] Weisser, D., On the economics of electricity consumption in small island developing states: a role for renewable energy technologies?, Energy Policy 2004; 52(1): 127-40

[11] Weisser, D., Power sector reform in small island developing states: what role for renewable energy technologies?, Renewable and Sustainable Energy Reviews 8 (2004): 101-127

a changing regulatory framework, as well as allowing careful assessment of the potential outcomes of reform. However, careful planning and execution of reform is often inadequate due to urgent needs of meeting fast rising electricity demand.

It is therefore clear that short-term profit maximization of privatized enterprises can conflict with long-term governmental energy planning goals. A Sustainable Energy Plan (SEP) contains all the aspects to provide a stable and responsible electricity production development for small island states that forms a pre-requisite for healthy economic and social development.

1.2 Research question & objective

This thesis is the result of a co-operation between the Copernicus Institute of Utrecht University, the Netherlands and the Organization of American States (OAS) as part of the Global Sustainable Energy Islands Initiative project (GSEII). This is a project where the OAS and other international partners help Caribbean islands to develop Sustainable Energy Plans. Currently the OAS is helping three small islands states, namely Dominica, Saint Lucia and Grenada, with the formulation of a Sustainable Energy Plan and St Kitts and Nevis will likely be added to this group.

The small island developing state of St. Kitts and Nevis is located in the north-eastern Caribbean and is used in this thesis as case study. This research can be of great value to provide the islands' government and the aiding international organizations better insight to have a better judgment of the choices for sustainable energy policy making.

Since it is not possible to tackle all the limitations inherent in the implementation of RETs for electricity production, this research will mainly concentrate on the problem related to the economics of the RETs. To be more specific on the electricity production costs related to the introduction and operation of RETs into the electricity production mix of a small island as St. Kitts and Nevis over a period of 10 years. This is done by the usage of electricity supply scenarios to project possible outcomes and evaluate them on a financial basis. The research will not only focus on the techno-economic feasibility of RETs but has a starting point from an energy resource analysis and is also evaluated on the social and environmental impacts to identify the best combination of renewable technological options.

Main research question:

Will the introduction of technically pre-selected RETs to the energy production mix of St. Kitts and Nevis cause a decrease in the levelized cost of electricity production within 2005 to 2015 compared to a capacity expansion based on conventional diesel generation sets?

The importance of focusing on the costs related to the RETs is that policy makers should make a good assessment of alternative electricity supply solutions and their long-term cost implication a priority, because once a decision has been made in favor of one or another project, the island may make itself dependent on that choice for years or even decades to come and potentially make its fragile financial budget worse (Weisser, 2003)[8].

Main objective

The main goal of this research is to provide policy and energy planners related to the Caribbean island of St. Kitts and Nevis a long term (2005-2015) electricity cost assessment of different *electricity supply scenarios including renewable energy technologies to meet future estimated electricity demands.*

Other related objectives are: 1) to promote a more varied mix of electricity production technologies or increase the contribution of renewable energy technologies to the electricity supply system to decrease the energy supply dependency of SIDS in the Caribbean; 2) to set up a general methodology for SIDS using the HOMER model to facilitate and set more realistic targets to improve the introduction renewable energy technologies when setting up a Sustainable Energy Plan. See chapter 2 for a detailed description of the calculations used by the HOMER model.

An important characteristic of RETs is that there are high initial investment costs involved with their installment because the fuel equivalent for the life cycle of the system is essentially purchased at one time (i.e., fuel costs are negligible). This characteristic, together with the usually large existing foreign debts and high prevailing rates of interest in the Caribbean islands, makes access to investment capital an essential requirement for the widespread use of RET systems. The multilateral lending agencies normally provide capital for large energy projects, and by extension, exercise the ability to influence electricity sector planning in developing countries.

Therefore, institutions such as the World Bank, Global Environmental Facility (GEF) and the Inter American Development Bank (IDB) are often identified as important financing or implementing agencies for RET dispersion for the Caribbean region. Commercial banks are normally willing to finance renewable energy investment projects as long as bank requirements are met and the bank is convinced that the technologies work reliably.

Figure 1.1 displays a map of the Caribbean region where the above named islands are located. The islands of Saint Kitts (Christopher) and Nevis are located in the north eastern part of the Caribbean region.

Figure 1.1 Map of St. Kitts and Nevis in the Caribbean region

1.3 Structure of this thesis

This thesis is structured as follows. *Chapter 2* describes the research methodology used in this thesis. First an overview is given of the detailed research questions used in this research; secondly a description of the natural energy resource analysis method is given. Thirdly the HOMER model is described in detail, where focus is set on the theoretical background of the economical analysis. And last a brief explanation of the BOSDA model for multi-criteria analysis is described.

Chapter 3 aims at giving background information about the island of St. Kitts and Nevis to give the reader a better impression of the conditions for this research.

In *Chapter 4* the St. Kitts and Nevis´ energy sector is described. The focus is set on the energy production and consumption of the two islands. Further, the development of the energy policies is highlighted and a brief view on the Caribbean energy market is given to understand what role St. Kitts and Nevis plays in this market.

Chapter 5 deals with the natural energy resource analysis performed for St. Kitts and Nevis. The purpose of this resource analysis is to perform a quick scan of available energy sources on St. Kitts and Nevis and identify the theoretical energy production of each RET selected based on the availability of the energy source. This means that we will look at the physical conditions present on the islands and try to identify the amount of electricity that each RET could theoretically produce using the most common technology available.

In *Chapter 6* scenarios are set up for each separate island. The general assumptions made for the creation of the scenarios are explained. The scenarios include the business as usual scenario, where the conventional capacity expansion is described, and the alternative scenarios that contain a variation in combinations of RETs to comply with the projected capacity demand. Also an analysis is done on the global investment costs of RETs, the financial data of diesel fueled generators and possible fuel price development are discussed. At the end the general input data for the HOMER model are discussed.

Chapter 7 contains the overview of the results of the energy and economical analysis. The most important performance indicators for each scenario are provided and some general conclusions are drawn.

A sensitivity analysis is performed by using the HOMER model and the results of this are described in *Chapter 8*. The idea of a sensitivity analysis is to deal with the uncertainties within the input data. By entering several values covering a range of input data one can see how the results vary across that range. The results of a sensitivity analysis can also function as evaluation of trade-offs.

In *Chapter 9* the socio-environmental costs and benefits are discussed. Here the idea is to give an overview of the benefits in costs savings due to avoidance of CO_2 emissions, or savings in net present costs that could be invested in other sectors of the economy or social development.

Finnaly, in *Chapter 10* the results are discussed and in *Chapter 11* general conclusions are drawn and recommendations are formulated. It will highlight the functionality of the HOMER model for this type of study and also give general ideas how to progress further towards a Sustainable Energy Plan for St. Kitts and Nevis.

2. Research methodology

To reach the main objective and answer the following research questions, several steps have to be taken to gather relevant data and do research to finally produce data and evaluate them for final conclusions. In this section the research methodology of this study is described in steps. As the starting point, the main research question is considered.

Main research question:

Will the introduction of technically pre-selected RETs to the energy production mix of St. Kitts and Nevis cause a decrease in the levelized cost of electricity production within 2005 to 2015 compared to a capacity expansion based on conventional diesel generation sets?

The following research sub questions were used to gather relevant data for this study.

General research sub questions	
General background	
1a	What is the demography and the geo-physical character of the islands?
1b	How is the infrastructure and the economical development of the islands?
Energy Sector of St. Kitts and Nevis	
2a	What diesel fueled generation sets are used? What are the investment and O&M costs related to the existing diesel fueled systems?
2b	How much electricity is being produced and consumed?
2c	What is the diesel oil import quantity, type and costs? And what are the possible oil/diesel developments?
2d	What is the current price of the electricity (US$/kWh) on the islands?
2e	What are the energy demand projections for the coming 10-15 years?
2f	How is the current energy policy on the island? Are there targets set to introduce or increase contribution of RETs or energy efficiency upgrade?
2g	Are there or which renewable energy technologies are used on the island? If yes, what is their installed capacity?
Renewable Energy Technologies	
3a	What are the renewable energy sources available on or around the island?
3b	Which renewable energy technologies are feasible based on energy resource availability? What is the theoretical energy production potential?
3c	What are the investment and O&M costs related to the pre-selected RETs?
Scenarios, Models and Analysis	
4a	Which assumptions and demarcations are taken into account to create the electricity production scenarios?
4c	What are the possible investment cost developments for the diesel generator sets and the RETs?
4d	What is the cost of electricity production competition between the electricity production scenarios? (use of HOMER model)
4e	What impact do the scenarios have on the socio-economical and environmental aspects? (use of BOSDA model)
Results and Conclusions	
5a	Which electricity production scenario scores the best, based on techno-economic and socio-environmental perspective?
5b	What recommendations can be given related to energy policy development?

2.1 Renewable energy resource analysis

The renewable energy resource analysis is done in a brief way; the objective is to estimate the current renewable energy resource availability and to quantify the theoretical energy production capacity. This means that for each renewable energy source a simple methodology will be used to quantify the amount of energy that could be produced by a RET. The resource availability and general comparison between all RETs considered will give an indication of which RET has the greatest potential and is pre-selected for further analysis.

2.2 Scenario build-up

A total of eight scenarios were developed for this study. Four scenarios for St. Kitts and four for Nevis. For each island there is a business-as-usual scenario (BAUK, BAUN), high and fast RET contribution scenario (K1, N1), an intermediate RET introduction time and contribution scenario (K2, N2), and as last a slow RET introduction and low contribution scenario (K3, N3). Each scenario projects a possible investment in capacity expansion development with variations in RET contribution and start of operation over the period 2005 to 2015.

Demand and load curve projections

In the case of St. Kitts Electricity Department, a private consultancy calculated the demand projections based on their own projection model. Their projection method was based on analyzing the energy demand of three sales categories (General Services, Domestic Services and Industrial/Commercial sector) and using three scenarios where the likelihood of implementation of future development projects differs[12]. For NEVLEC use is made of the historical data provided by NEVLEC and these have been extrapolated to create demand projections with a max and min range of +/- 20%, the maximum roof or point in demand where the projection will become linear is set at 80 MW after 2035.

For the future load curves, use is made of the percentual growth rate of the base line scenarios of the demand projection of each island. This is done to be able to use the HOMER model more effectively. Also 4 evaluation moments are considered, the years 2005, 2008, 2012 and 2015 to build up the energy supply scenarios for St. Kitts and Nevis.

2.3 Energy and Economical Analysis

This study aims to identify the best possible electricity production system based on economic, social and environmental perspective. Hereby it is thus important to calculate the electricity production costs and compare them to the social and environmental benefits that can be attained from each scenario. Due to limited availability of data a qualitative analysis is done related to the social and environmental costs.

Electricity production cost calculation

The HOMER model[13] (Lambert, 2006) is used to calculate the levelized electricity generation costs (US$/kWh) and the net present costs (NPC) related to each scenario. The model models a power system's physical behavior and its life-cycle cost, which is the total cost of installing and operating the system over its lifetime, see also Appendix 1. The levelized electricity production cost (COE) is the average cost for electricity production for a single or an integration of

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[12] Stanley Consultants, Generation Expansion Plan for the St. Kitts Electricity Department (2005-2015), April 2005

[13] From a comparative study on RET evaluation models, the HOMER model resulted to have the best flexibility for combining RETs and least input data complexity and thus good fit to the conditions for this study. See the following sources for more information on alternative evaluation models: http://www.retscreen.net/ang/d_0_4.php (Canadian, RETScreen model), http://www.nrel.gov/international/analysis_software.html (NREL models), http://www.eere.energy.gov/tribalenergy/guide/economics.html#energy (US dep. of Energy), http://www.discoversolarenergy.com/resources/software.htm (Renewable Energy Software).

electricity production systems, including renewable energy production systems. In this cost calculation the main parameters are the generation capital investment costs, the generation operation and maintenance costs, the replacement costs and the fuel costs. The net present cost (NPC) is calculated based on the capital recovery factor and the project lifetime and includes all the costs and revenues that occur within the project lifetime into one lump sum in today's dollars, with future cash flows discounted back to the present using the discount rate. All costs provided in the results are real costs, thus constant dollars of the year 2005.

The net present cost (NPC)
All the analysis output of the electricity production systems in HOMER are ranked according to net present cost, and all other economic outputs are calculated for the purpose of finding the net present cost. The net present cost is calculated with the following equation:

$$C_{NPC} = \frac{C_{ann,tot}}{\mathrm{CRF}\left(i, R_{proj}\right)} \qquad (2.1)$$

where:
$C_{ann,tot}$ = total annualized costs (US$/yr)
CRF ( ) = capital recovery factor
i = interest rate (%)
R_{proj} = project lifetime (years)

The total annualized cost is the sum of the annualized costs of each system component, plus the other annualized costs. It is an important value because HOMER uses it to calculate both the levelized costs of energy production and the total net present cost. The project lifetime is the length of time over which the costs of the system occur. HOMER uses the project lifetime to calculate the annualized replacement cost and annualized capital cost of each component, as well as the total net present cost of the system.

The capital recovery factor
The capital recovery factor is a ratio used to calculate the present value of an annuity (a series of equal annual cash flows). The equation for the capital recovery factor is:

$$\mathrm{CRF}\left(i, N\right) = \frac{i\left(1+i\right)^N}{\left(1+i\right)^N - 1} \qquad (2.2)$$

where:
i = interest rate (%)
N = number of years

The interest rate
The interest rate that one enters as HOMER's input is the annual real interest rate (also called the *real interest rate* or just *interest rate*). It is the discount rate used to convert between one-time costs and annualized costs. The annual real interest rate is related to the nominal interest rate by the equation given below.

$$i = \frac{i' - f}{1 + f} \qquad (2.3)$$

where:
i = real interest rate
i' = nominal interest rate (the rate at which you could get a loan)
f = annual inflation rate

The levelized cost of energy (COE)
HOMER calculates the average cost of producing electricity (COE) using the following formula:

$$COE = \frac{C_{ann,tot}}{E_{prim,AC} + E_{prim,DC} + E_{def} + E_{grid,sales}} \tag{2.4}$$

where:
$C_{ann,tot}$ = total annualized cost of the system (US$/yr)
$E_{prim,AC}$ = AC primary load served (kWh/yr)
$E_{prim,DC}$ = DC primary load served (kWh/yr)
E_{def} = deferrable load served (kWh/yr)
$E_{grid,sales}$ = total grid sales (kWh/yr)

The AC primary load served is the total amount of energy that went towards serving the AC primary load(s) during the year. The DC primary load served is the total amount of energy that went towards serving the DC primary load(s) during the year. The deferrable load served is the total amount of energy that went towards serving the deferrable load during the year. The grid sales are the excess energy produced by the system that can be sold to the grid.

Environmental impact
For the environmental impact assessment and as part of the economical analysis the CO_2 emission reduction is calculated for each scenario. The CO_2 emissions related to each scenario are compared to the business as usual scenarios (BAUK and BAUN scenarios) to estimate the CO_2 emission reduction and this will be quantified in money value. This is because since the ratification of the Kyoto Protocol by Russia[14] to combat the global warming, the Carbon credit market has become official. It is a booming market and it is important for savings in investment costs for projects within the Clean Development Mechanism (CDM) or Joint Implementation (JI) schemes for which St. Kitts and Nevis is entitled to.

2.4 Multi Criteria Analysis

With the BOSDA model (see appendix 2 for more detail), a multi criteria analysis is performed using the collected data on the COE, NPC, CO2 emissions and renewable fraction related to each scenario to identify the best scenario for further scrutinization, based on adding weighing factors to each parameter to create two opposite perspectives, as the economical and the socio-environmental perspective.

2.5 Sensitivity analysis

The sensitivity analysis is done to evaluate the uncertainty incurred in the results or the robustness of the scenarios. By entering several values covering a range of input data one can see how the results vary across that range. The results of a sensitivity analysis can also function as evaluation of trade-offs.

[14] The Kyoto Protocol took effect in February 16, 2005, source: UNFCC website http://unfccc.int/2860.php/

3. Background information St. Kitts and Nevis

In this chapter a first look is taken at the general aspects of the islands of St. Kitts and Nevis. In Chapter 4 the focus will be on the energy sector of the islands, and the historical electricity production and consumption will be highlighted. Also, the development of the energy policies and a brief view on the Caribbean energy market is given to understand what role St. Kitts and Nevis play in this market.

3.1 General information

The Federation of St. Kitts and Nevis is part of the Leeward Islands group lying about 200 miles southeast of Puerto Rico and to the north of the Windward group. The islands cover a total area of 269 sq. km (104 sq. mi.). The two islands are separated by a two mile stretch of water. St. Kitts is 176 sq. km. (68 sq. mi.) in size and is approximately 36.8 km (23 mi) long. It is roughly oval in shape with a narrow neck of land extending like a handle from the southeastern end. Nevis has a surface area of 93 sq. km. (36 sq. mi), with a length of 12.3 km (7.64 mi) and a width of 9.6 km (5.96 mi) at its widest point[15].

There are 57 km (35.4 mi.) of railroads on the narrow gauge on St. Kitts used solely for sugar cane. Next to this there are 300 km (186 mi.) of roads. On each island there is one airport located, the Robert Liewelyn Bradshaw International Airport is located about two miles from Basseterre (St. Kitts) and the Newcastle Airport is located about 6 miles from Charlestown (Nevis). See figure 1.1 for an overview of the islands.

The climate of the Federation of St. Kitts and Nevis is classified as tropical marine. Generally, it is influenced by steady northeast trade winds and tropical oceanic and cyclonic movements. The relative humidity is fairly high all year round - approximately 75% - 80%. It is usually low in the dry season and high in the wet season. The mean value is 76%, but it ranges from 70% in March, to 78% in September, October and November. Rainfall is mainly cyclonic and increases in amount and frequency with altitude. Mean annual rainfall ranges from about 890 – 1000 mm (35 - 40 inches) in the coastal areas, to about 2500 – 3800 mm (100 - 150 inches) in the central mountain ranges. The rainfall is unevenly distributed between years and between months, but there is a reliable wet period from August to September and a dry period from January - April. Temperatures average approximately 27˚ Celsius and seasonal variations in temperature are small.

3.2 Population

The population of St. Kitts and Nevis is currently about 42,740 (2005). The population on St. Kitts is around 32,397 (75.8% of the total) with a population density of 186 persons per sq. km, where about 40% of the St. Kitts population lives in the Basseterre capital region. In Nevis the population is 10,343 (24.2%) with a lower population density of 111 persons per sq. km.

In figure 3.1 the population development from 1991-2001 is shown, with a linear extrapolation untill 2015.

[15] Climate Institute, http://unfccc.int/resource/docs/natc/kitnc1.pdf

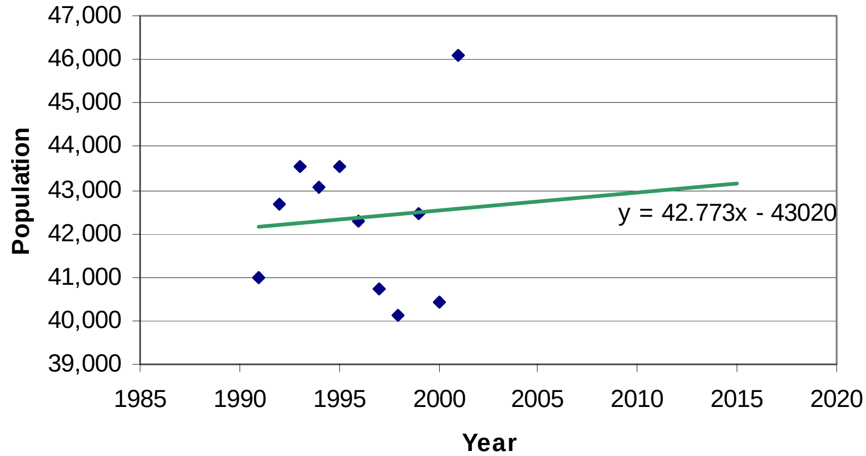

Figure 3.1 Population of St. Kitts and Nevis for the period 1991-2015[16]

When we look at figure 3.1, the population dynamics resulted to be relatively stable between 40,000 to 44,000 for the period 1991-2000. Only in 2001 the population increased up to 46,111. Thus it is decided to extrapolate lineairly to have a rough estimate of the population growth, which is about 0.1% per year.

3.3 State and economy

Nevis and St. Kitts were discovered by Columbus in 1493 and settled by the English in 1625. For 200 years their considerable sugar production made them one of the richest spots on earth. They remained British colonies until they gained their independence in 1983, as the Federation of St Kitts and Nevis. The country is a member of the Organization of Eastern Caribbean States (OECS), the Caribbean Community (CARICOM), the Organization of American States (OAS) and the United Nations (UN).

The prime minister, as leader of the majority party in the House, leads a cabinet of four other ministers and an attorney general. The Constitution allows for Nevis to have its own legislature, premier, deputy governor general, and cabinet members, as well as a guaranteed central government representation. The legal system in the islands is based on English common law. They are served by a Regional Supreme Court of judicature, established for the Associated States, composed of a High Court of justice and a Court of Appeal.

The Federation of St. Kitts and Nevis is one of eight island governments using the Eastern Caribbean dollar ($EC). It is pegged to the US dollar at a fixed rate of $US 1.00 to $EC 2.70. That rate of exchange has remained constant for over 20 years, and all eight participating Governments must agree on any change in currency value. It is a very stable currency[17].

Figure 3.2 shows the development of the Gross Domestic Product (GDP[18]) per capita of St. Kitts and Nevis. This is the gross domestic product divided by the total population. The annual GDP

[16] Extrapolation of collected data for period 1999-2001, St. Kitts & Nevis 1999-2004 Statistical Review, Statistics Division, Planning Unit, Ministry of Finance, Technology & Sustainable Development, 2005
[17] Source: http://www.inttrust.com/nevis.html
[18] The GDP is the sum of value added by all resident producers in the economy plus any product taxes (less subsidies) not included in the valuation output. It is calculated without making deductions for depreciation of fabricated capital assets or for depletion and

per capita growth rate for the period 1993-2003 was about 4.0% and the most recent data available is for 2003 with a GDP per capita of US$ 5427/capita.

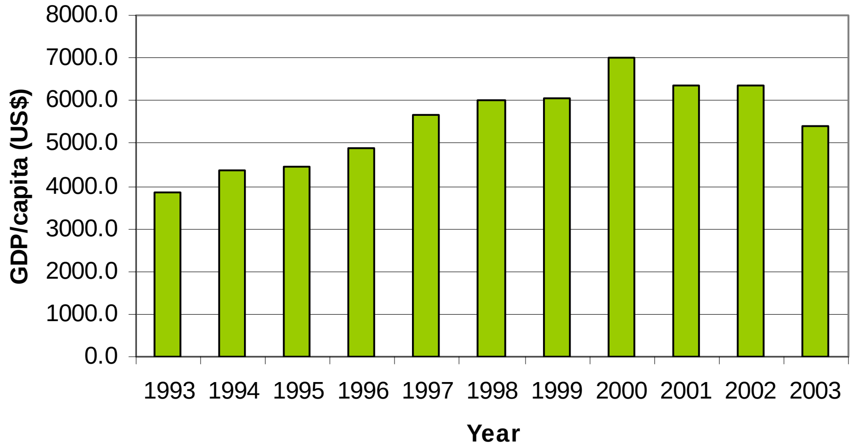

Figure 3.2 Gross Domestic Product in US$ per capita on St. Kitts and Nevis for the period 1993-2003[19]

St. Kitts' economy is based largely on sugar cultivation and tourism, with the latter hanging for strong growth in the wake of major recent infrastructure improvements. Cruise ship arrivals were on the increase in 1998 after two straight years of decline, as the Cruise Ship Pier Complex completed mid-1997 bustled with activity. In case of the sugar, because of negative sugar price development the Federation is confronted with high losses in the sugar industry and has decided to stop the production of sugar at the end of July 2005 (see section 5.1.1 for more detail). Food, manufactured goods, machinery and transportation equipment, mineral fuels, lubricants and related materials are mainly imported. In table 3.1 the contribution of each sector in the economy to the GDP of St. Kitts and Nevis is shown.

Table 3.1 GDP of St. Kitts & Nevis, by sector in constant prices (EC$ million) for the period 1994-2004[20]

SECTOR	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Agriculture	27.1	25.6	28.1	34.0	30.0	27.3	25.0	27.7	31.4	27.4	30.8
Manufacturing & Mining	48.0	50.7	53.4	59.3	58.9	63.6	74.6	79.3	76.8	75.7	80.8
Wholesale & Retail	60.3	64.6	68.4	72.3	75.3	78.1	75.6	66.9	67.1	70.2	66.8
Hotels & Restaurants	38.7	30.2	33.0	34.7	35.5	31.0	23.8	24.7	23.8	31.2	41.4
Transport	33.47	35.81	36.58	39.02	38.84	39.62	41.08	42.52	45.89	46.21	54.91
Communications	37.46	41.08	45.80	48.36	48.80	54.61	58.50	59.69	55.62	55.01	57.30
Banks & Insurance	44.03	49.69	54.27	61.20	61.16	63.25	70.49	69.77	71.04	73.35	84.88
Real Estate & Housing	13.88	14.22	14.66	15.10	12.84	13.87	14.70	15.36	15.51	15.82	16.05
Government Services	70.1	70.8	73.7	76.0	79.6	81.8	83.8	86.0	89.3	88.5	90.8
Other Services	18.8	19.8	20.5	21.2	20.5	21.4	22.2	21.6	21.9	22.5	26.1
Total	**391.8**	**402.6**	**428.4**	**461.0**	**461.5**	**474.5**	**489.7**	**493.6**	**498.5**	**505.8**	**549.8**

degradation of natural resources. Value added is the net output of an industry after adding up all the outputs and subtracting intermediate outputs

[19] Source: Statistics Division, Planning Unit, St. Kitts & Nevis Ministry of Finance, Technology & Sustainable Development, 2005

[20] Source: St. Kitts Statistics Division / ECCB (data 2003 and 2004 are provisorial)

In 2004, the largest sectorial contributors to the GDP of St. Kitts and Nevis were Government Services (16.5%), Banks / Insurance (15.4%) and Manufacturing and Minning/Quarrying (14.7%).

Until the 1970s, sugar export was the main economic income source for St. Kitts and Nevis. Due to declining profits in the sugar industry, the government began a program to diversify the agriculture sector and stimulate other sectors of the economy. Investment incentives were initiated for businesses to encourage domestic and foreign private investment.
Although the economy grew at an acceptable rate of 4.0% GDP/capita during the period (1993-2000), see figure 3.2, the domestic oriented sectors of wholesale and retail trades and Government services display relative strength in comparison with the export sectors of manufacturing and agriculture.

The economy experienced strong growth in the 1990s until 1998, when growth decreased due to effects from hurricanes. A major challenge for the government is and will be, creating economic flexibility and revitalization capacity for stimulating economic growth in case of natural disasters.

4. St. Kitts and Nevis energy sector

In the last few years, the energy sector of St. Kitts and Nevis has been having some difficulties to keep up with the demand. An article in the Caribbean Net News[21] indicated that a relatively not long time ago St. Kitts was dealing with continuous blackouts. An important declaration by the prime minister was that the government will “use the services of Stanley Consultants of Iowa, to perform a generation expansion plan for the generating system for the next 10 years, from 2005 to 2015”. Policies will be adapted to make use of full waiver of tax and duties. This report is provided and forms a good base for the present study to evaluate and forecast options for introduction of renewable energy technologies in the electricity production system of St. Kitts for sustainable energy production on long term. In the case of Nevis information was requested from the Nevis Electricity Corporation (NEVLEC).

In this chapter an overview will be given of the historic development and the current situation of the energy sector on the islands of St. Kitts and Nevis. The general data given will show information for both islands unless indicated specifically for each island. Note that this research only focuses on grid connected electricity production (energy sector) and does not go into detail for the transport sector (origin of highest GHG emissions) or industrial sector.

4.1 Energy balance

In 2004 St. Kitts and Nevis produced a total of 169.3 GWh of electricity. About 1591 TJ of primary energy was consumed in the form of Diesel/Gas Oil. Figure 4.1 gives a brief overview of the energy balance for the electricity production sector on St. Kitts and Nevis.

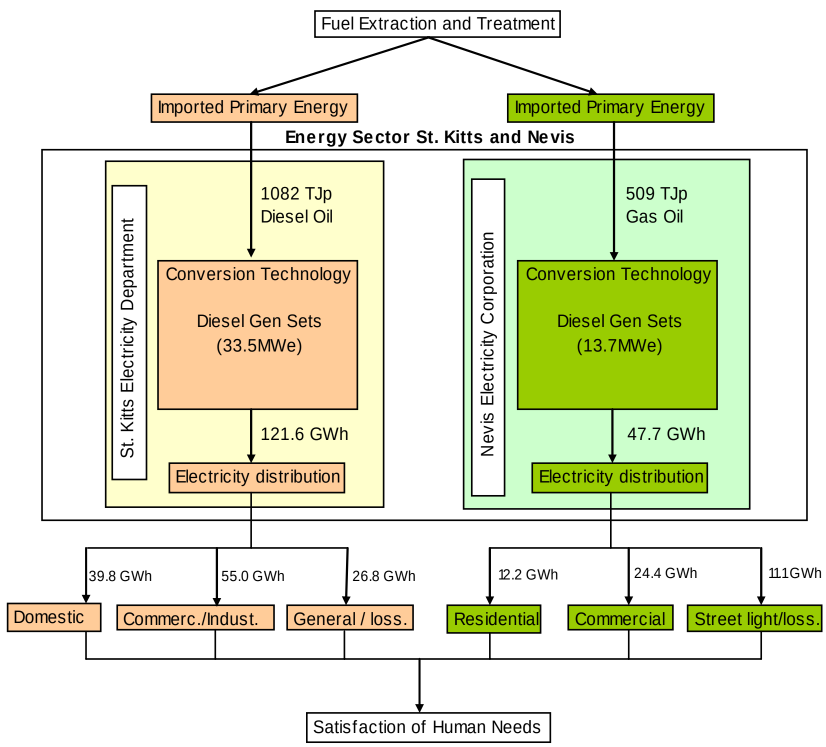

Figure 4.1 Schematic overview of St. Kitts & Nevis 2004 Energy balance[22]

[21] Article of October 21, 2004, “Power crisis forces St. Kitts and Nevis PM to take over energy ministry” by N. Thomas
[22] Sources: Operational Statistics of St. Kitts Electricity Department and NEVLEC (2005)

As can be seen on the scheme in figure 4.1, St. Kitts and Nevis' energy sector is run by two utilities, on St. Kitts the state owned St. Kitts Electricity Department with an installed power production capacity of 33.5 MW and on Nevis the private/state owned Nevis Electricity Company Ltd. (NEVLEC) with an installed capacity of 13.7 MW. They both manage the production and distribution of the electricity.

The total electricity production at St. Kitts Electricity Department was 121.6 GWh in 2004. And as described on the scheme, St. Kitts Electricity Department applies three user categories, domestic, commercial/industrial and general. In this case the generation and distribution losses and internal power use was added to the category "general". The losses and internal power plant use accounted for 25.4 GWh, this accounts for about 20.9 % of the total electricity generated in 2004. In the case of NEVLEC, the total electricity production was 47.7 GWh in 2004 and they also apply three user categories, residential, commercial and street lightning.

4.2 Electricity generation

St. Kitts Electricity Department

The St. Kitts Electricity Department has 33.5 MW of installed capacity using 7 diesel fuel oil #2 fueled generators. There are two 3.6 MW (units #1 and #2), both installed in 1971. In 1987 a 3.5 MW (unit #3) was installed. Next to these two 4.4 MW (units #4 and #5) were added in 1989 and 1995. And finally in 1999 two more units, a 6.1 MW (unit #7) and a 7.9 MW (unit #6) were added to the production site. See table 4.1 for an overview of these installed diesel sets.

Table 4.1 Generating Unit information at St. Kitts Electricity Department (Stanley Consultants, 2005)

Unit	Diesel type	Capacity (MWe)	Installation year
#1	Mirrlees KV12	3.6	1971
#2	Mirrlees KV12	3.6	1971
#3	Mirrlees K8	3.5	1987
#4	Caterpillar 3616 (#1)	4.4	1989
#5	Caterpillar 3616 (#2)	4.4	1995
#6	Mirrlees 12MB430	7.9	1999
#7	Mirrlees 8MB430	6.1	1999
Total		**33.5**	

The fuel that is used for electricity production is Diesel 45 Cetane 0.5% Sulfur fuel oil #2 also referred to as "Gasoil"[23]. The diesel fuel is supplied by TEXACO West Indies Limited (Texaco) located in Trinidad and Tobago. In 2004, St. Kitts Electricity Department consumed a total amount of 6.61 Million Imperial Gallons (1082 TJp[24]) at a cost of 9.19 million US$ (24.8 M EC$) and generated 121.6 GWh[25] of electricity. This means that the fuel cost in 2004 was about 0.31 US$/Liter. The Needmust power plant of St. Kitts Electricity Department has a load factor of 0.73 and the overall power plant fuel efficiency is 40%[26].

[23] A gas oil type distillate of lower volatility with distillation temperatures at the 90 percent boiling point between 540 and 640o F. No. 2 distillate meets the specifications for No. 2 heating or fuel oil as defined in ASTM D396 and/or specifications for No. 2 diesel fuel as defined in ASTM Specification D975, source: T. Lidderdale, EIA, 1993

[24] This is calculated with conversion factor 0.22 (Imp.Gallon / Liter) and Diesel Oil LHV of 0.036 GJ/L (EIA (1997), Energy Balances of OECD countries 1994-1995, OECD, Paris)

[25] Stanley Consultants, Generation Expansion Plan (2005-2015), Appendix B, St. Kitts Electricity Department (2005)

[26] From communication with representatives of St. Kitts Electricity Department, 2005

In figure 4.2 one can see the historical development of the capacity at St. Kitts Electricity Department. The firm capacity indicates the amount of installed diesel units that are still within their economical lifetime[27]. This means that if we look at the units installed at the St. Kitts Electricity Department, we see that there are two units (#1 and #2) that were installed in 1971. In 2005 these units have been running for 34 years. This is 14 years over their technical lifetime; of course, as any other engine it is possible to maintain and replace parts to extend the lifetime. When the 20 year economical lifetime is applied, the firm capacity in 2005 will be about 19 MW, while the peak demand is around 20 MW and thus there is a shortage of firm capacity.

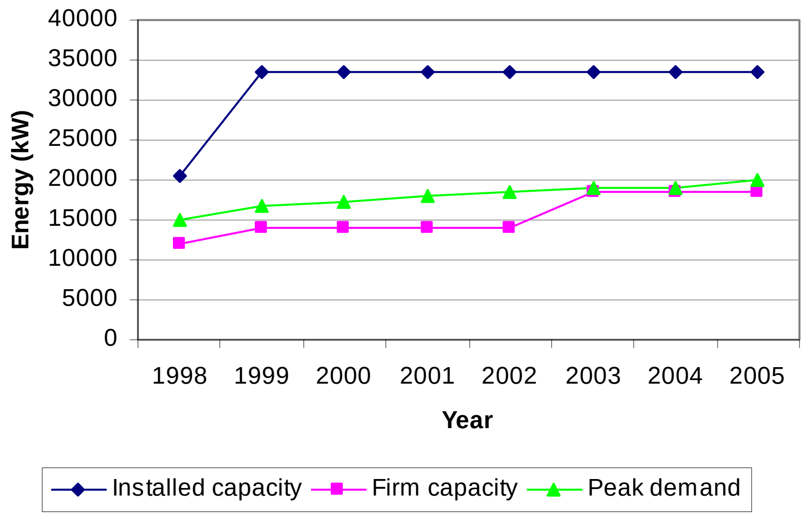

Figure 4.2 Installed capacity at St. Kitts Electricity Department for the period 1998-2005 (Source: St. Kitts Electricity Department, 2005)

It is the choice of the utility to set a safety margin or capacity margin above the peak demand and reflects the needed installed capacity. In case this capacity margin is 30%, the installed capacity in 2005 will have had to be 26 MW. The total installed and operating capacity for now is 33.5 MW but in case unit #6 of 7.9 MW falls out then 25.6 MW installed capacity will be available to deal with the primary load demand. All the above described possibilities indicate that there is a shortage of firm installed capacity. And that on the short term there is a high priority for generation expansion.

Projected capacity expansion

In figure 4.3 the annual peak demand projection for St. Kitts Electricity Department in the period 2005 till 2015 is shown. If we look at the base line scenario an annual peak demand of 36.9 MW is projected for 2015.

A private consultancy calculated these demand projections based on their own projection model. Their projection method was based on analyzing the energy demand of three sales categories (General Services, Domestic Services and Industrial/Commercial) and using three scenarios where the likelihood of implementation of future development projects differs[28].

Up until the year 2007, the growth in peak demand will be relatively parallel. After this year the three scenarios deviate in annual peak demand growth rate, with the maximal scenario considering a large new hotel project and intensification of the economy.

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[27] Lifetime set on 20 years for all units

[28] Stanley Consultants, Generation Expansion Plan for the St. Kitts Electricity Department (2005-2015), April 2005

Figure 4.3 Projection of the Annual peak demand for St. Kitts for the period 2005-2015[29]

Also an expansion plan was created for the utility to deal with the short term shortage of capacity. The options are as follows.

Plan 1 assumes that the St. Kitts electric system is interconnected with the La Vallee distribution system, and the Department purchases all the output from the La Vallee generating units. The La Vallee Project is a major hotel development including 300 rooms, over 400 homes, championship golf courses, a sports complex, 140 slip marinas, desalination plant, sewage treatment facility and other electric loads. The project is currently under construction and located on the northwest coast of St. Kitts. The total La Vallee load is therefore served by the Department as done with any other load. Plan 1 assumes that the Department purchases on a continuous basis from La Vallee at least 7.5 MW in 2006 through 2008 and 10.0 MW in either 2008 or 2009 and thereafter, depending upon the size of the unit.

Plan 2 assumes that the La Vallee remains independent of the St. Kitts system and relies solely on its own generating units to serve its load. La Vallee´s ultimate peak load is estimated at 5.0 MW with the installation of four 2.5 MW generating units planned.

The Department has opted for plan 1 which means that there are plans to purchase 7.5 MW in 2006 from La Vallee and building up the generation capacity at the Needmust power plant by 4 MW in 2007, 2011 and 2015, see Table 4.2.

Table 4.2 Generation Expansion Plan for St. Kitts Electricity Department (2005)

Year	2006	2007	2011	2015
Power Purchase (MW)	7.5			
New Unit (MW)		4	4	4

Nevis Electricity Company (NEVLEC)

Nevis Electricity Company has a total installed capacity of 13.7 MW using 7 diesel fueled generation units. In 1983 a 0.9 MW (unit #2) was installed, in 1985 a 0.9 MW (unit #3), in 1990 a 2.0 MW (unit #4), in 1992 a 2.5MW (unit #7) and in 1996 two units where purchased, a 2.2 MW

[29] Source: Generation Expansion Plan (2005-2015), St. Kitts Electricity Department (2005)

(unit #5) and a 2.5 MW (unit #6). Later after 7 years in 2003 the last 2.7 MW (unit #8) was added to the total capacity.

Table 4.3 Generating Unit information at NEVLEC (Nevis Electricity Company, 2005)

Unit	Diesel type	Capacity (MWe)	Year installation
#2	Blackstone	0.9	1983
#3	Blackstone	0.9	1985
#4	Blackstone	2	1990
#7	EMD (GM)	2.5	1992
#5	Blackstone	2.2	1996
#6	Blackstone	2.5	1996
#8	Wartsila	2.7	2003
Total		**13.7**	

There were problems with unit #2 and it has not operated in 2004 which means that the operating capacity was in reality 12.8 MW. The overall load factor is around 0.74 and the power plant has an overall fuel efficiency of 35%[30]. The total electricity generated in 2004 was 47.7 GWh. The amount of consumed gas oil was 3.08 Million Imperial gallons (509 TJp) in the period May 2004-May 2005.

Figure 4.4 gives an overview of the development of the installed capacity at NEVLEC during the period 2001-2005. The firm capacity projection is based on the economical lifetime set on 20 years for all the installed units. In 2005 the capacity margin decreased to 25%, which may mean that there is a capacity shortage.

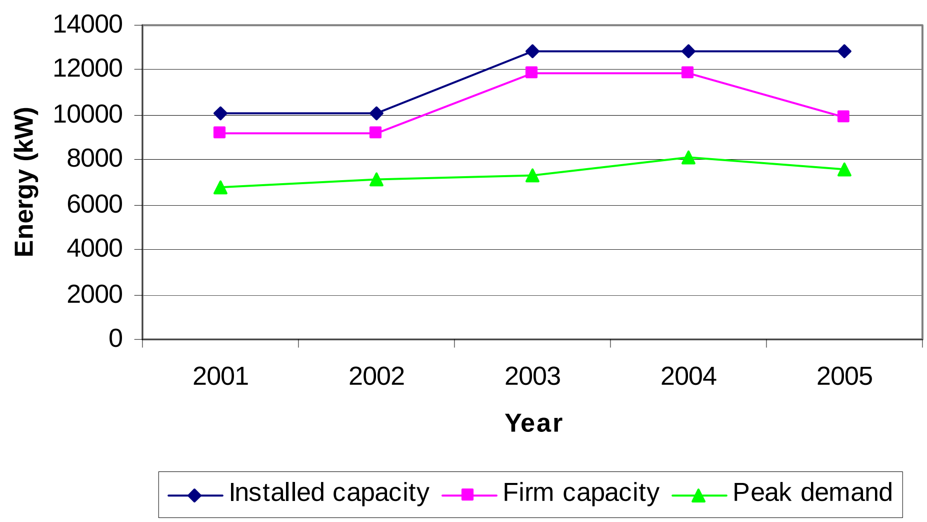

Figure 4.4 Installed capacity at NEVLEC for the period 2001-2005 (Source: NEVLEC, 2005)[31]

Projected capacity expansion

NEVLEC is planning to purchase a 3.0 MW diesel fueled generator by the end of 2005 or first quarter of 2006. In figure 4.5 one can see that the expected peak demand in 2015 is 15.6 MW (base line).

[30] From communications with representatives of NEVLEC, 2005

[31] Installed capacity and firm capacity is based on a lifetime of 20 years for each unit and excluding unit #2 (0.9MW)

In the case of the energy demand projection for Nevis another method was used compared to the projections done for St. Kitts. The extrapolation of the historic demand data functioned as the baseline projection and including a ±20% margin of positive or negative economic development resulted in peak demands of 17.7 MW (positive) and 13.7 MW (negative) in the year 2015.

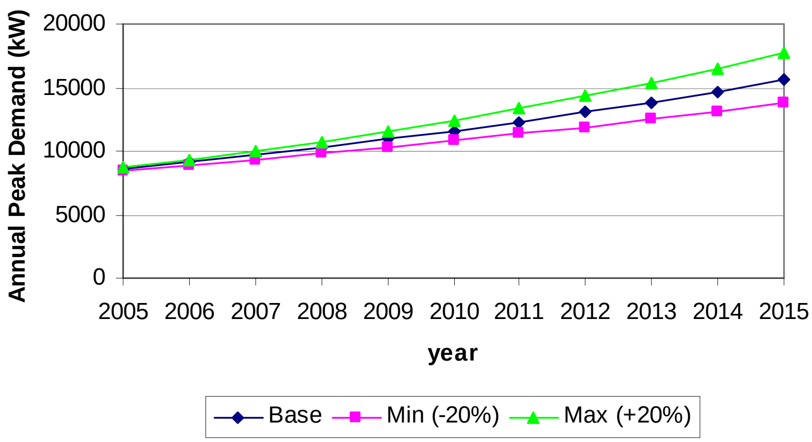

Figure 4.5 Projections of the peak demand for Nevis for the period 2005-2015

4.3 Electricity prices

St. Kitts Electricity Department

St. Kitts Electricity Department categorizes its main costumers in three groups, Domestic, Commercial/Industrial and General Supplies. See figure 4.6 for the relative consumption per category.

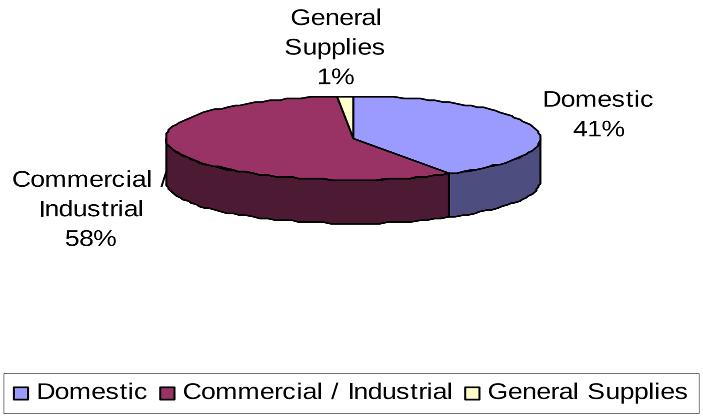

Figure 4.6 Relative electricity consumption per consumer category on St. Kitts in 2004 (Source: St. Kitts Electricity Department, 2005)

In 2004 the total amount of electricity sales reached 96.1 GWh while 121.5 GWh was generated. This means that there was a loss of about 21% that can be accounted for losses in the grid and electricity use in the power station and its offices and other not identified reasons. See table 4.4 for the most recent electricity prices per consumption category on St. Kitts.

The electricity prices in the Caribbean are on average among the highest in the American region. One of the main factors for this high electricity price is the fuel costs, this is because many island states depend for 100% on imported fuels for their electricity generation and thereby depend on the global price development of the crude/fuel oil. The crude oil price was 50 to 60 US$/Barrel[32] in the month of June 2005. We can show the difference in price when we compare the average electricity price of St. Kitts (0.169 US$/kWh) with the average electricity price of the US of 0.07 US$/kWh (2003 US$)[33].

Table 4.4 St. Kitts Electricity prices per consumption category for the period 2003-2005 (St. Kitts Electricity Department, 2005)

Electricity prices (US$/kWh)			
Year	**2005**	**2004**	**2003**
Average electricity cost	0.169	0.156	0.169
Electricity cost (domestic)	0.1544	0.1493	0.1403
Electricity cost (commercial)	0.1881	0.1601	0.1765
Electricity cost (industrial)	0.1881	0.1601	0.1765

From a World Bank report the total (critical) cost for import of diesel fuel oil for electricity generation was US$ 1.5 million in 2001[34].

Nevis Electricity Company (NEVLEC)

Nevis Electricity Company categorizes their customers in three groups, residential, commercial and street lighting. Figure 4.7 shows the relative consumption per category.

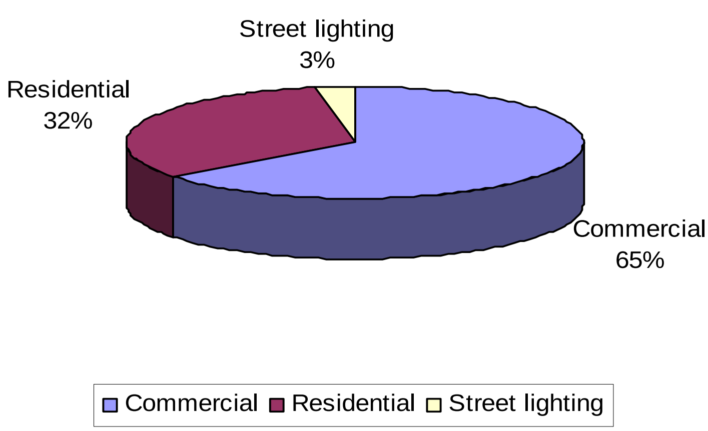

Figure 4.7 Relative electricity consumption per customer category on Nevis in 2004 (Source: Nevis Electricity Company, 2005)

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[32] OPEC website: http://www.opecnews.com/, visited 27 June 2005

[33] Lesourd, J.B.and Park, S., The economics of grid-connected electricity production from solar photovoltaic systems, 2003

[34] St. Kitts and Nevis Emergency Recovery Report, Finance, Private Sector and Infrastructure Management Unit, Caribbean Country Management Unit, Latin America and the Caribbean Region, World Bank Group, Report No. T 7506-LAC, February 2002

In 2004 the total amount of sales was 37.6 GWh while the total amount generated was 47.7 GWh. NEVLEC consumed about 129 MWh for internal use in the power plant. This means that about 20.9% has to be accounted for losses in distribution and unidentified causes.

Data on the historical electricity price development is not available, but the current (2005) average electricity price on Nevis is US$ 0.19/kWh (EC$ 0.51/kWh). While the diesel fuel price in 2005 was EC$ 5.96/imp. gallon (US$ 0.486/liter).

4.4 Energy development in the Caribbean

This section will show a short overview of the fossil fuel market in the Caribbean region and after this, the focus will be on renewable energy development in the Caribbean.

Fossil fuels

For much of this century the Caribbean has been a major centre of refining activity, with close links to crude sources in Venezuela and Mexico, and to markets in the United States. The refineries are based in Trinidad, in the Dutch Antilles (Curaçao), Aruba and in United States possessions (St. Croix and Puerto Rico). Since the 1970s output from some of these refineries has fluctuated considerably. The refineries were mainly configured to process heavy crudes from nearby sources and produced a high proportion of residual fuel oil, which was sold principally to electric utilities and industrial users along the United States East Coast. In the 1970s and 1980s several developments led to a sharp fall in demand for this product. These factors included: increases in the crude oil price, which resulted in oil products being replaced by coal and natural gas for steam generation; the removal of some United States regulatory controls on the use of natural gas for power generation; and tighter environmental regulations regarding the sulphur content of fuels (the residual fuel oil from these refineries tended to be high in sulphur). The nationalization of some oil production and refining assets in Venezuela and Trinidad and Tobago also had the effect of "de-integrating" the supply chains which, through common ownership, had previously tied production to refinery to markets. In view of the limited size of the islands' economies, the local employment and economic impacts of such changes have been considerable[35].

Only three Caribbean countries have oil and natural gas reserves: Barbados, Cuba, and Trinidad and Tobago. Of these, Trinidad and Tobago currently is the only significant exporter, see table 4.5.

Table 4.5 Proven oil and natural gas reserves and production in the Caribbean

	Proven reserves as of 1/1/2001		Production	
	Crude oil (1,000 barrels)	Natural gas (billion cubic feet)	Oil (crude, liquids, refinery gain) (1,000 barrels per day)*	Natural gas (billion cubis feet)**
Barbados	2,508	5	1	1
Cuba	283,500	636	42.75	17.7
Trinidad & Tobago	686,000	21,351	125.16	414
Total	**972,008**	**21992**	**168.91**	**432.7**

* Data of year 2000
** Data of year 1999

Trinidad and Tobago has become one of the major gas development centers in the world. It has made a transition from an oil-based economy to one based on natural gas. In 2004, natural gas production averaged 2.9 trillion cubic feet per day (tcf/d), an increase of 12.9% from 2003. The petrochemical sector, including plants producing methanol, ammonia, urea, and natural gas liquids, has continued to grow in line with natural gas production, which continues to expand and

[35]International Labour Organization, Source: http://www.ilo.org/public/english/dialogue/sector/techmeet/tmor98/tmorr.htm

should meet the needs of new industrial plants coming on stream in the next few years. The major development in 2005 was the opening of the fourth production module or "train" for liquefied natural gas (LNG) at Atlantic LNG[36]. Train 4 will increase Atlantic LNG overall output by almost 50% and will be the largest LNG train in the world at 5.2 million tons/year of LNG. Trinidad and Tobago is the 5th largest exporter of LNG in the world and the single largest supplier of LNG to the U.S., supplying between 70-75% of all LNG imported into the U.S. Overall, the petroleum sector grew by 10.5% in 2004, the third straight year of double-digit growth[37].

Refining

Refining capacity in the Caribbean exceeds 1.6 million bbl/d. Smaller refineries are geared primarily to local demand, while the larger refineries in Aruba, the Netherlands Antilles, Trinidad and Tobago, and the U.S. Virgin Islands serve both local and export markets. See table 4.6 for an overview of refineries.

Table 4.6 Crude Oil Refining Capacity in barrels (January 1, 2000)

Crude Oil Refining Capacity (January 1, 2000)		
Country	**Company/Location**	**Capacity**
Aruba (Dutch Caribbean)	Valero Aruba Refining Co./San Nicolas	280.000
Cuba	Cienfuegos	76,000
	Ermonos Dias/Santiago	101.500
	Niko Lopes/Habana	121.800
	Serhio Soto/Cabaiguan	2,100
	Subtotal, Cuba	*301.400*
Dominican Republic	Falconbridge Dominicana/Bonao	16,000
	Refineria Dominicana de Petroleo/Haina	33,250
	Subtotal, Dominican Republic	*49.250*
Jamaica	Petrojam/Kingston	34.200
Martinique (FR)	Societe Anonyme de la Raffinerie des Antilles/Fort-de-France	17.000
Netherlands Antilles (Dutch Car.)	Refineria Isla Curazao/Emmastad	320,000
Puerto Rico (US)	Caribbean Petroleum Corp./Bayamon	49.000
Trinidad & Tobago	Petroleum Co. of Trinidad & Tobago/Pointe-a-Pierre	160,000
U.S. Virgin Islands	Hovensa/St. Croix	525,000
TOTAL	**13 Plants**	**1,680,850**

Source: Oil and Gas Journal, January 1, 2001

[36] Atlantic LNG website: http://www.atlanticlng.com/news.php3?article=68 , visited 02 Jan 2006

[37] Background info Trinidad & Tobago, Bureau of Western Hemisphere Affairs, US Department of State, August 2005, source: http://www.state.gov/r/pa/ei/bgn/35638.htm

Storage
The Caribbean area also has independent petroleum storage facilities with the capacity to store approximately 100 million barrels of crude oil and petroleum products. In addition to long-term storage arrangements, these facilities offer logistical options for petroleum shipments.

Exports to the United States
In January 2001, the United States imported about 586,000 bbl/d of petroleum from the Caribbean, of which about 91% were petroleum products. The Virgin Islands was the largest single regional exporter to the United States (about 339,000 bbl/d of petroleum products), followed by Netherlands Antilles (about 141,000 bbl/d of petroleum products), Trinidad and Tobago (nearly 95,000 bbl/d of crude and petroleum products), and Puerto Rico (about 11,000 bbl/d of petroleum products). Trinidad and Tobago (55,000 bbl/d) is the only supplier of crude oil from the region. Trade flow is primarily to the U.S. Gulf and East Coast. Trinidad and Tobago is starting a venture to sell gasoline in U.S. retail outlets.

Renewable energy
Table 4.7 shows an overview of the current renewable energy state in the Caribbean region. The main renewable energy source is hydropower with a total production capacity of approx. 522 MW. There seem to be good potentials for all the RETs, with focus on Solar Water Heaters, Biomass and Geothermal energy production.

Table 4.7 Renewable Energy Development in the Caribbean[38]

<table>
<tr><th>RET</th><th>Country</th><th>Capacity (MW)</th><th>Description</th></tr>
<tr><td rowspan="3">Wind</td><td>Jamaica</td><td>20</td><td rowspan="3"></td></tr>
<tr><td rowspan="2">Curacao</td><td>3</td></tr>
<tr><td>9</td></tr>
<tr><td rowspan="7">Hydro</td><td>Guyana</td><td>0.5</td><td rowspan="7"></td></tr>
<tr><td>Suriname</td><td>189</td></tr>
<tr><td>Belize</td><td>25.2</td></tr>
<tr><td>Dominica</td><td>7.6</td></tr>
<tr><td>St. Vincent & the Grenadines</td><td>5.6</td></tr>
<tr><td>Cuba</td><td>56.2</td></tr>
<tr><td>Jamaica</td><td>238</td></tr>
<tr><td>Biomass</td><td>Jamaica</td><td>5.7% of Electricity</td><td>Agricultural by-products (Bagasse and Sugar Cane tops)</td></tr>
<tr><td rowspan="2">Solar Water Heaters</td><td>Barbados</td><td rowspan="2"></td><td>30% market penetration, 70% in new construction sub-sector</td></tr>
<tr><td>Others</td><td>Potential in Jamaica, St. Lucia and St. Kitts & Nevis</td></tr>
<tr><td>Geothermal</td><td>Others</td><td></td><td>Potential in Monserat, St. Lucia, Dominica and St. Kitts & Nevis</td></tr>
</table>

Coming back to the point of the limitations for the introduction of RETs on small island states, it is very important as an independent island state to join regional projects or programs to facilitate the transfer of RETs to the islands. The projects can provide a framework for transfer of knowledge, technology and especially finance.

[38] Renewable Energy Sources in Latin America and the Caribbean: Situation and Policy Proposals by UNECLAC, GTZ 19 May 2004.

St. Kitts and Nevis is involved in several regional projects. The OAS has an important role in three running projects, the Renewable Energy Initiative in the Americas (REIA), the Eastern Caribbean Geothermal Development Project (GEO-Caraibes) and the Global Sustainable Energy Islands Initiative (GSEII) of which this report forms a part of. See table 4.8 for a brief overview of energy projects and programs related to St. Kitts and Nevis and that are presently running in the Caribbean region.

Table 4.8 Regional Energy Projects and Programs related to Saint Kitts and Nevis

Project	Time frame	Project initiators	Expected outcomes	Project partners
Renewable Energy in the Americas Initiative (REIA)	1999-present	OSDE/OAS	Improve the use of clean, renewable and efficient energy technologies and services to enable improvement on economic and social conditions in Latin America and the Caribbean	OAS; USAID; World Bank; WI; NREL; UNF; ESG
Global Sustainable Energy Island Initiative (GSEII)	2000-present	OSDE/OAS	Reduce GHG-emissions by bringing renewable energy and energy efficiency projects, models and concepts together in sustainable energy plans for SIDS	OAS; CI; CPI; ESG; INSE; UNIDO; WI
Eastern Caribbean Geothermal Development Project (Geo-Caraibes)	2003-present	OSDE/OAS	Create the conditions for the "best case" commercial development of geothermal energy in the Eastern Caribbean (St. Lucia, Dominica and St Kitts & Nevis)	OAS; GEF; UNEP
Caribbean Renewable Energy Development Program (CREDP)	1998-present	CARICOM	To remove barriers to the increased use of renewable energy thus reducing the dependence on fossil fuels while contributing to the reduction of greenhouse gas (GHG) emissions	CARICOM; UNDP/GEF; OAS; GTZ; CARILEC; UWI; CSES; National Governments; Multilateral banks; Development Agencies
ESMAP	2005	OECS/World Bank	Regional Large Scale options for energy production in the OECS region	OECS; World Bank
Energy Efficiency Caribbean	2002-present	OLADE	Come up with full size projects for the Caribbean to overcome or reduce the barriers to energy efficiency projects and programs	OLADE; GEF; UNDP; CARILEC; OAS; CEIS; UWICED; CDB; World Bank
Caribbean Energy Information System (CEIS)	present	CEIS	Collect data about Energy sectors, Renewable Energy Sources and Technology for Caribbean islands	CEIS; National Governments

5. Renewable Energy Resources on St. Kitts and Nevis

The purpose of this resource analysis is to perform a quick scan of available energy sources on St. Kitts and Nevis and identify the RETs that are technically feasible. The nature and the availability of the natural resources have influence on the behavior and economics of the renewable energy technologies, since the resource determines the timing and performance of renewable energy production. A look will be taken at the physical conditions present on the islands and an attempt is made to identify the amount of electricity that each RET could theoretically produce using the most common renewable energy technology available. Attention is paid to the physical limitations, such as limited space, topography and other technical related issues.

5.1 Resource analysis and theoretical energy production

Within the scope of this research, resource analysis has to consist of collection of literature data that can indicate the amount of available renewable energy sources. Sometimes this type of data might not be available because historically no initiatives have been taken to assess the renewable energy resources or there is lack of monitoring and processing of data. In these cases best possible assumptions will be made, by interviewing experts and institutes dealing directly with these issues.

5.1.1 Biomass

Modern biomass is seen as a promising renewable energy source for the future for the islands of St. Kitts and Nevis. In the case of St. Kitts it is interesting to analyze the theoretical energy production potential of biomass technologies on the island since there is interest in converting their sugar producing industry into energy production from sugarcane. This is because the sugar industry on the island is not competitive anymore due to high production costs and low sugar market prices.

Technical possibilities

There are several technological options available for the treatment of the biomass resource. See figure 5.1 for a general overview of possible biomass energy conversion routes.

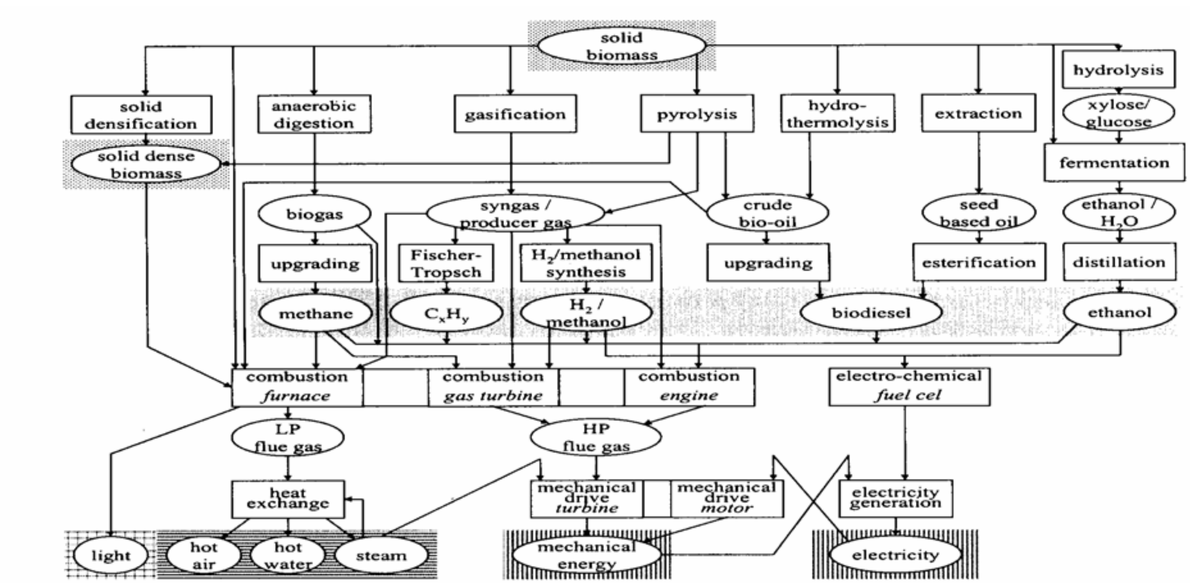

Figure 5.1 Main Biomass Energy conversion routes[39]

[39] Van den Broek, R., PhD thesis: "Sustainability of biomass electricity systems, 2000", Utrecht University

The rectangles represent energy conversion processes and the ellipses represent energy carriers. The gray shaded area shows the liquid and gaseous fuels that can be produced from biomass. The dotted area shows the solid energy carriers. The horizontally striped area represents various forms of heat, the blocked area shows energy in the form of light and the vertically striped areas mechanical and electrical energy.

There are two biochemical conversion processes, anaerobic digestion and fermentation. Anaerobic digestion entails, with the use of bacteria the conversion of biomass to methane rich biogas that can be used to fire an engine. Fermentation is a common process in the sugar industry that includes the conversion of sugar to ethanol. In the case of thermo chemical conversions a categorization can be made based on the amount of oxygen used during the conversion; biomass combustion (excess of oxygen), gasification (less oxygen) and pyrolysis and hydro thermolysis (no oxygen). Biomass combustion forms the basic technology of modern biomass plants to produce steam and/or electricity, using Rankine steam cycles.

St. Kitts and Nevis Agricultural sector

Before we quantify the biomass energy available on the islands we will first have a look at the agricultural sector of the islands to have a better understanding of the situation on St. Kitts and Nevis.

Agricultural production has traditionally been synonymous with sugar (St. Kitts) and cotton (Nevis). While St. Kitts has continued production of sugar cane despite the difficulties experienced in the industry, cotton production in Nevis has been essentially replaced by a mix of vegetable production and small cattle farming. On Nevis, a variety of environmental, economic and social factors have hindered the development of agriculture. Low and unreliable rainfall and extended periods of drought make moisture the most critical factor limiting agricultural productivity and availability of an adequate water supply, remains a considerable obstacle to agricultural development. Soil erosion, given the island's topography, is also a concern exacerbated by foraging from goats and other livestock.

In 2004 the agricultural sector contribution to the GDP of St. Kitts and Nevis was US$ 11.4 million (EC$ 30.8 million[40]), this is equal to 5.14% of the GDP. The contribution of the agricultural sector to GDP of St. Kitts and Nevis has over the last few years shown a decline. During the period 1994 - 2004, the contribution of the agricultural sector to the GDP declined from 6.42% to 5.14% of GDP, see table 5.1. The contribution of the sugarcane sub-sector to the agricultural sector, declined from 36.8% to 30.4% in the period 1994 to 2004. In 2004 fishing activities contributed 33.3% to the agricultural sector and became the highest share to the agricultural sector. The primary activity is sugar cane production that falls under the Agricultural sector, see table 5.1, and the secondary activity is sugar production and this falls under the Manufacturing sector. The total contribution of the sugar industry (sugar cane and sugar production) in 2004 amounted to US$ 5.1 million (EC$ 13.7 million or 2.5% of GDP).

The sugar production takes only place on St. Kitts and is in the hands of the St. Kitts Sugar Manufacturing Company (SSMC). The Federal Government is the owner of the SSMC that employs about 2,000 people (5% of population on St. Kitts). The sugar industry depends totally on the preferential EU Sugar Protocol quota and the US quota. In fact more than 90% of the sugar produced in St. Kitts is exported to these markets with the EU market being the larger.

[40] St. Kitts Statistics Division (2005) value in constant prices

The sugar industry has had several set backs during the last decades. Factors as high factory operating costs, lower revenue from exports, high fixed costs with no possibilities for expansion of area under cultivation and a series of hurricanes and flood damages between 1995 and 1999 followed by unusual drought in 2002 and 2003 have caused the production of sugar in St. Kitts to become uneconomic.

Table 5.1 St. Kitts and Nevis Agricultural sector percentual contribution to the Gross Domestic Product for the period 1994-2004[41] (St. Kitts and Nevis Statistics Division, 2005)

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Agriculture (% of GDP)	**6.42**	**5.86**	**6.08**	**6.84**	**5.98**	**5.23**	**4.50**	**4.92**	**5.59**	**4.85**	**5.14**
Sugar cane	2.36	2.28	2.43	3.40	2.64	2.09	1.87	2.07	2.23	1.65	1.56
Crops	1.26	1.09	1.22	1.16	0.90	0.97	0.90	0.84	1.13	1.15	1.15
Livestock	0.92	0.59	0.65	0.57	0.63	0.54	0.35	0.49	0.59	0.59	0.63
Forestry	0.08	0.08	0.08	0.08	0.09	0.08	0.08	0.08	0.08	0.08	0.08
Fishing	1.79	1.81	1.70	1.63	1.72	1.55	1.29	1.43	1.55	1.38	1.71
Agriculture (100%)											
Sugar cane	36.8	38.9	40.0	49.6	44.2	39.8	41.7	42.1	40.0	34.1	30.4
Crops	19.7	18.7	20.0	17.0	15.1	18.6	20.0	17.2	20.2	23.7	22.4
Livestock	14.4	10.1	10.7	8.3	10.6	10.3	7.9	9.9	10.5	12.1	12.3
Forestry	1.3	1.4	1.4	1.2	1.4	1.6	1.8	1.7	1.5	1.7	1.6
Fishing	27.9	30.9	28.0	23.9	28.7	29.7	28.6	29.1	27.8	28.4	33.3

The production costs of a ton of raw sugar is much larger than the Sugar Protocol price of US$ 523.7 per ton and the world market price of US$ 155 per ton. This leads to a loss of approximately US$ 935.1 for every metric ton of sugar produced and exported in 2003 (Government of St. Kitts and Nevis, 2005).

Since 2002 the SSMC has accumulated a debt of about US$ 133 million (EC$ 360 million) [42] by mid-2005 through the St. Kitts and Nevis National Bank. Because of the losses of the SSMC, the Government has come to a decision to stop the sugar production at the end of July 2005. Because of the need to come to a solution for the sugar industry, it is interesting to look at the potential for energy production from sugar cane on the island of St. Kitts.

Available biomass

The availability of biomass resource depends in part on human effort for harvesting, transportation and storage. If managed adequately the resource will not be intermittent, although it is seasonal. This requires labour and investments in collection and transportation machines, which means that the biomass feedstock has costs attached. A second issue related to the biomass feedstock is that it may be converted to a gaseous or liquefied fuel via many alternative conversion routes, to generally be consumed in conventional generators. These aspects make the choice for an optimal bio-energy production system very challenging.

In 2004, St. Kitts is estimated to house a total cultivable area of about 9,000 acres (about 3642 ha); sugar cane cultivation occupies about 7,000 acres (2833 ha) of the cultivable area[43]. This sugar cane cultivation area yielded about 170,000 tons of sugarcane and produced 14,000 tons of sugar. This means that the yield in 2004 was about 24.3 ton/acre (60.0 ton/ha) and the efficiency (ton sugar / ton sugar cane) of the sugar production about 8.2%, see also table 5.2.

[41] Data for 2003 and 2004 are provisorial
[42] Interview with representatives of the St. Kitts Sugar Manufacturing Corporation (SSMC), July 2005.
[43] From communication with representatives of the St. Kitts Sugar Manufacturing Company (SSMC, 2005)

The current sugarcane processing technology at SSMC entails sugar milling and extraction using tandem mills. When the sugar has been extracted, the remaining fibrous residue after dewatering, which is called bagasse, is conveyed to storage facilities where in later stage they can be used as fuel to burn in the boilers to produce process heat. Its moisture content is around 45-55%[44].

The bagasse its percentage from cane can vary from 23% to 37% and it averages 30%[44]. This depends on the fibre percentage of the sugarcane, which normally ranges from 12-19%[44]. The rest of the bagasse is made up of trapped dissolved matter, trash and water.

Table 5.2 lists the historical data for the sugar production on St. Kitts. It shows a varying sugarcane and sugar production, as well as a variation of efficiency of sugar production, which is on average 9.7±0.8 %. This shows that 2004 was the worst year since 1990 in terms of sugar production.

Table 5.2 Production of Sugar and Molasses for the period 1990-2004 (SSMC, 2005)

Year	Sugar Cane (x1000 tons)	Sugar (x1000 tons)	Molasses (x1000 tons)	Efficiency (Sugar/Sugar Cane) (%)
1990	168	15	6	8,929
1991	219	19	7	8,676
1992	200	20	6	10
1993	220	21	7	9,545
1994	180	20	6	11,111
1995	180	20	6	11,111
1996	204	20	7	9,804
1997	305	31	9	10,163
1998	240	25	8	10,416
1999	197	18	6	9,137
2000	188	18	5	9,574
2001	212	22	5	10,377
2002	228	21	8	9,211
2003	169	16	5	9,467
2004	170	14	5	8,235
Average	205±36	20±4	**average:**	9,7±0.8

Due to the intense competition in land-use, between land under sugar cultivation and land for housing and tourism-related constructions, as well as the geological constraints it is important that the Government reserves as much sugarcane cultivation area as possible to have viable future sugarcane production for possible energy production.

Theoretical energy production

Biomass energy systems are often more complex than the modular wind energy or photovoltaic systems, as they require biomass fuel and their costs are often dependent on the local conditions. The yield of the sugarcane is a main determinant of the economic and environmental performance of the biomass energy system. Next to yields, another important factor for the cost of bio-energy is the availability and cost of land. The economical analysis is further discussed in chapter 6.

[44] Mbohwa, C. and Fukuda, S., Electricity from Bagasse in Zimbabwe, Tokyo Metropolitan Institute of Technology, Japan

For the theoretical energy production we will use the average of the data on sugarcane production for the period 1990 to 2004. We assume that the available land was 7,000 acres during this time frame, which results in an average sugar cane yield of 29.3 ton/acre in 306 days per year cycle, thus with an average sugarcane production of 205,333 ton/year. During two months per year no sugarcane can be harvested.

If we only consider combustion of bagasse, thus 30% of the available 205,333 ton/year is 61,600 ton/year of bagasse, with a LHV of 7.62 MJ/kg[44] for wet bagasse (moisture content of 50%) a total of 469.4 TJ of primary energy can be used for electricity production. The capacity factor of thermal plants cover a wide range often between 70-90%, one might expect a new biomass thermal plant to have an 80% capacity factor[45]. Assuming a boiler efficiency of 35%[46], a total of 164.3 TJe can be produced. This is equal to 164.3 TJe * 0.2778 GWh/TJ * 0.8 (load factor) = 36.5 GWh. This is equavalent to a biomass fueled plant of 4.2 MWe running at full load.

Since the SSMC is considering the option to combust the sugarcane directly, then this so-called "fuel cane" with a LHV of 5.95 GJ/ton[47] contains a primary energy level of 1,221.7 TJp. Assuming a boiler efficiency of 35%[46], a total of 427.6 TJe can be produced. This is equal to 427.6 TJe * 0.2778 GWh/TJ * 0.8 (load factor) = 95.0 GWh. This is equal to a biomass fueled plant of 10.8 MWe.

See chapter 6 for more detailed information on the energy and economical analysis performed by the HOMER model.

5.1.2 Wind

Wind energy is the fastest growing energy sector in the world. On global level the installed capacity has grown from 2 GW to 50 GW in mid 2005 which will generate approximately 100 TWh of electricity[48]. Technical efficiency and economic performance of wind turbines have improved during the last decades that make it more attractive to find their potential to be introduced on St. Kitts and Nevis.

Technical possibilities

Wind turbines have been used for many decades for pumping water or graining seeds. In the 1930s small scale grid connected turbines were introduced, but since the 1980s the commercial use of grid connected wind turbines for electricity production was developed fast. See table 5.3 for a general overview of uses of wind turbines.

Table 5.3 Overview of Wind Energy Conversion Technologies (2000)

Wind energy		
Technology	Energy product	Application
Water pump and battery charging	Mechanical power	Small wind machines, widely applied
Onshore Wind turbines	Electricity	Widely applied commercially
Offshore Wind turbines	Electricity	Development and demonstration phase

Source: World Energy Assessment 2000, UNDP[49]

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[45] Renewable Energy Research Laboratory, *Wind Power: Capacity Factor, Intermittency, and what happens when the wind doesn't blow?*, University of Massachusetts, Amherst.

[46] US Environmental Protection Agency (EPA), Introduction to CHP Catalog of Technologies (2002, page 7)

[47] Moreira, J.B., Sugarcane for Energy – recent results and progress in Brazil, National Reference Centre of Biomass (CENBIO), São Paulo, Brazil

[48] Source: http://www.gwec.net/fileadmin/documents/PressReleases/0922-Husum-GWEC.pdf

[49] World Energy Assessment, UNDP, 1998, source http://www.undp.org/seed/eap/activities/wea/drafts-frame.html

Available Wind

To quantify the available wind for wind energy projects, a basic wind map is required with specific wind speeds and direction on and around the islands. Since this is not available we will use data collected from the meteorological service at the St. Kitts International Airport and the New Castle Nevis Airport. Based on the results of the energy and economical analysis an evaluation is made to the need of a sensitivity analysis related to the variation in wind speeds, see chapter 8 for more detail.

For identifying possible areas for wind park development many physical factors have to be taken into account such as available land or vicinity to urban areas. In this study a choice is made to look at the topography of the islands and simultaneously looking at areas where there is no urbanization and where wind parks can for instance be integrated within the sugarcane plantations.

St. Kitts

St. Kitts is characterized by three volcanic centers. The central northwest range, dominated by Mt. Liamuiga, rises with a pronounced crater to 1,156 meters (3,792 ft). It is the Federation's highest peak. The middle area consists of a number of irregular related peaks dominated by Vrechild's mountain at a height of 975 meters (3,200 ft). The slopes in this range are steeper and shorter towards the leeward coast[50].

The southeast area consists of a number of irregular peaks, with the highest being 900 meters (2,953 feet) above mean sea level. Here the slopes are steeper and shorter on the leeward side. The middle and southeast areas are separated by a broad gently sloping saddle of about 457 meters (1,500 feet) high, known as Phillips and Wingfield levels. These ranges are complemented by the Canada hills on the northeastern part of the island, which rises to about 335 meters (1,100 feet) and are separated by a deep depression from the Morne and Conaree hills.

See figure 5.2. to get an impression of the elevations on St. Kitts. The map indicates the huricane wind hazards of three levels, namely high, moderate and low. On the figure one can see that the high wind regimes are located in the higher elevations on the atlantic ocean side towards the peaks. Also on the peninsula at the coastlines the high wind regimes are present.

The South-east Peninsula is largely characterized by tied islands, about one third of a mile wide and with peaks of up to 183 – 213 meters (600 -700 feet). The southern extremity has hills with elevations up to 335 meters (1,100 feet), see figure 5.3 for an impression of this area.

[50] Source: St. Kitts and Nevis Initial National Communication, 1994

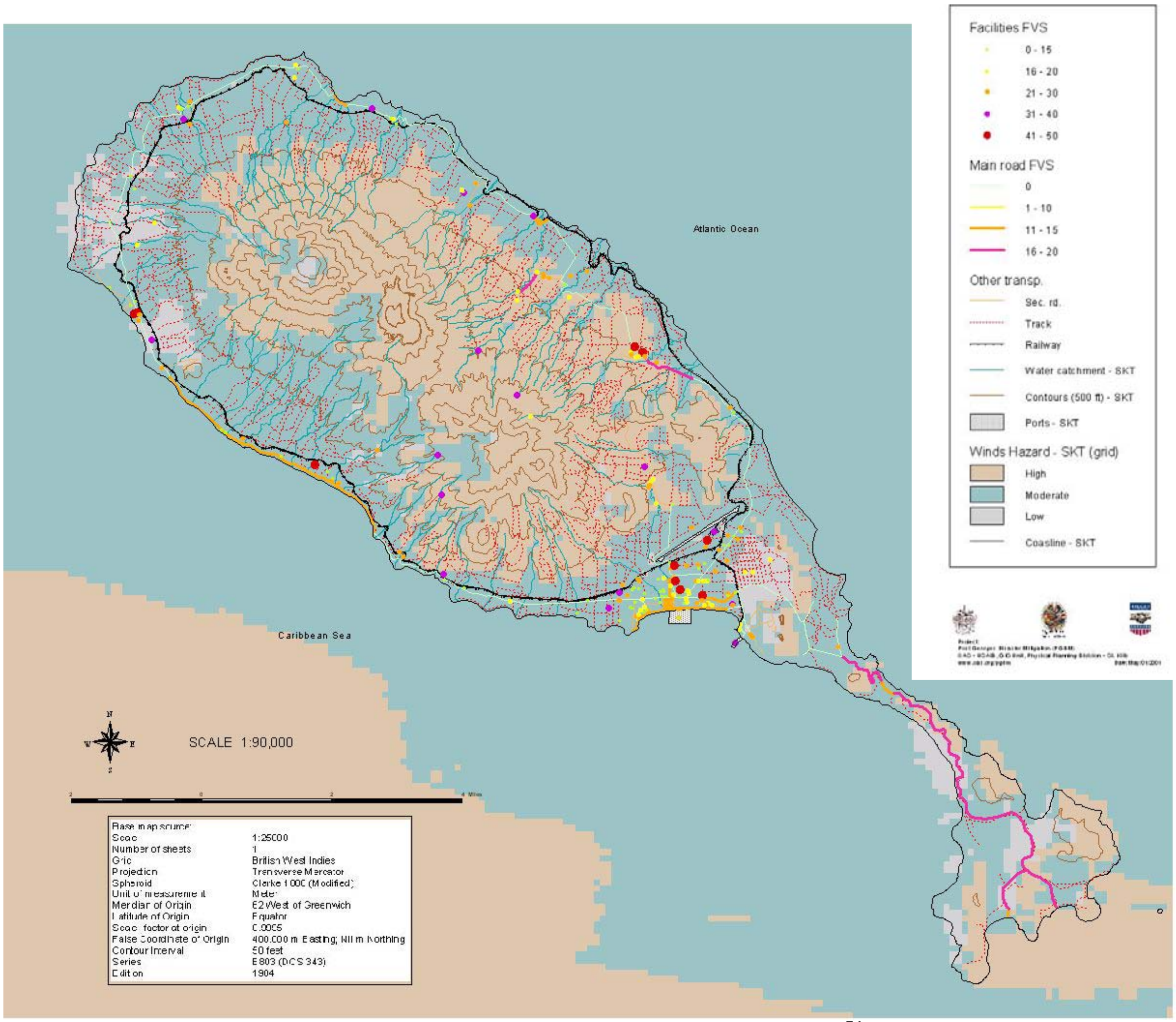


Figure 5.2 Wind hazard map of St. Kitts (OAS)[51]

In figure 5.3 both the Atlantic Ocean (left) and the Caribbean Sea (right) can be seen. The average wind direction is from North East-East (NE-E) or 80 Wind-degrees. Looking at the picture from this angle it means that the wind comes from left to right.

Unlike the main land, there is no sugarcane production on the peninsula. The area is not very big, roughly estimated the area seen on figure 5.3 is about 0.3 mile by 0.3 mile, thus 0.09 square miles (233,010 m^2 or 23.3 ha). Other areas where sugarcane is produced may be more interesting to look at since there is more land available and there is the possibility to combine two land use functions in the same area. Also the slopes are not extreme since agricultural equipments need to be used to collect and transport the sugarcane to the sugar factory.

[51] Source: OAS website, http://www.oas.org/pgdm/document/knvulnas/layouts/wind/skt_winds_fvs.jpg

Figure 5.3 South-east Peninsula of St. Kitts

In table 5.4 the average monthly wind speeds at 60 meter height above sea level, thus at 10 m above ground level, are given for the period 1993 to 2004. These data are collected from the meteorological service at the Bradshaw International Airport on St. Kitts. The exact location of the airport is (17 31´11 N Latitude, 062 71´86 W Longitude)[52].

Table 5.4 Wind speed (m/s) at the St. Kitts International Airport for period 1993-2004 [53]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1993	6.69	5.14	5.66	4.12	3.60	6.17	7.20	5.66	5.66	5.14	5.66	5.14	**5.49**
1994	6.69	6.69	5.14	5.66	5.66	6.69	7.20	7.20	6.17	4.63	4.63	5.14	**5.96**
1995	4.63	5.66	6.69	4.63	4.63	6.17	7.72	6.69	6.17	7.72	6.17	6.17	**6.09**
1996	6.17	7.20	6.69	6.69	6.69	7.20	7.20	6.17	6.69	5.14	6.17	6.17	**6.52**
1997	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	**n.a.**
1998	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	**n.a.**
1999	6.69	4.12	3.60	4.12	3.09	4.12	4.12	4.12	3.60	3.60	3.09	4.63	**4.07**
2000	5.14	4.63	4.63	4.63	4.12	6.17	6.17	5.66	3.60	3.09	4.12	4.63	**4.72**
2001	4.12	6.17	4.12	4.63	4.63	4.63	5.14	5.66	4.12	5.14	3.09	5.14	**4.72**
2002	5.66	5.14	5.14	5.14	6.17	5.66	5.14	4.63	3.60	4.12	4.12	4.63	**4.93**
2003	4.63	5.14	4.12	4.12	4.63	5.66	5.66	4.63	4.12	3.60	3.60	4.63	**4.54**
2004	4.63	4.63	4.63	4.12	4.63	4.63	4.12	4.12	3.60	3.60	4.63	5.14	**4.37**
9-year Average (10m height)[54]	**5.50**	**5.45**	**5.04**	**4.78**	**4.78**	**5.71**	**5.97**	**5.45**	**4.73**	**4.58**	**4.53**	**5.14**	**5.14**
9-year average (50m height)	**7.02**	**6.96**	**6.44**	**6.10**	**6.10**	**7.29**	**7.62**	**6.96**	**6.08**	**5.85**	**5.78**	**6.56**	**6.56**

[52] Source: Google Earth software (2005)
[53] Source: St. Kitts Meteorological Services, R.L. Bradshaw International Airport (2005), '97 and '98 monitoring equipment damaged.
[54] This is the height above the ground level where the wind measuring equipment is located (this is the same as 60 m above sea level)

Meteorological wind measurements are usually done at 10 m height above ground level, but anemometers studies are often made at hub height of the wind turbines (on average at 50 m above ground level).

The 9-year average wind speed (no data available for ’97 and ’98) was 5.14 m/s at a height of 60 m above sea level. Note that there is a difference in monthly average wind speeds after 1998. This might be caused due to the new installed wind measuring equipment that might have been calibrated differently or the average wind speed did reduce from 1999 on forward. This leads to a big uncertainty. To cover this uncertainty we will put an uncertainty factor of 50% on the average wind speed values that will be used in the continuing calculations.

The average yearly wind speeds at 50 m height (hub height) was 6.56 m/s for the period 1993 to 2004 and was calculated using the wind shear formula. The wind shear is when the wind slows down, near the ground, to an extent determined by the surface roughness. See table 5.5 for an overview of the different categories in roughness lengths (z_0).

Table 5.5 Roughness lengths categories (Lysen, E., 1982[55])

Roughness lengths (Z_0)		(m)
flat	beach, ice, snow landscape, ocean	0.005
open	low grass, airports, empty crop land	0.03
	high grass, low crops	0.1
rough	tall row crops, low woods	0.25
very rough	forests, orchards	0.5
closed	villages, suburbs	1
towns	town centres, open spaces in forests	> 2

The Wind Shear formula is defined as:

$$v = v_{ref} * \ln\left(\frac{z}{z_0}\right) / \ln\left(\frac{z_{ref}}{z_0}\right) \tag{5.1}$$

where:
v = new velocity (m/s)
v_{ref} = known or measured velocity (m/s)
z = the new height (m)
z_0 = roughness length (m)
z_{ref} = height of known measurement (m)

The average monthly wind speeds at 50 meter height were calculated using a roughness length of $z_0 = 0.03$ m. As example, the yearly average of 5.14 m/s in table 5.4 is used as the v_{ref}. The z value is 50 m, and the z_{ref} is 10 m. Thus v is 6.56 m/s at 50 meter height above ground level (hub height).

Nevis
Topographically, Nevis is approximately circular and dominated by the central Nevis Peak, 985 m (3,232 ft.) high. Windy Hill (309m) and Saddle Hill (381m) at the head and tail of the island, respectively, align with Nevis Peak to form a north-northwest/south-south-east trending spine comparable to the more pronounced spine of St. Kitts. To the east, the spine is thickened by the

[55] E. Lysen, Introduction to wind energy, 1982, source http://www.uce-uu.nl/swd.htm

bulge of Butlers Mountain (478m). Slopes vary from almost zero near the sea, to over 40 percent in the vicinity of Saddle Hill, Butlers Mountain, Nevis Peak and Windy Hill. See figure 5.4 to get an impression of the wind distribution on Nevis. Note that the colors used in the legends for this map are different compared to the colors used for the map of St. Kitts.

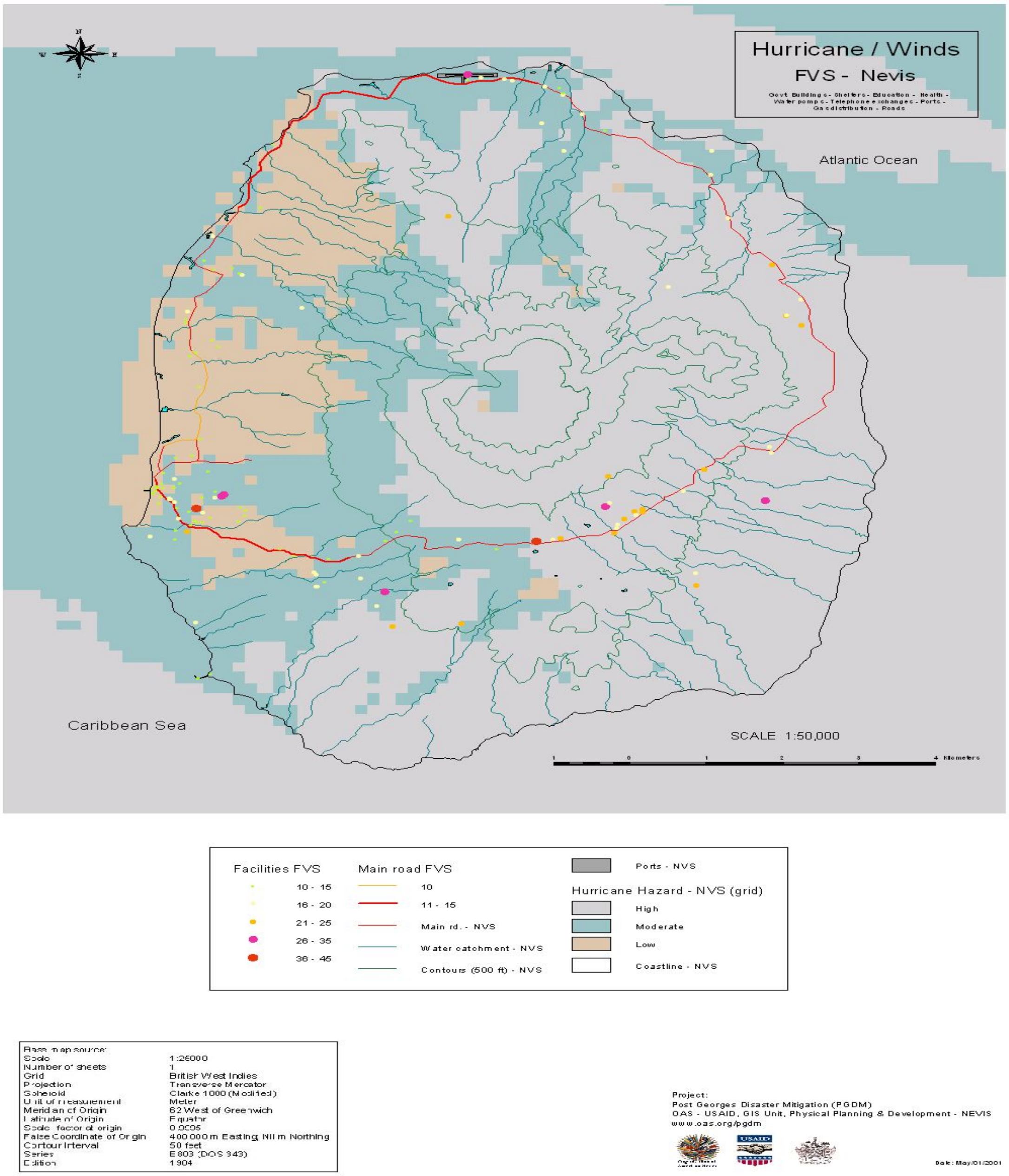


Figure 5.4 Wind hazard map of Nevis (OAS)[56]

The high wind regimes cover about 50% of the island surface with location in the South-East area. This means that in general the wind direction originates from the South-East.

[56] Source: OAS website, http://www.oas.org/pgdm/document/knvulnas/layouts/wind/nvs_winds_fvs.jpg

Table 5.6 shows the average wind speed for the period 2000 till 2004 at the New Castle airport on Nevis. The exact location of the airport is (17 12'40 N Latitude, 062 35'30 W Longitude). The average wind direction is from East South-East (E-SE) or 110 Wind degrees.

Table 5.6 Wind speed (m/s) at the New Castle Nevis Airport (Nevis) for period 2000-2004[57]

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
2000	7.72	6.17	6.17	6.69	5.66	8.23	7.20	6.69	4.63	4.63	5.66	6.69	**6.34**
2001	6.69	7.72	7.20	6.17	5.66	6.69	7.20	6.69	4.63	6.17	3.60	6.17	**6.22**
2002	7.20	6.17	6.17	6.69	7.72	7.20	7.20	6.17	5.14	5.66	5.14	6.17	**6.39**
2003	5.14	6.69	5.66	6.17	6.69	7.72	8.23	6.69	5.14	4.63	4.63	5.14	**6.04**
2004	5.66	6.17	6.69	5.66	7.20	6.69	6.69	6.17	4.63	3.60	5.66	6.17	**5.92**
5-year average (10m height)[58]	**6.48**	**6.58**	**6.38**	**6.28**	**6.58**	**7.30**	**7.30**	**6.48**	**4.84**	**4.94**	**4.94**	**6.07**	**6.18**
5-year average (50m height)[59]	**8.28**	**8.40**	**8.15**	**8.02**	**8.40**	**9.32**	**9.32**	**8.28**	**6.18**	**6.31**	**6.31**	**7.75**	**7.89**

The 5-year wind speed average was about 6.18 m/s at a height of 60m above sea level and is on average higher than the average wind speeds on St. Kitts. On hub height (50 m above ground surface) the yearly average wind speed was about 7.89 m/s over the period 2000 to 2004.

We have to keep in mind that the wind speeds used in the following calculations are only indicative, since the measurements were only done at the airports of both islands. For better wind assessment wind maps of the area on and around the islands are needed.

Theoretical Energy production

Wind energy utilizes the kinetic energy in flowing air masses. The flow of kinetic energy through a vertical plane is proportional to the third power of the wind speed. This can be understood, considering that the kinetic energy in the wind is proportional to the square of the wind speed and the mass flow through a wind turbine rotor. Using presently available types of wind turbines the maximum theoretical amount of power that can be extracted is, according to Betz' theorem:

$$P = \frac{16}{27} \cdot \tfrac{1}{2} \rho v^3 \cdot A_t \qquad (5.2)$$

where:

P = wind power (W)
ρ = specific mass of air (kg/m3)
v = wind speed (m/s)
A_t = swept rotor area of the wind turbine (m2)

Modern wind turbines can produce up to 85% of this theoretical maximum[60]. In order to calculate the theoretical wind energy potential in a more detailed manner, use is made of the wind turbine power calculator from the Danish Wind Industry Association (DWIA)[61]. It is based on formula

[57] Source: Meteorological Office at the Vance W. Amory Airport (New Castle, Nevis)
[58] This is the height at 10 m above ground level (in this case 30 m above sea level)
[59] Here we also used a roughness length of $z_0 = 0.03$
[60] EWEA, Wind energy, the facts, volume 1, Technology, 2004, source: http://www.ewea.org/06projects_events/proj_WEfacts.htm
[61] Danish Wind Industry Association, See website: http://www.windpower.org/en/tour/wres/pow/index.htm

5.2 but facilitates in choosing realistic turbine options while taking in account some important factors as the wind distribution, roughness lengths and power curves.

Since St. Kitts and Nevis have a mountainous topography it becomes more difficult to select sites for wind park development compared to plain areas. Under these conditions there are three main factors that have to be taken in account to evaluate the theoretical energy production potential by wind turbines. These are wind shear, turbulence and acceleration.

On St. Kitts, we know that the average wind speed is 6.56 m/s at hub height and on Nevis the average wind speed is 7.89 m/s. These figures are already calculated using the roughness lengths. For the calculation of the annual energy output we would additionally need the annual distribution of wind speeds, which may be represented by a Weibull curve. As the distribution is not known for the area around St. Kitts and Nevis, the Weibull parameter is set at a value of 2, this value is an indication of the shape of the distribution curve. This Weibull factor is also known as the Rayleigh distribution that is often used by wind turbines manufacturers to produce standard performance figures (source: Danish Wind Industry Association). Figure 5.4 shows a distribution curve with a Weibull factor of 2. This graph expresses the wind speed distribution for a typical site over the period of a year.

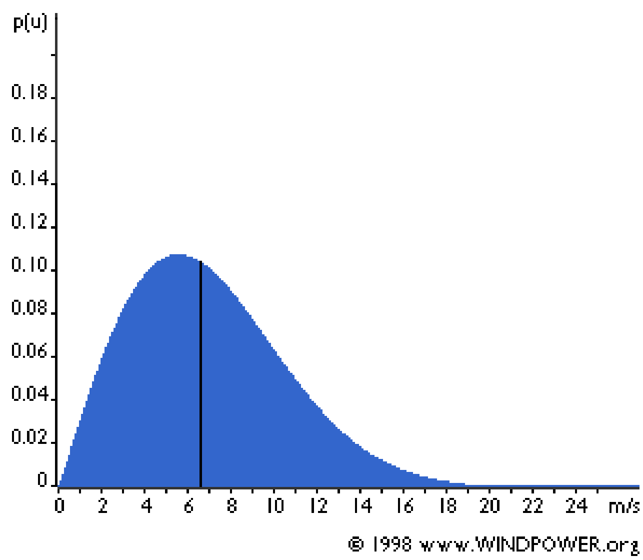


Figure 5.4 Wind distributions (Weibull graph)

To calculate the theoretical potential we have to make a choice between a series of wind turbines. One selection is based on the turbine size. The larger the rotor diameter of a wind turbine the more power output can be created. But large turbines may not rotate during low wind speeds and are more difficult to transport and install. Therefore we show in table 5.7 a brief overview of possible arguments for choosing either for a small or large turbine.

Table 5.7 Overview of arguments for opting for large or small wind turbines

Large rotor diameter	**Small rotor diameter**
Economies of scale (larger turbines deliver lower electricity costs then smaller turbines)	The local grid may be too weak to handle the electricity output from a large turbine
The cost of foundations does not rise in proportion to the size of the machine, and maintenance costs are largely independent of the size of the machine	There is less fluctuation in the electricity output from a wind park consisting of a number of smaller turbines, since wind fluctuations occur randomly
In areas where it is difficult to find sites for more than a single turbine, a large turbine with a tall tower uses the existing wind resource more efficiently.	The cost of using large cranes, and building a road strong enough to carry the turbine components may make smaller machines more economic in some areas.
	Several smaller machines spread the risk in case of temporary machine failure
	Aesthetical landscape considerations may sometimes dictate the use of smaller machines

St. Kitts

When we calculate the energy output with the use of the wind power calculator[62] for the island of St. Kitts (v_{av} = 6.56 m/s) we find different energy output levels between three analyzed wind turbines with similar capacity. See the energy output for the 600 kW turbines, NEG Micon 600/48, Nordex N43/600 and the Vestas V39 600/39 in figure 5.5.

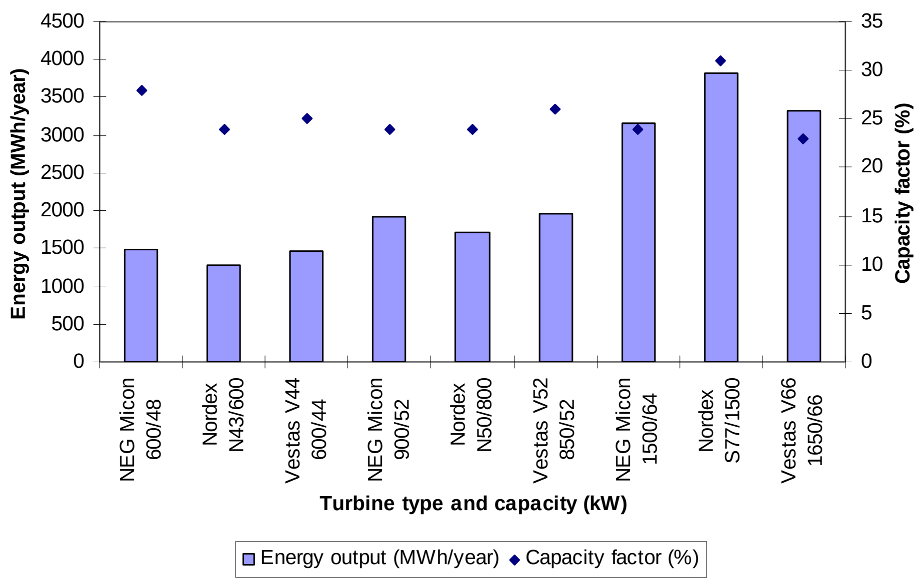


Figure 5.5 Energy output per turbines capacity based on the average wind speed of 6.56 m/s on St. Kitts

All the turbine sizes shown in figure 5.5 are standard manufacturing sizes of each company. As can be seen in the figure, the turbine sizes are not always equal and this makes it difficult to compare them with each other. From figure 5.5 the only clear comparison next to the 600 kW turbines is that the Nordex S70/1500 has a higher energy output than the NEG Micon 1500/64, while even though the Vestas V66 1650/66 its capacity is larger, it still has a lower energy output compared to one of the turbine types, that can also be seen at its capacity factor c_f of 23%. A

[62] Danish Wind Industry Association, See website: http://www.windpower.org/en/tour/wres/pow/index.htm, the calculations were done using an average temperature of 25 degrees Celsius, wind speed on hub height (50 m), Weibull factor of 2 and a roughness length of z_0=0.03

criterion to compare the wind turbines on their performance is the capacity factor. The capacity factor is the ratio of the actual energy produced in a given period, to the hypothetical maximum possible, i.e. running full time at rated power[63]. In figure 5.5 we see that the capacity factor are all within 23-26% with two exceptions by the NEG Micon 600/48 (c_f = 28%) and the Nordex S77/1500 (c_f = 31%). The differences in capacity factors lie in the difference in power curves of each wind turbine and these differences in power curve can be attributed to the design of the turbines, the rate between the rotor diameter and the generator size and differences in designs in the gear boxes of the wind turbines to regulate or maintain the rpm and capture the fluctuations in wind speeds.

Nevis

Also for the island of Nevis the energy output of three different wind turbines have been calculated using the wind power calculator. The result is shown in figure 5.6. Here we see that there is a general similarity in relative differences to the calculations done for St. Kitts. The only clear difference is in capacity factor of the Nordex N43/600 that has become higher than the capacity factor of the Vestas V44 600/44 (compare figure 5.5 and 5.6). Also the general energy output level of all the turbines are considerably higher for Nevis compared to St. Kitts, on average about 41% higher energy output over all the turbines, which is due to the larger average wind speed, of course.

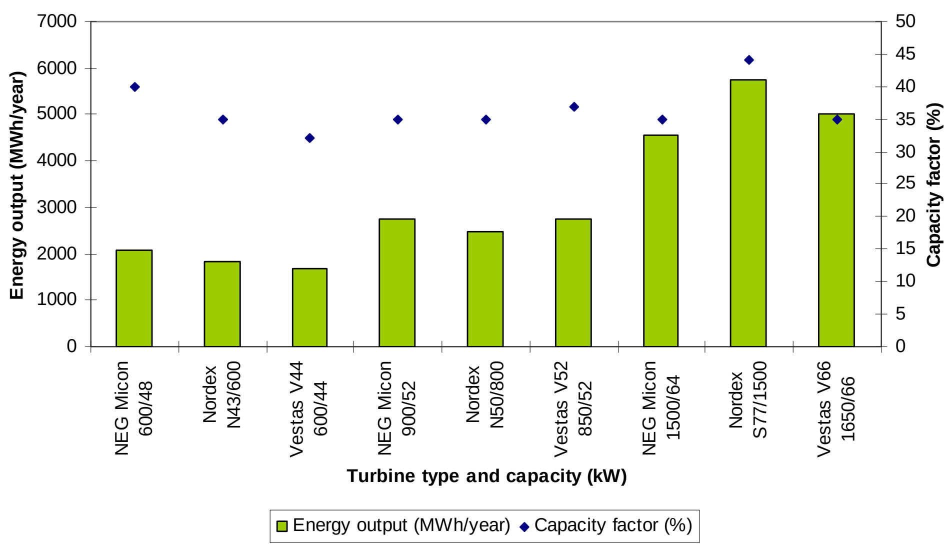


Figure 5.6 Energy output per turbines capacity based on the average wind speed on Nevis

Based on the arguments given in table 5.7 and the data shown in figures 5.5 and 5.6 we select the 800 kW wind turbine (Nordex N50/800) for both the islands for further studies. The turbine's energy output and capacity factor falls in the middle of its comparable unit sizes. And an 800 kW turbine has fewer logistical complexities when being transported to the islands compared to bigger turbines, while producing higher levels of energy output compared to smaller turbines. Also they tend to be more prudent against bad weather conditions or hurricanes.

Be aware that this option is only chosen to illustrate possible wind energy production and is not per definition the best applicable turbine type for the St. Kitts and Nevis conditions. There are low speed (longer blades) and high speed (shorter blades) wind turbines available with different

[63] Renewable Energy Research Laboratory, University of Massachussets, *Wind Power: Capacity factor, Intermittency, and what happens when the wind does not blow*, Amherst

capacities ranging between 300-2500 kW. The reason that the following calculations are just indicative is that no extensive wind resource assessment is performed and no objective comparative analysis is done between all the available wind turbines on the global market[64]. Since the objective of this study is to assess the theoretical potential over all the RETs, this detailed research falls beyond the scope of this study.

Each wind turbine has its own wind power curve that indicates at what speed what amount of power could be produced. Figure 5.7 shows the wind power curve of the Nordex N50/800 turbine. The cut in speed is 3.0 m/s, this is the moment when there is enough wind to start producing energy (see figure 5.7) and the cut out speed is 25.0 m/s, this is when the turbine turns off to prevent turbulence or material damage. As each turbine has its own power curve with different cut in/out speeds and different turbine sizes it forms a challenge to find the correct turbine for a certain spot, i.e., wind regime.

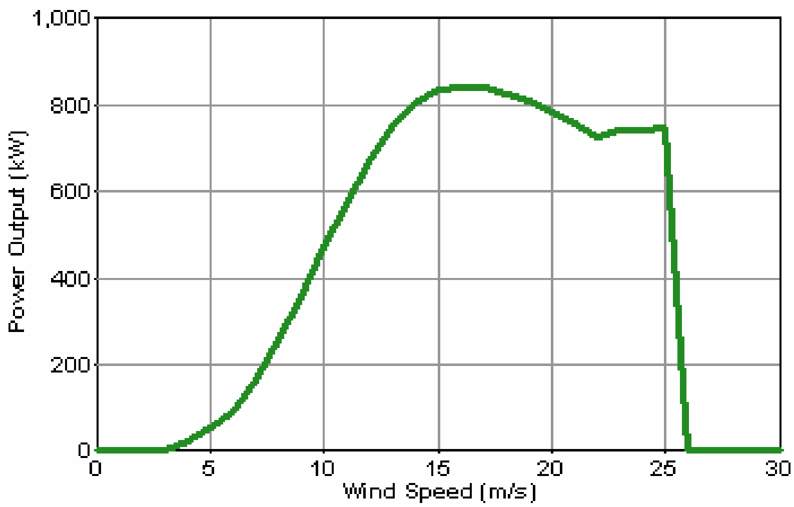


Figure 5.7 Wind power curve of the Nordex N50/800 (DWIA)

St. Kitts

The Nordex N50/800 has a hub height of 46 m and a rotor diameter of 50 m. Using a Weibull factor of 2 at 25 degrees Celsius, and a yearly average wind speed of 6.56 m/s on a height of 50 m, with a roughness length of z_0 = 0.03, we arrive at a total energy output of 1.62 GWh/year with a capacity factor of 23%.

Suppose we want to deal for instance with a load of 10 MW for St. Kitts. To comply with this demand, knowing that the above shown turbine can produce 1.62 GWh/year of electricity (equivalent to one 184.9 kW turbine running at 100% capacity), this will require about 54 turbines. A basic requirement when designing wind farms is that the space between each turbine should be about 5 times[65] the rotor diameter, in this case 50m, makes 250m. Say you have two rows of 27, this will take a surface area of about 2x27x250x250= 3,375,000 m2 (3.38 km2 or 337.5 ha) which is comparable to 459 soccer fields (105x70m2)[66].

[64] See: EWEA, Wind energy, the facts, volume 1, Technology, 2004, page 19, source: http://www.ewea.org/06projects_events/proj_WEfacts.htm for an updated overview of wind turbines.
[65] E. Lysen, Introduction to wind energy, 1982, source http://www.uce-uu.nl/swd.htm
[66] FIFA (Fédération Internationale de Football Association) rules on the size of a soccer field state minimum and maximum size for international matches: length between 100 and 110 meters, width between 64 and 75 meters. As average we take 105x70 which makes an area of 7350m^2, see http://www.fifa.com/en/regulations/regulation/0,1584,3,00.html

Thus a 10 MW wind park will require a considerable amount of space for an island as St. Kitts having 176 km2 of surface area. Also taking in mind that the island is of volcanic origin with many slopes and there are other land use functions in place, as urban areas that decrease the amount potential wind park areas. This means that a more conservative capacity should be taken in the further analysis.

Based on the previous topographic analysis and the information available on the land use for sugarcane production with a used area of 7,000 acres (2833 ha) and other general land uses we opt for a 3 MW production capacity wind park, which means we need about 18 Nordex N50/800 wind turbines, thus an installed capacity of 14.4 MW. In case we have two rows of turbines, the surface required will be 2x9x250x250 = 1,125,000 m2 (1.13 km2 or 112.5 ha or 153 soccer fields). Setting the wind turbines on sugarcane plantations could be considered an option, since the slopes and access to these lands are reasonable and also the combination of land use (wind park / agricultural land) in the Netherlands for example has become a common practice.

Nevis

For Nevis the energy output of the Nordex N50/800 is different because of a higher yearly average wind speed of 7.89 m/s on a height of 50 m. The turbine has a hub height of 46 m and a rotor diameter of 50 m, using a Weibull factor of 2 at 25 degrees Celsius, with a roughness length of z_0 = 0.03, we arrive at a total energy output of 2.46 GWh/year with a capacity factor of 35%.
Suppose we want to deal for instance with the peak load of NEVLEC of 8 MW (2005). To comply with this demand, knowing that the above shown turbine can produce 2.46 GWh/year of electricity (280.8 kW), this will require about 30 turbines. As described before the basic requirement when designing wind farms is that the space between each turbine should be about 5 times[67] the rotor diameter, in this case 50m, makes 250m. Say you have than two rows of 15, this will take a surface area of about 2x15x250x250 = 1,875,000 m2 (1.88 km2) which is comparable to 255 soccer fields (105x70m2)[68].

Thus an 8 MW wind park will require a considerable amount of space for an island as Nevis having 93 km2 of surface area. In this case the island is also of volcanic origin with many slopes and there are other land use functions in place that decreases the amount potential wind park areas. This means that here we also have to consider a more conservative capacity in the further analysis. For Nevis we will also opt for a 3 MW production capacity wind park, this will require about 12 Nordex N50/800 wind turbines, thus a total installed capacity of 9.6 MW. In case we have two rows of turbines, the surface required will be 2x6x250x250 = 750,000 m2 (0.75 km2 or 75 ha or 102 soccer fields). The total required area for wind energy on St. Kitts and Nevis is thus 112.5 ha (St. Kitts) and 75 ha (Nevis) is 187.5 ha.

In this section the wind energy potential was simulated in the Wind Power Calculator of the Wind Turbine Industry Association, later in this study the analysis will be performed in the HOMER model. The difference between the two models is that HOMER can integrate the electricity potential of the wind turbines into the electricity production mix for each island. Thus integrating wind energy potential next to bio-energy, solar and other RETs and find out what is the best combination for the islands of St. Kitts and Nevis.

[67] E. Lysen, Introduction to wind energy, 1982, source http://www.uce-uu.nl/swd.htm

[68] FIFA (Fédération Internationale de Football Association) rules on the size of a soccer field state minimum and maximum size for international matches: length between 100 and 110 meters, width between 64 and 75 meters. As average we take 105x70 which makes an area of 7350m^2, see http://www.fifa.com/en/regulations/regulation/0,1584,3,00.html

5.1.3 Solar

St. Kitts and Nevis is located in an area where the whole year through it is sunny and warm. The solar intensity is very high compared to other regions as Europe or North America. Thus the theoretical potential is expected to be large.

Technical possibilities

It is common to describe the solar source in terms of insulation; this is the energy available per unit of area and per unit of time (such as kilowatt-hours per square meter a year). The generally accepted solar constant is about 1368 W/m^2 measured as a yearly average, irrespective of location[69]. The most common solar energy conversion technologies are shown in table 5.8.

Table 5.8 Overview of Solar Energy Conversion Technologies (2000)

Solar Energy		
Technology	Energy product	Application
Photovoltaic solar energy conversion	Electricity	Widely applied; rather expensive, further development needed
Solar thermal electricity	Heat, steam , electricity	Demonstrated; further development needed
Low-temperature solar energy use	Heat (water and space heating)	Solar collectors commercially applied
Passive solar energy use	Heat, cold, light, ventilation	Demonstrations and applications; no active parts
Artificial photosynthesis	H2 or hydrogen rich fuels	Fundamental and applied research

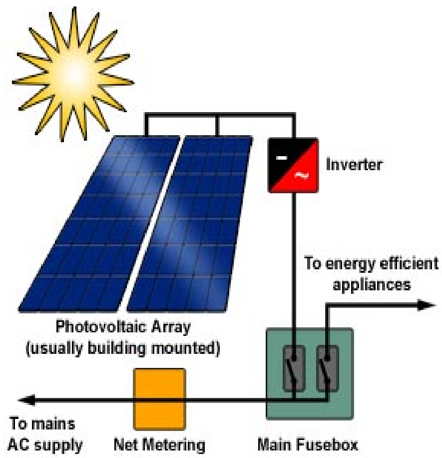
Source: World Energy Assessment 2000, UNDP

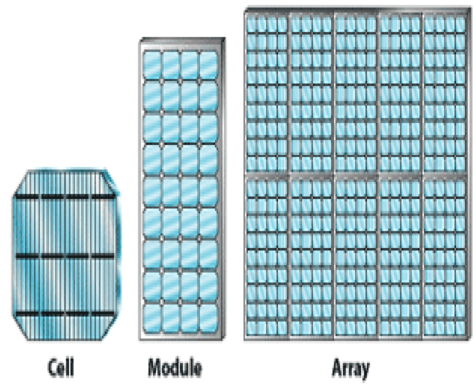
Since the focus of this study is on grid connected RETs we will focus on the grid connected PV systems available on the global market. The technical potential of photovoltaic systems (PV) has been studied in some detail in several countries. In densely populated countries with a well-developed infrastructure, there is an emphasis on applications of grid-connected photovoltaic systems in the built environment, including infrastructural objects like railways and roads, see figure 5.8. These systems are necessarily small- or medium sized, typically 1 kW to 1 MW.

Figure 5.8 Examples of grid connected PV systems in urban areas

Using grid-connected PV power can have economic as well as environmental advantages. Where utility power is available, consumers can use a grid-connected PV system to supply some of the power they need and use utility-generated power at night and on very cloudy days. When the PV system supplies power to the grid as well as to a specific building or piece of equipment, the grid may be considered a kind of storage device or battery for PV-generated power[70]. In figure 5.9 one can see on the left that a PV system exists of several interconnected arrays that produce energy.

[69] NASA, source: http://edmall.gsfc.nasa.gov/inv99Project.Site/Pages/science-briefs/ed-stickler/ed-irradiance.html
[70] US Department of Energy, Solar Energy Technologies Program, source: http://www.eere.energy.gov/solar/grid_connect.html





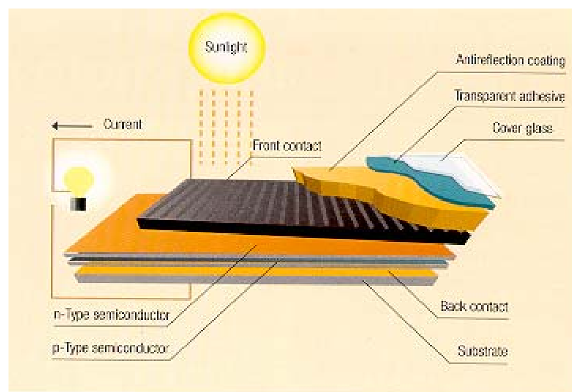


Figure 5.9 Schematic overviews of a PV system (Renewable Energy Technology Compendium, March 2005 (Libertas Capital))

The size of an array depends on several factors, such as the amount of sunlight available in a particular location and the needs of the consumer. In the top-right of figure 5.9 one can see that a PV array exists of several modules that on its turn consist of cells. The modules of the array make up the major part of a PV system, which can also include electrical connections, mounting hardware and power-conditioning equipment. On the bottom-right a general picture is shown of the components of which a cell is built up. Figure 5.10 gives a more detailed view of how the PV cell functions.

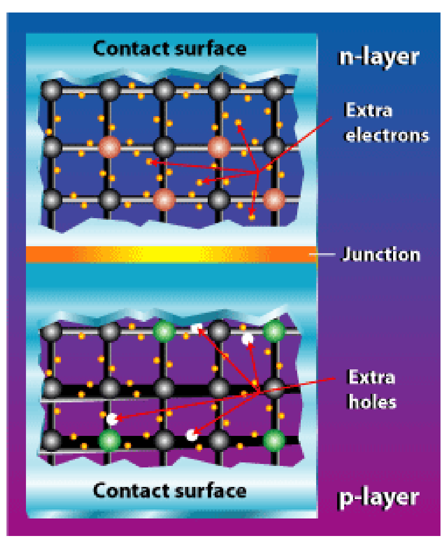


Figure 5.10 Detailed view of a PV cell (US Department of Energy)

The photoelectric effect is the basic physical process by which a PV cell converts sunlight into electricity. When light shines on a PV cell, it may be reflected, absorbed, or pass right through, and only the absorbed light generates electricity. The energy of the absorbed light is transferred to electrons in the atoms of the PV cell. With their newfound energy, these electrons escape from their normal positions in the atoms of the semiconductor PV material and become part of the electrical flow, or current, in an electrical circuit. A special electrical property of the PV cell—what we call a "built-in electric field"—provides the force, or voltage, needed to drive the current through an external "load," such as a light bulb.

To induce the built-in electric field within a PV cell, two layers of somewhat differing semiconductor materials are placed in contact with one another. One layer is an "n-type" semiconductor with an abundance of electrons, which have a negative electrical charge. The other layer is a "p-type" semiconductor with an abundance of "holes," which have a positive electrical charge. Although both materials are electrically neutral, n-type silicon has excess electrons and p-type silicon has excess holes. Sandwiching these together creates a p/n junction at their interface, thereby creating an electric field.

When n- and p-type silicon comes into contact, excess electrons move from the n-type side to the p-type side. The result is a buildup of positive charge along the n-type side of the interface and a buildup of negative charge along the p-type side. Because of the flow of electrons and holes, the two semiconductors behave like a battery, creating an electric field at the surface where they meet—what we call the p/n junction. The electrical field causes the electrons to move from the semiconductor toward the negative surface, where they become available to the electrical circuit. At the same time, the holes move in the opposite direction, toward the positive surface, where they await incoming electrons[71].

Available solar energy

Since there are no equipments available on St. Kitts and Nevis to monitor the solar irradiation or insulation an alternative data source is found via HOMER in the Meteorological NASA data base[72]. By inserting the coordinates of St. Kitts and Nevis (17 18N Latitude, 062 40W Longitude) and the time zone, solar data can be requested from their data base. See figure 5.11 for the average monthly solar radiation data for St. Kitts and Nevis.

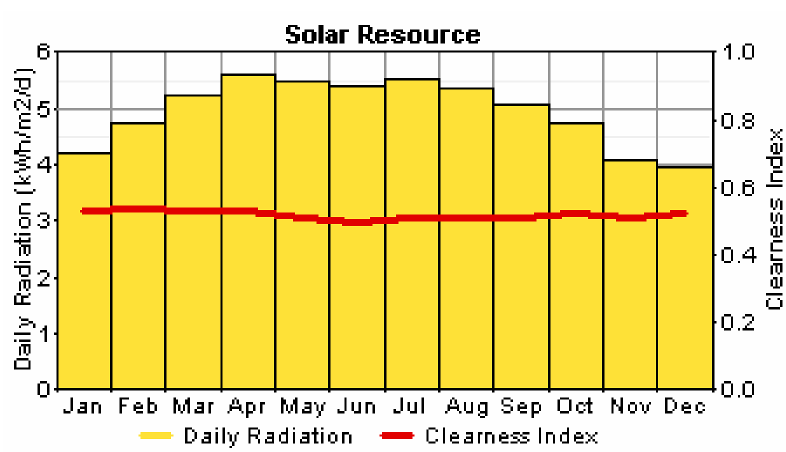


Figure 5.11 Average monthly solar radiation for St. Kitts and Nevis[73]

[71] US Department of Energy, Solar Energy Technology Programs, source : http://www.eere.energy.gov/solar/photoelectric_effect.html
[72] Source: http://eosweb.larc.nasa.gov/sse/
[73] Source: HOMER (National Renewable Energy Laboratory)/NASA meteo database, the data are the 10 year average (1993-2003)

The average yearly solar radiation is 4.96 kWh/m^2/day[74], this number is based on a 10 year average of monthly solar radiation data.

Theoretical energy production

For the theoretical energy production of the PV technology a choice is made to focus on the capital of St. Kitts and Nevis, where the highest population density exists and thus also more urban infrastructure to install PV systems. The population of Basseterre forms about 40% of St. Kitts population (32,397 inhabitants), which is 12,959 people. From the 2001 census we know that the amount of persons per household was on average 3[75]. If we assume that in 2005 the amount of persons per household did not change, we find a total amount of households of 4,320 in Basseterre. If each house has about 50 m^2 available roof space and we use 50% of it, this means that about 108,000 m2 is available for PV. This is excluding government buildings and other factories.

The overall energy conversion efficiency is 12.5%[76] for the whole PV system. Because of dust, salination or availability of the sunlight (shading) a derating factor of 0.8[77] is taken which accounts for possible losses in energy production. Multiplying the average solar radiation of 4.96 kWh/m^2/day with the derating factor of 0.8 and the energy conversion efficiency of 0.125 leads to 0.496 kWh/m^2/day of theoretical electricity production. The total amount of kWh that can be produced per day is then 108,000 m2 * 0.496 kWh/m^2/day is 53,568 kWh/day. So in a year this will be 19.55 GWh. Alternatively, PV systems are rated at 125 Wp/m^2 [77], the installed capacity thus is 108,000 m^2 times 125 is 13.5 MWp. The capacity factor can thus be calculated to be 19.55 GWh divided by the 13.5 MW times 8760 hours, which yields a capacity factor of 16.5%.

Box 1 Solar Water Heater Technologies

The easiest and most direct application of solar energy is the direct conversion of sunlight into low-temperature heat—up to a temperature of 100 degrees Celsius. In general, two classes of technologies can be distinguished: passive and active solar energy conversion. With active conversion there is always a solar collector, and the heat is transported to the process by a medium. With passive conversion the conversion takes place in the process, so no active components are used. In the Caribbean the best known active solar energy conversion system is the solar water heater system (SWHS).

The SWHS contribute to the reduction of energy need to heat up water and consists of three components: a solar collector panel, a storage tank, and a circulation system to transfer the heat from the panel to the store. SWHS systems for household differ in range and size, because of differences in hot water demands and climate conditions.

In general price/performance analysis will have to be made to size the solar hot water system and to investigate the optimum solar fraction (contribution of solar energy in energy demand). General results show a general dependence on the climate. The SWHS systems in Northern and Central Europe are designed to operate on a solar fraction of 50–65 percent. Subtropical climates as in St. Kitts & Nevis generally achieve solar fractions of 80–100 percent and this may result in solar heat production costs ranging from $0.03–0.12 a kilowatt-hour. See Batidzirai,, 2004 for more detail.

Note that this is the theoretical energy production potential; the main limiting factor for the kind of systems is their investment cost. This will be evaluated in the HOMER model.

5.1.4 Geo-thermal

Since the islands of St. Kitts and Nevis are on first look of volcanic origin, it is an indication that there are or at least have been activities related to convection of tectonic plates. This movement of the tectonic plates causes cracks in the earth surface and thereby allowing magma or lava to escape to higher levels in the earth mantle. A geothermal system is made up of three main elements: a heat source, a reservoir and a fluid, which is the carrier that transfers the heat. The heat source can be either a very high temperature (> 600 °C) magmatic intrusion that has reached relatively shallow depths (5-10 km) or because of the normal geothermal gradient of the earth that

[74] HOMER generates synthetic hourly global solar radiation data using na algorithm developed by Graham and Hollands (1990). The inputs to this algorithm are the monthly average solar radiation values and the latitude. The output is na 8760-hour data set with statistical characteritics similar to those of real meassured data sets.
[75] St. Kitts & Nevis Statistical Division, 2005
[76] NREL, Energy Efficiency and Renewable Energy Program, source: http://www.eere.energy.gov/RE/solar_photovoltaics.html
[77] Dr. Van Sark, W.G.J.H.M., Copernicus Institute, Utrecht University (2005)

expresses the increase in temperature with depth in the Earth's crust. Down to the depths accessible by drilling with modern technology, i.e. over 10,000 m, the average geothermal gradient is about 2.5-3 °C/100 m[78]. See figure 5.12 to get an impression of such geothermal system.

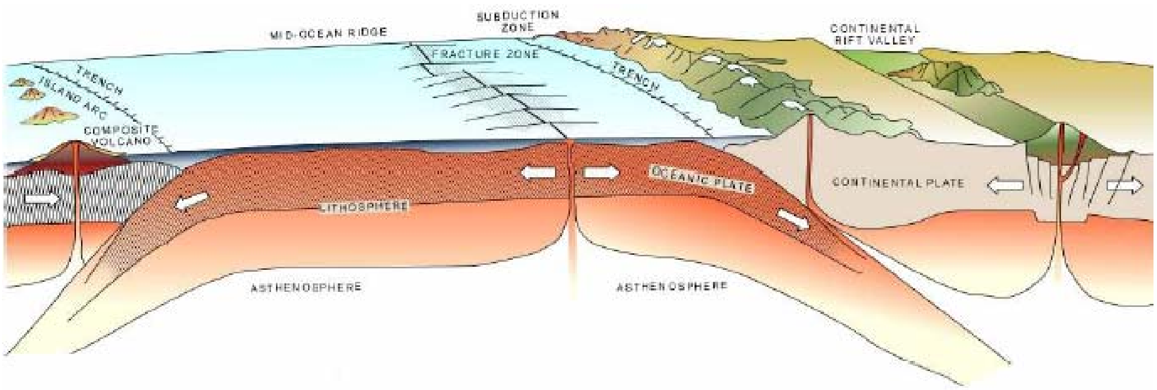


Figure 5.12 Schematic cross-section showing plate tectonic processes (Dickson and Fanelli, 2004)

In the case of the Caribbean islands we see a comparable situation on the left side of figure 5.12, where two tectonic plates are moving towards each other, causing one plate to submerge under the other and causing cracks in the earth mantle where the lava or magma can penetrate to create volcanic islands.

Geology

St. Kitts

The islands are the summits of a submerged mountain range that forms the eastern boundary of what is known as the Caribbean Tectonic Plate. The entire island archipelago is geologically young, having begun to form probably less than 50 million years ago, during the Miocene era. Volcanic activity occurred along the ridges of this arc during the Miocene era and has continued since.

St. Kitts has since undergone numerous and considerable changes in elevation but is now relatively stable. Newer volcanic material rest on a basement of older rocks, now only exposed where the newer deposits have been denuded. Mt. Liamuiga, the most northerly volcano has a youthful appearance and was active in recent (geologic) time. No obvious geologic faults can be observed, although several lineation have been noted which may be deeper faults masked by volcanic ejects. The island is composed almost exclusively of volcanic rocks of andesite[79] or dacite[80] mineralogy. Most of the deposits are pyroclastics[81] and range in size from silt-sized particles to boulders several feet in diameter[82].

[78] Dickson, M.H. and Fanelli, M., Instituto de Geoscienze e Georesorse, CNR, Pisa, Italy, 2004
[79] Andesite is a gray to black volcanic rock with between about 52 and 63 weight percent silica (SiO_2).
[80] Dacite lava is most often light gray, but can be dark gray to black. Dacite lava consists of about 63 to 68 percent silica (SiO_2).
[81] A pyroclastic deposit is the resulting layer or pile of material that has fallen to the ground by one or many pyroclastic eruptions.
[82] Source: Lang and Caroll, St. Kitts and Nevis Soil and Land use survey, 1966 in St. Kitts and Nevis Initial National Communication 1994

Nevis

Nevis is located in the northern part of the Lesser Antilles island arc and is built exclusively of volcanic rock. The island arc is situated along the junction where the North/South American tectonic plate subducts beneath the Caribbean plate. Nearly all of the islands along the arc are the result of subduction related volcanism. The islands in an older north-eastern section of the arc through eastern Guadeloupe, Antigua and Barbuda are built of carbonate platforms on ancient volcanic substrates of Eocene to mid-Oligocene age (50 to 30 million years). The remaining islands from Grenada in the south to Saba in the north are almost entirely volcanic in origin, and most have dormant or active volcanoes. These islands have been built since early Miocene times (last 20 million years).

Although the most recent eruptions appear to have been about 100,000 years ago, other manifestations of a potentially active volcano have been witnessed in recorded history, including seismic activity beneath the island and appearance and variability in hot spring and fumarole (soufrière) activity at the surface[83].

Available geothermal sources

The most common criterion for classifying geothermal resources is based on the enthalpy of the geothermal fluids that act as the carrier transporting heat from the deep hot rocks to the surface. Enthalpy, which can be considered more or less proportional to temperature, is used to express the heat (thermal energy) content of the fluids, and gives a rough idea of their 'value'. The resources are divided into low, medium and high enthalpy (or temperature) resources, according to criteria that are generally based on the energy content of the fluids and their potential forms of utilization. Because there is no standard classification an overview of several literature sources is shown in figure 5.13.

Within the Geo-Caraibas project (OAS), it resulted from pre-feasibility studies that there is a greater geothermal development potential on Nevis compared to St. Kitts. Nevis has sites where great potential exists for geothermal energy production development[84]. Unfortunatelly no information was available on the technical information related to this project and thus this section will highlight the general characteristics of this energy production system.

	(a)	(b)	(c)	(d)	(e)
Low enthalpy resources	< 90	<125	<100	≤150	≤190
Intermediate enthalpy resources	90-150	125-225	100-200	-	-
High enthalpy resources	>150	>225	>200	>150	>190

Source: *(a) Muffler and Cataldi (1978).*
(b) Hochstein (1990).
(c) Benderitter and Cormy (1990).
(d) Nicholson (1993).
(e) Axelsson and Gunnlaugsson (2000)

Figure 5.13 Classification of Geothermal resources in degrees Celsius (Dickson, H.M. and Fanelli, M., 2004)

[83] Source: Geothermal prospectiviy of Nevis island: a review and summary of existing data, Young, S.R., 2004
[84] Eastern Caribbean Geothermal project document (PDF-B), OAS, 2003, source: http://www.gefonline.org/projectDetails.cfm?projID=2113

In 2004 and 2005 geological studies were performed to assess the geothermal potential on Nevis. Studies related to geology, geochemistry and geophysics (containing gravity and self potential indicators) are done. Geochemical studies (including isotope geochemistry) are a useful means of determining whether the geothermal system is water- or vapour-dominated, of estimating the minimum temperature expected at depth, of estimating the homogeneity of the water supply, of inferring the chemical characteristics of the deep fluid, and of determining the source of recharge water. The geophysical studies are directed at obtaining indirectly, from the surface or from depth intervals close to the surface, the physical parameters of deep geological formations[85].

These physical parameters include:

- temperature (thermal survey)
- electrical conductivity (electrical and electromagnetic methods)
- propagation velocity of elastic waves (seismic survey)
- density (gravity survey)
- magnetic susceptibility (magnetic survey).

To quantify the real potential, additional studies will have to be done. One of these studies is an off-shore geochemistry study using deep well drilling for the identification of the geothermal reservoir in and around Nevis. Drilling of exploratory wells in general represents the final phase of any geothermal exploration program and is the only means of determining the real characteristics of the geothermal reservoir and thus of assessing its potential (Combs and Muffler, 1973).

Technical possibility
See table 5.9 for an overview of the existing geothermal energy conversion technologies.

Table 5.9 Overview of geothermal energy conversion technologies (NREL)

Geothermal energy		
Technology	Energy product	Application
Dry Steam Power Plant	Electricity	Widely applied commercially
Flash Steam Power Plant	Electricity	Widely applied commercially
Hot Dry Rock Mining	Electricity	Development and demonstration phase
Binary Power Plant	Electricity	Widely applied commercially

From information of the OAS[86] the Binary Cycle Power Plant is being scrutinized. Binary plants use hot water resources (37 °C – 150 °C). The hot water is passed through a heat exchanger in conjunction with a secondary (hence, "binary plant") fluid with a lower boiling point (usually a hydrocarbon such as isobutane or isopentane). The secondary fluid vaporizes, which turns the turbines, which drive the generators. An ammonia-water working fluid is also used in what is known as the Kalina Cycle. The remaining secondary fluid is simply recycled through the heat exchanger. The geothermal fluid is condensed and returned to the reservoir. Figure 5.14 gives a schematic view of the Binary Cycle Power Plant.

[85] Dickson, M.H. and Fanelli, M., Instituto de Geoscienze e Georesorse, CNR, Pisa, Italy, 2004
[86] Geo-Caraibas project coordinator, Mr. M. Lambrides

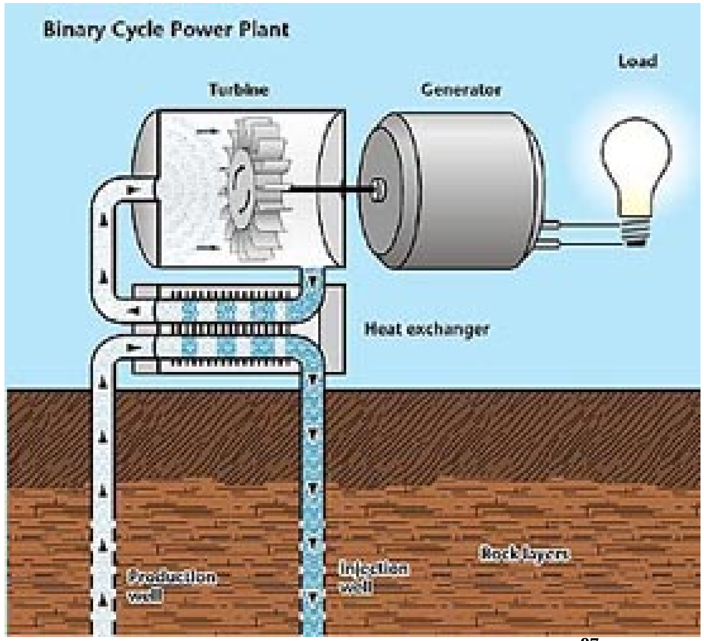


Figure 5.14 Binary Cycle Power Plant[87]

Because binary plants use a self-contained cycle, nothing is emitted. Energy produced by binary plants currently costs about 5-8 US$ cents per kWh (2004). Because these lower-temperature reservoirs are far more common, binary plants are the more prevalent[88].

Theoretical energy production

The curves in figure 5.15 give an indication of the electrical power output from a binary plant over a range of flows and geothermal reservoir temperatures.

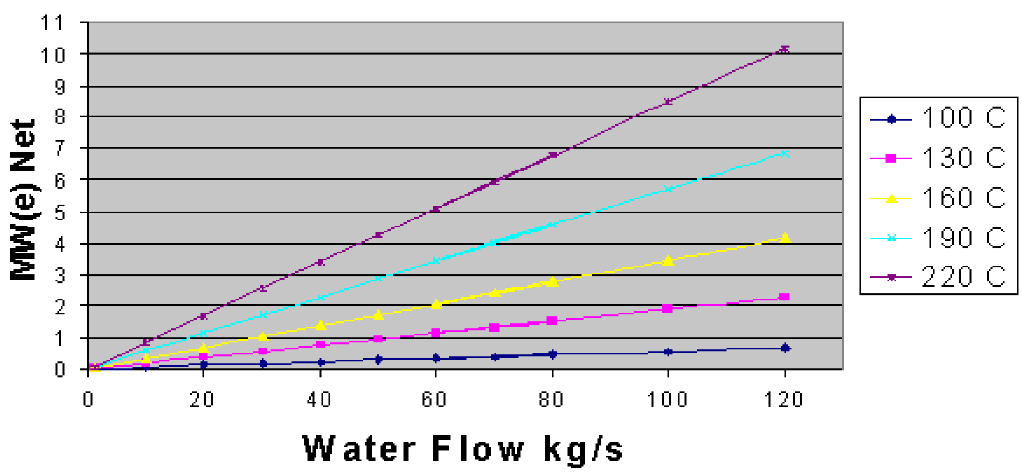


Figure 5.15 Power from Moderate to Low Temperature Fluids (World Bank Group[89])

Binary Cycle plants typically vary in size from 500 kW to 10 MW. If we look at a 5 MWe and a 10 MWe unit we can calculate the energy conversion efficiency for the units from figure 5.15

[87] Source: NREL Website, http://www.nrel.gov/geothermal/geoelectricity.html
[88] National Renewable Energy Laboratory (NREL), Geothermal Technologies Program, source: http://www.nrel.gov/geothermal/geoelectricity.html
[89] The World Bank Group, source: http://www.worldbank.org/html/fpd/energy/geothermal/technology.htm

with formula 5.3. The overall efficiency of a geothermal power plant is based on energy output subtracting the energy loads used for the cooling system and feed pump as well as down hole pump and other electrical equipment. So the benefit of the geothermal power plant at design conditions is the net capacity.

Formula 5.3 shows how the energy efficiency can be calculated for the binary system.

$$\eta_{plant} = \frac{P_{net}}{m_b * c_b * (T_b - T_0)} \tag{5.3}$$

η_{plant} = overall efficiency of the plant (kWe)
P_{net} = net capacity (kW)
m_b = mass flow rate brine (kg/s)
c_b = specific heat capacity brine (4.18 kJ/kg*˚K)
T_b = temperature of the brine (˚K)
T_0 = temperature of the environment / reference temperature (˚K)

When we look at figure 5.15 for the 5 MWe net capacity, with a reference temperature of 25 ˚C (298 K), for the range of flows between 60-85 kg/s and geothermal reservoir temperatures between 190-220 ˚C (463-493 K) the energy efficiency is between 8.5-10.2%. For a 10 MWe unit with the same reference temperature with a flow of 120 kg/s and a geothermal reservoir temperature of 220 ˚C (493 K), we find an energy conversion efficiency of 10.2%.

From assumptions made within the Geo-Caraibes project document an amount of 10 MWe is estimated as the energy production potential for the island of Nevis[90]. Geothermal power plants can boast high capacity factors (typically 85-95%[91]). If we assume Nevis will use two 5 MWe units with a capacity factor of 90% (mean of capacity factor 85-95%) a total amount of 78.8 GWh of electricity is produced in a year.

As geothermal energy is usually described as *renewable* and *sustainable*, it is important to define these terms. Renewable describes a property of the energy source, whereas sustainable describes how the resource is utilized. The most critical factor for the classification of geothermal energy as a renewable energy source is the rate of energy recharge. In the exploitation of natural geothermal systems, energy recharge takes place by advection of thermal water on the same time scale as production from the resource. The *sustainability in consumption* of a resource is dependent on its original quantity, its rate of generation and its rate of consumption.

5.1.5 Hydro

Large scale hydro power is considered a mature renewable technology, this in the sense of energy conversion efficiency and cost reductions achieved for the conventional hydro systems. But for small scaled hydro power there are still possibilities for further technical development.

After a first look at St. Kitts and Nevis it is unlikely that there are big running rivers to use the option of large scale hydro dams, but small hydro use potential will have to be researched.

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[90] Eastern Caribbean Geothermal project document (PDF-B), OAS, 2003, source: http://www.gefonline.org/projectDetails.cfm?projID=2113
[91] The World Bank Group, Geothermal Energy, the Technology and the Development Process, source: http://www.worldbank.org/html/fpd/energy/geothermal/technology.htm

Available Water

St. Kitts

Rain water drains in a radial pattern from the central mountain range to the ocean, interrupted only by the minor volcanic cones at Brimstone Hill, Ottley's mountain, Sandy Point Hill and Monkey Hill. Precipitation on St. Kitts falls along the northeastern side of the island at high altitude. Most of the water channels are deep and steep-sided, and that is why along all or most of their stretches they are usually dry. Only the relatively large Wingfield, Cayon and New River rivers flow almost to the sea for much of the wetter part of the year. The central mountain ranges drain radially, but due to the loose and porous nature of the soil, much of the water goes underground.

Most of the country's major watersheds are concentrated in the central area of the islands. The area's forest resources provide a reliable rainwater storage service. Rainwater is intercepted by the forest canopy and then absorbed by the soil and root systems. The surface water flows are very variable and are insufficient to meet the current demands during most of the year. Six ditches supply surface water on a year round basis in quantities sufficient to meet domestic demand. Storm runoff from heavy rainfall occurs infrequently and can cause traffic disruption, erosion and flooding of houses in the lower lying areas. This heavy runoff occurs once every few years and lasts only a few hours[92].

Nevis

Nevis has suffered three documented drought episodes since 1990. Normal annual rainfall for the island is 1,170 mm (46 inches) per year. During the 1990 to 1991 drought, average rainfall for the 2-year period was 942 mm (37 inches). In 1993, average rainfall was 942 mm (37 inches), and it was 885 mm (35 inches) in 1997. Rainfall is mostly orographic on St. Kitts and Nevis. Orographic refers to rain falling when moisture-laden air is forced up and over mountains. The air currents in the region usually move in a westerly direction causing rainfall to occur on the eastern side of the islands. Annual rainfall is less than 1,016 mm (40 inches) in the southeastern peninsula of St. Kitts[93].

Technical possibility

Examples of small hydro units include the use of variable speed turbines at low heads, induction generators, electronic control and telemetry, submersible turbo-generators, new materials, and the further development of innovative turbines, see table 5.10 (WEA,2000).

Table 5.10 Overview of Hydro Power Turbines (WEA, 2000)

Hydro energy		
Hydro Power Turbine	Energy product	Application
Bulb turbine	Electricity	Widely applied commercially
Francis turbine	Electricity	Widely applied commercially
Kaplan turbine	Electricity	Widely applied commercially
Pump turbine	Electricity	Widely applied commercially
Pelton turbine	Electricity	Widely applied commercially

[92] Source: Jeffers, R. and Hughes, J., SUSTAINABLE USE OF THE COASTAL ZONE, Using Economic incentive mechanisms to promote adaptation to Climate Change in the Hotel Sector, ST. Kitts and Nevis

[93] Source: http://www.sam.usace.army.mil/en/wra/N_Caribbean/N%20CARIBBEAN%20WRA%201%20DEC%202004.pdf

Theoretical energy production

From the above described situation we conclude that it will not be feasible to look for possible hydro power generation. To make hydro power economically feasible you need at minimum a year through flowing water current that can decrease the insecurity of resource availability and reduce the costs of energy production.

5.1.6 Marine/Ocean energy

There are several marine energy technologies. The islands are surrounded by deep water, on one side the Caribbean Sea and at the other side the Atlantic Ocean. Because of the trade winds (NE-E wind) there is a constant flow of waves towards the islands on the Atlantic side. An interesting area to look for marine energy resource is the canal between St. Kitts and Nevis where the current might be strong enough for marine turbines.

Technical possibilities

The main marine/ocean energy resources can be summarized, in order of maturity and use, as shown in table 5.11.

Table 5.11 Overview of Marine Energy Conversion Technologies (2000)

Marine Energy		
Technology	Energy production	Application
Tidal energy	Electricity	Applied; relatively expensive
Wave energy	Electricity	Research, development and demonstration phase
Current energy	Electricity	Research and development phase
Ocean thermal energy conversion	Heat, electricity	Research, development and demonstration phase
Osmotic energy	Electricity	Theoretical option
Marine biomass production	Fuels	Research and development phase

Source: World Energy Assessment 2000, UNDP

Tidal energy

Tidal energy traditionally involves erecting a dam across the opening to a tidal basin. The dam includes a sluice that is opened to allow the tide to flow into the basin; the sluice is then closed, and as the sea level drops, traditional hydropower technologies can be used to generate electricity from the elevated water in the basin. The combination of high costs, major environmental impact, and poor load factors makes this technology generally unattractive, but there may be occasional niche applications for it in the future in especially favorable locations. On first instance, due to lack of documentation and incentives towards this technology in the area it seems not to be an option on the islands of St. Kitts and Nevis.

Wave energy

Energy can be extracted from waves. The highest energy waves are concentrated off the western coasts in the 40˚–60˚ latitude range north and south of the globe. The power in the wave fronts varies in these areas between 30 and 70 kW/m with peaks to 100kW/m in the Atlantic SW of Ireland, the Southern Ocean and off Cape Horn. The capability to supply electricity from this resource is such that, if harnessed appropriately, 10% of the current level of world supply could be provided. As an example, in deep water off the northwest coast of Scotland (one of the more intense wave climates in the world) the average energy along the prevailing wave front can be 70 kilowatts a meter (or more). Closer inshore this falls to an average of around 20 or 30 kilowatts a meter, and along the shoreline to about 10 kilowatts a meter or less. The energy availability is thus sensitive to the distance from the shoreline[94].

[94] World Energy Council, source: http://www.worldenergy.org/wec-geis/publications/reports/ser/wave/wave.asp

Wave energy remains at an experimental stage, with only a few prototype systems actually working. Total grid-connected wave power is less than 1 MW, consisting of several small oscillating water column devices in China, India, and the United Kingdom. The technology of the Oscillating Water Column (OWC)[95], in terms of the science of wave energy, is the most widely accepted[96]. A new generation of larger devices is under development, due to be installed notably in the Azores (Pico) and Japan.

If we look around for island groups in the world, the Government of the Maldives has announced that it intends to introduce wave energy power to the islands. Sea Power of Sweden has signed a letter of intent with the government to supply a floating wave power vessel. If the first installation proves successful, the concept might be extended to cover the electricity requirements of other islands in the Maldives. There are more than 200 inhabited atolls in the group, located fairly far apart, with deep water in between as in the case of the water between St. Kitts and Nevis. At present all power in the Maldives is provided by diesel generators: conceptually, a proportion of these might be replaced by floating wave power vessels tailored to the needs of each particular location[94].

Ocean Thermal Energy Conversion (OTEC)

This technology makes use of differences in water temperatures at the surface and lower levels of the ocean and can be used for power generation or desalination plants[97]. A range of other usage methods of the OTEC principle are researched as marine aqua-culture (mari-culture) and horticulture, in which cold water supplies are used to cool soils through underground pipes to in greenhouses to reduce evapotranspiration and increase the yield of high value crops; the production of desalinated water on an appreciable scale; the biological extraction of fertilizers from the nutrient rich cold waters from the ocean depths; cold water for district cooling; and the possibility—this is a testable hypothesis—of using the cooled water from the outlet side of the heat exchangers to irrigate and restore coral reefs under threat from rising ocean temperatures in the region[101].

Available wave/tidal or ocean thermal energy

From the interviews performed and requested information on St. Kitts and Nevis the only information gathered was related to a tidal gauge positioned at the Coast Guard base (Birdrock) to collect and record information on sea-level rise as part of Caribbean Project for the adaptation to Climate Change (CPACC)[98]. Unfortunately no data is available on the average height difference that is being measured to calculate the theoretical potential[99]. Thus it can be concluded that no studies are done on collecting information to assess the wave energy production.

Also the Ocean Thermal Energy Conversion (OTEC) was mentioned during a visit to St. Kitts and Nevis. From literature research a study was found about the potential of the OTEC technology in Small Island Developing States (SIDS)[100], where a 30 kW experiment plant at Imari, in the Saga Prefecture, part of the Institute of Ocean Energy, Saga University, which is the only facility of its kind in the world, provides hard evidence of technological viability. There is no OTEC plant that is operating at the commercial scale equivalent to conventional power plants or wind and mini-hydro renewable energy plants. Absence of OTEC plants in the commercial

[95] K.J. Kimball, Embedded Shoreline Devices and Uses as Power Generation Sources, 2003, source: http://classes.engr.oregonstate.edu/eecs/fall2003/ece441/groups/g12/White_Papers/Kelly.htm

[96] BC Hydro, Executive report on the Green Energy Study for British Columbia, Vancouver island, July 2001, source: www.bchydro.com/rx_files/environment/environment1838.pdf

[97] Source: http://www.otecnews.org/whatisotec.html

[98] Communication from R. Edmead, Senior Environmental Officer, Department of Physical Planning and Environment, June 2005

[99] Caribbean Project for the Adaptation to Climate Change (CPACC), source: http://www.cpacc.org/download/OPJD98.rtf.

[100] Binger, A., Potential and Future Prospects for Ocean Thermal Energy Conversion (OTEC) in Small Island Developing States (SIDS), 2004, source: www.sidsnet.org/docshare/ **energy**/20040428105917_OTEC_UN.pdf

scale remains due to questions of the technical and economic viability of the entire system as well as environmental impacts.

The above mentioned does not mean that there is no potential for this renewable technology, there is considerable scope for innovation to reduce costs. One example, identified by research institutes in the Caribbean: the possibility of a second generation of plant using solar ponds to raise inlet temperatures, which would more than triple the efficiency of the plant. Solar pond technologies, which also have a good potential, would also benefit by having access to a low temperature coolant. In other words, OTEC may hold considerable benefits for another promising renewable energy technology, and vice versa[101]. Nevertheless for this study we will exclude the OTEC technology because of lack of commercially available scales and a lack of information on the natural energy resource availability which forms a pre-requirement for the selection of feasible RETs in this study.

Theoretical energy production

Because of limited experience with the marine renewable technologies, it is difficult to be certain how economic they will be if developed to a mature stage. The economics of the OTEC process have yet to be established for commercial applications in a large demonstration plant[102]. Thus we conclude that on short and medium term this will not by a feasible option for St. Kitts and Nevis.

5.2 Pre-selection of Renewable Technologies

Based on the gathered data for the resource assessment it seems that for the islands of St. Kitts and Nevis the hydro and marine options will not be feasible. In the case of hydro energy technology there is no year through flowing river that could make an investment in small hydro power feasible. This is because the availability of a current has to be constant or stable enough to reduce the costs of electricity production and reliability of electricity production, see section 5.1.5. For the marine energy production technologies there is at this moment a lack of basic information to be able to assess their theoretical potential. These systems are also not commercially proven and will require more research and development to become available for practical use in the Caribbean in the long term, see section 5.1.6.

To summarize, table 5.12 gives an overview of the RETs that are pre-selected based on their natural energy resource availability and expressed by their theoretical energy production potential.

Table 5.12 Theoretical energy production of pre-selected Renewable Energy Technologies (RETs) for St. Kitts and Nevis

RETs	Sub-technology	Theoretical capacity (MW)	Theoretical energy production (MWe)	Theoretical electricity production (GWh)	Area (ha)	Energy production per area (GWh/ha)
Biomass	Direct bagasse combustion	5.3	4.2	36.5	2833	0.013
Wind	On shore wind turbine	30 x 800kW	6	52.6	187.5	0.28
Solar	Photovoltaic system	13.5	2.23	19.6	10.8	1.81
Geothermal	Binary Cycle system	10	9	78.8	1-5[103]	16-79

The theoretical energy production was calculated with the use of the sub technologies shown in table 5.12 and assumptions considered for each resource (see previous sections 5.1.1 to 5.1.6).

[101] Global Environmental Facility (GEF), source: http://www.gefweb.org/COUNCIL/GEF_C15/GEF_C15_Inf.19.doc
[102] Renewable Energy Technologies Compendium, March 2005 (Libertas Capital)
[103] This is a rough estimation done by author

Also, the needed area is listed as well, which shows differing energy production per unit area. Note that it is worthwhile to investigate if certain areas can have multiple functions, such as sugarcane production in a wind park.

The RETs that remained after the resource assessment are biomass, solar, wind and geothermal energy conversion technologies. They seem to be more promising based on the availability of the natural energy resource and therefore scenarios will be set up based on these four RET options. See next chapter for more detail.

5.3 Evaluation of pre-selected RETs

For **wind energy** development, as discussed in section 5.1.2, a 3 MW wind park is considered for each island, this is equal to the capacity installed in the first phase of an economically proven 12 MW wind farm project done on Curacao (Dutch Antilles) in 1993[104]. Curacao has a total surface area of 444 km^2 (171.4 square miles). Taking into account that there is not much space on each island and the presence of other land use options (housing, infrastructure, tourism etc.), this 3 MW is considered to be acceptable. This is not the St. Kitts and Nevis limit for wind energy development and production. In the medium to long term future it might become possible to produce wind energy from off-shore wind farms[105, 106]. But in this study we will keep ourselves to the most directly feasible option, which is an on shore wind park development of 3 MW production capacity on each island.

In the case of **biomass energy**, the theoretical calculated capacity of 10.8 MWe (fuel cane) and 4.2 MWe (bagasse) by direct combustion on St. Kitts is considered indicative enough to use as starting point for the economical analysis. In the analysis though, a digestion plant (considered a mature technology to treat wet materials as bagasse[107,108]) will be analyzed in stead of direct combustion furnace or a fluidized bed reactor. The HOMER model assumes a biomass feedstock is fed into a gasifier/digester to create biogas (as the only bio-energy conversion option). The term biogas refers to gasified biomass. Biogas contains typically between 60-70% methane[109]. Biomass feedstock (such as wood waste, agricultural residue, sugarcane bagasse or other energy crops) can be gasified by thermo-chemical or biological processes, and the product may be called one of several different names, including synthesis gas, syngas, producer gas, and wood gas. Whatever the feedstock and the means of gasification, the major constituent gases of biogas are typically carbon monoxide, hydrogen, and carbon dioxide, plus a significant amount of nitrogen if thermal gasification is performed in the presence of air. Minor constituent gases include methane and water vapor. Biogas typically has a low heating value compared with fossil fuels, particularly if it contains a large amount of nitrogen, which is noncombustible. But it has several advantages over solid biomass, including cleaner combustion, higher efficiency, and better control[110]. The biogas is combusted in the biogas-fueled generator.

Energy production using digestion-gas engine system

The above leads us to calculate the energy production using a digestion system. As input we have 61,600 ton/year of baggase. Biogas production from vegetable origin (in this case sugarcane

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[104] Source: http://www.umassd.edu/SpecialPrograms/caboverde/windfarm.html
[105] See Henderson et al., Offshore Wind Energy in Europe, 2001
[106] Junginger, M. and Faaij, A., Cost reduction prospects for the offshore wind energy sector, Copernicus Institute (UU), 2003
[107] Sims, R.E.H., Climate change solutions from biomass, bio-energy and biomaterials, Centre for Energy Research, Massey University, New Zealand, 2003.
[108] Food and Agriculture Organization (FAO), source: http://www.fao.org/docrep/T1804E/t1804e06.htm
[109] CanREN, Natural Resources Canada, source: http://www.canren.gc.ca/tech_appl/index.asp?CaID=2&PgId=1114
[110] HOMER model help guide

baggase) is about 0.5 m^3/kg[111] and with a calorific value of $4MJ/m^3$ [112] we get a primary energy level of 123.2 TJp. By combusting the biogas in a gas engine with an electrical efficiency of 75% (70-80%)[113] an amount of 92.4 TJe is produced. This is equal to 92.4 TJe * 0.2778 GWh/TJ * 0.8 (load factor) = 20.5 GWh. This is equavalent to a biomass fueled plant of 2.3 MWe.

For **solar energy** development, PV systems are chosen as sub-technology because they can be grid connected and are easy to install and transport. In table 5.13 a more pessimistic number is used than calculated in the theoretical energy production section, see section 5.1.3. The reason is that the average income level of the population is low (US$ 5427/capita in 2003[114]) and thus, even with government support (in form of subsidies) it will be difficult to introduce PV systems on the given amount of households. Thus the aim is to do the analysis in case that at least 40% of the 13.5 MW that is calculated for Basseterre on St. Kitts is installed. This is thus 5.4 MW that we will incorporate in the scenarios for Basseterre on St. Kitts and 5.4 MW for Charles Town on Nevis, coming to a total of 10.8 MW. In the future the investment costs will decrease and energy conversion efficiency will improve and make this option more attractive to introduce on the islands[115].

For the **geothermal energy** option, we will assume, as discussed in section 5.1.4, a 10 MWe development on Nevis. The real potential is not known yet, but international negotiations are in the end phase, a Global Environmental Facility (GEF) project grant proposal is finished[116] and the next phase will be the agreement on the finance and start of the real feasibility study, by drilling wells.

Table 5.13 Starting point of RET energy supply scenarios for St. Kitts and Nevis during the period 2005 to 2015

RET	Sub-technology	Installed capacity (MW)	Energy production (MWe)	Energy production (GWh)	Capacity factor
Biomass	Anaerobic Digestion	2.9	2.3	20.5	0.8
Wind	On shore wind turbine	30 x 800kW	6.0	52.6	0.23-0.35[117]
Solar	Photovoltaic system	10.8	1.8	18.8[118]	0.17
Geothermal	Binary Cycle	10	9.0	78.8	0.9

Table 5.9 shows the overview of the general assumptions for the scenario build up as performed in chapter 6.

As a next step a time line from 2005 to 2015 will have to be made and assumptions made for when each of these renewable technologies will start their operation. Another factor is that one has to take in mind that for many of these technologies no or limited basic resource data is available on the islands and thus time is required to perform pre- and feasibility studies before coming to implementation and operation of the RETs. Next to this, the economical development

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[111] Pound, B. et al., Biogas production from mixtures of cattle slurry and pressed sugar cane stalk, with and without urea, CEDIPCA, CEAGANA, Dominican Republic.
[112] HOMER biogas fuel properties (LHV = 5.5 MJ/kg with a density of 0.72 kg/m3, thus about 4 MJ/m3)
[113] U.S. Environmental Protection Agency (EPA), Catalogue of CHP Technologies, Technology Characterization: Gas Turbines, USA, 2002
[114] See section 3.4
[115] Schaeffer, G.J. and Moor, H.H.C. de, Energy research Centre of the Netherlands (ECN), Learning in PV trends and future prospects, 2004.
[116] Eastern Caribbean Geothermal project document (PDF-B), OAS, 2003, source: http://www.gefonline.org/projectDetails.cfm?projID=2113
[117] The capacity factor of 0.23 that counts for St. Kitts and 0.35 for Nevis
[118] $10.8*10^6W$ / $125Wp/m^2$ * 0.5977 kWh/m2/day * 365days = 18.8 GWh

or future decrease in investment costs of the RETs is also important to look at, since the prices tend to decrease per doubling of production (see the experience curve theory in section 6.4.1).

Before we go into more detail, we have to note that during the modeling we will treat each island separately. This is because each island has its own available natural resources and utilities with their own power production units and load curves. At the end of the modeling analysis a general summary will be made for the Federation of St. Kitts and Nevis.

6. Scenario build up

In this chapter scenarios will be set up to make it possible to identify the most cost-effective electricity production system using the theoretical energy production potential of the pre-selected RETs, for the production of electricity on the islands of St. Kitts and Nevis.

An important step in this report is setting up the scenarios related to future peak demands up until the year 2015; see the introduction and objective of this study.

6.1 Future demand projections

The HOMER model uses typical **daily load curves** as primary data for energy demand analysis. It uses this information to calculate the electricity demand per hour to evaluate the best load operation, taking all the energy production technologies in account and also identifies the most cost-effective way or combination, to comply with this demand. One limiting factor that comes along with the HOMER model is that it cannot calculate future demand predictions by itself. It only analyzes the present situation. To perform the analysis of the possible future introduction of RETs in the period 2005-2015 for St. Kitts and Nevis, the energy demand and its average daily load curve has to be calculated manually.

6.1.1. Demand projections and future daily load curves

The method chosen to resolve the above mentioned problem is to calculate the percentual annual growth of the peak demand (see figures 6.1 and 6.2) and incorporate this information in the current available daily load curves of each utility to create future daily load curves.

Demand projections

On figures 6.1 and 6.2 you can see the peak demand projections for both St. Kitts Electricity Department as for NEVLEC. There is a difference in the projections, because two different projection methods are used.

In the case of St. Kitts Electricity Department, a private consultancy calculated the demand projections based on their own projection model based. Their projection method was based on analyzing the energy demand of three sales categories (General Services, Domestic Services and Industrial/Commercial) and using three scenarios where the likelihood of implementation of future development projects differs[119].

For NEVLEC use is made of the historical data provided by NEVLEC and has been extrapolated to create demand projections, the maximum roof in demand where the projection will become linear is set on 80 MW after 2035[120].

[119] Stanley Consultants, Generation Expansion Plan for the St. Kitts Electricity Department (2005-2015), April 2005
[120] Choice made by author after consultation with OAS and UU experts

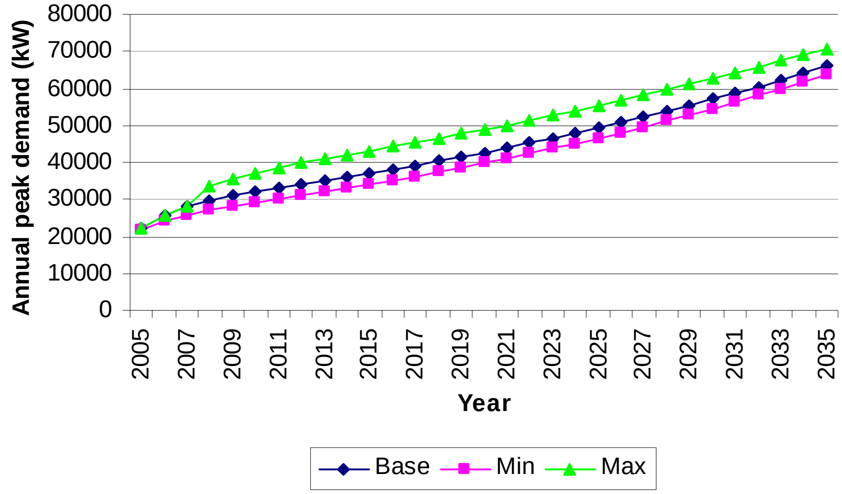

Figure 6.1 Projection of the Annual peak demand for St. Kitts for the period 2005-2035[121]

In the short term 2005-2008 the projections of each scenario for St. Kitts differ for the min-scenario (on average 7.1% growth per annum), base-scenario (on average 9.1% growth per annum) and max-scenario (on average 12.6% growth per annum). After this period till 2015, the scenarios develop relatively similar (on average between 2.9-3.3% growth per annum).

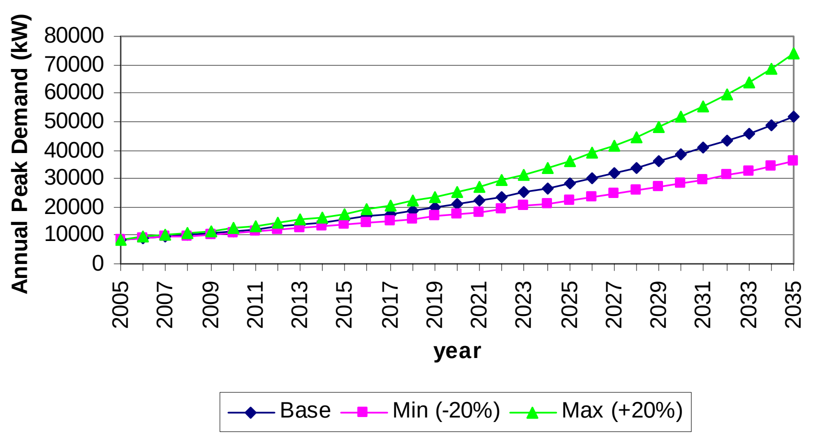

Figure 6.2 Projections of the peak demand for Nevis for the period 2005-2035

Figure 6.2 shows different projections for Nevis; here the historical data are extrapolated and a min- and max-scenario is created based on 20% deviation from the mean figures (base-scenario). Since we are only focusing on the period 2005-2015 the uncertainty level of these projections is reduced. The variation in average annual growth rate is for the min-scenario (4.9% per annum), base-scenario (6.2% per annum) and max-scenario (7.4% per annum).

Future daily load curves

In the future, due to economic development (expressed in new industry, commerce, infrastructures or buildings), the pattern of seasonal peak demands (load curves) can change. For

[121] Source: Calculated using the Generation Expansion Plan (2005-2015), St. Kitts Electricity Department (2005)

example as summer air conditioning becomes more common or due to the impact of increased electrification of public transport[122].

It is assumed for this study that the load curves will only increase in capacity related to the demand projections and will remain in the same shape or having similar curve slopes. This is because on long term maintaining this load curve shape, it can be considered as the worst case scenario for St. Kitts and Nevis, because the more developed a country the less fluctuation there is in the load curves[123]. Within the HOMER model there is a possibility to add daily and hourly noise factor that will make the load curves look more realistic.

Because of the large fluctuations in demand over the course of the day, it is normal to have several types of power stations broadly categorized as base load, intermediate load and peak load stations. The base load stations are usually steam-driven and run more or less continuously at near rated power output. On small island states coal, gas or diesel are the main energy sources used[124]. Intermediate load and peak load stations must be capable of being brought on line and shut down quickly once or twice daily. A variety of techniques are used for intermediate and peak load generation, including gas turbines, gas- and oil-fired steam boilers and hydro-electric generation.

Figures 6.3 and 6.4 show the typical current daily loads of both St. Kitts Electricity Department as NEVLEC for a typical week day. The hour or daily load curve can give a good impression of how the energy demand changes within a day or a month. From this information the real peak demand can be found. This peak demand is important to know because a power plant should always have a firm capacity installed that can handle this demand.

Note that the load capacity between the two utilities differs considerably. St. Kitts Electricity Department has an average daily load twice the one of NEVLEC. The shape of both the daily load curves is relatively similar (compare figure 6.3 and 6.4).

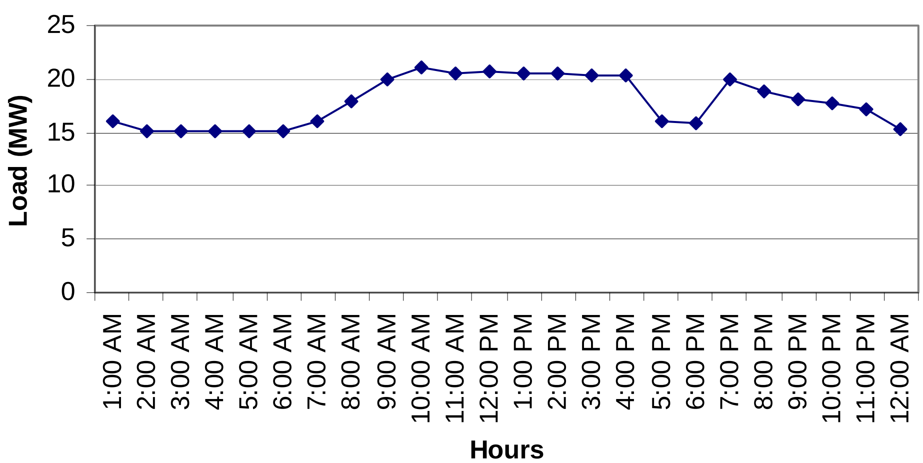

Figure 6.3 Load curve of a typical weekday on St. Kitts (Source: St. Kitts Electricity Department, 2005)

The peak load as shown in figure 6.3 was 20.8 MWe at 10.00 AM. The week day's base load for St. Kitts Electricity Department is 15.1 MWe.

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[122] Uranium Information Centre (UIC), Electricity Today and Tomorrow, source: www.uic.com.au/ne2.PDF
[123] Western Power Distribution (WPD), Long term development statement for Western Power Distribution, Electricity distribution system, November 2005, source: www.westernpower.co.uk/ servercode/showdocument.asp?ID=212
[124] Climate Institute, http://www.climate.org/topics/green/index.shtml

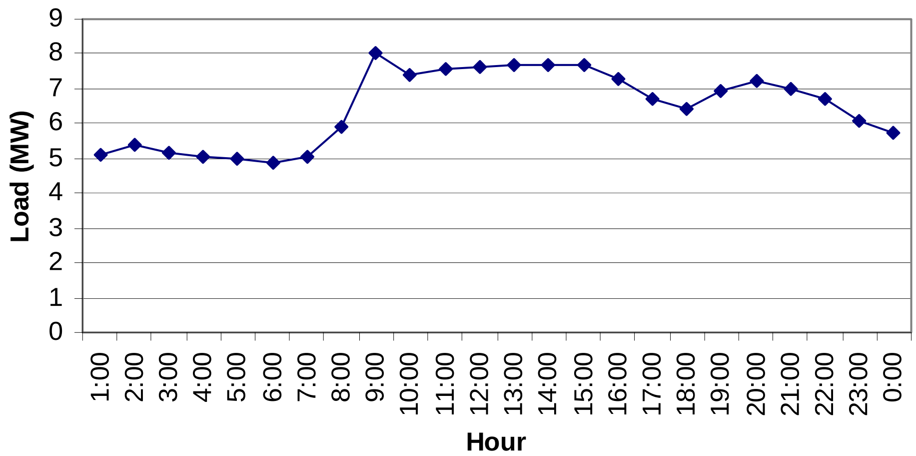


Figure 6.4 Load curve of 11 July 2005 on Nevis (Week day) (NEVLEC)

In the case of NEVLEC, the peak load was about 8.0 MWe on 11 July 2005. The reason for showing this specific day is because on this day the peak demand (8.02 MW) was the highest for the whole period of January 2005 till the end of July 2005. The base load of NEVLEC was 4.9 MWe during week days in the first half of 2005.

Figures 6.3 and 6.4 represent a load curve in a week day; the curve is on each week day almost identical. It is because it represents the week day's activities on Nevis. The working hours on St. Kitts and Nevis are between 8am to 4pm, that is when the governments buildings, schools, hotels, restaurants and shops are being cooled by Air Conditioning and other production activities in the industry sector are occurring.

For the future load curves, use is made of the base line scenarios that can be seen in figures 6.1 and 6.2 in blue. To use the HOMER model in a more practical manner, we will take 4 evaluation moments in the years 2005, 2008, 2012 and 2015 to build up the energy supply scenarios for St. Kitts and Nevis.

Table 6.1 Average relative annual growth in peak demand for St. Kitts Electricity Department and NEVLEC for the period 2005-2015

Year	St. Kitts kW	Nevis kW	St. Kitts Relative increase	Nevis Relative increase
2005	22109	8598		
2005-2008	22109 -29549	8598 -10285	33.7%	19.6%
2008-2012	29549 -33895	10285 -13059	14.7%	27.0%
2012-2015	33895 -36931	13059 -15621	9.0%	19.6%

Table 6.1 shows the relative increase in demand for both utilities for the intermediate periods 2005 to 2008, 2008 to 2012, etc. In this way we can multiply the relative increase with the energy demand per hour given in the load curves and create the future daily load curves. See as example figure 6.5 for the future week days daily load curves of NEVLEC.

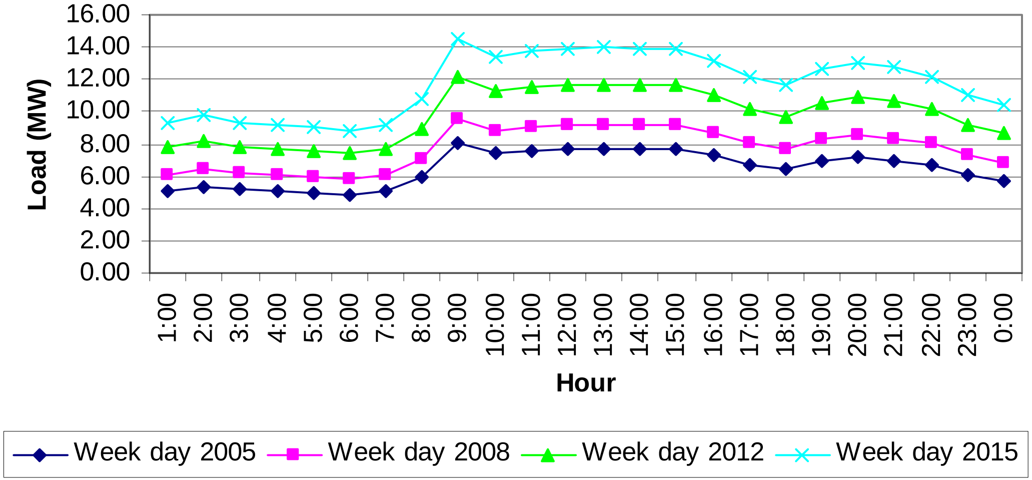


Figure 6.5 Future week day daily load curves of NEVLEC for the period 2005-2015

See appendix A3-1 to A3-4 for the results of the future week and weekend daily load curves of both NEVLEC and St. Kitts Electricity Department.

6.2 Comparing Business-as-Usual scenarios with existing expansion plans

St. Kitts Electricity Department

As known from section 4.2, the Department has opted to purchase 7.5 MW in 2006 from La Vallee and expanding the generation capacity at the Needmust power plant by 4 MW in 2007, 2011 and 2015.

In table 6.2 an overview is shown of parameters of interest in the business-as-usual (BAUK) scenario for St. Kitts. It indicates the minimal amount of required diesel capacity to comply with the peak capacity demand, which is calculated by the HOMER model[125]. This demand is based on the baseline scenario of the annual peak demand projection shown in figure 6.1, and is multiplied by noise factors of 5% daily deviation (load factor 0.73, see Section 4.2) that causes the annual peak demand to be somewhat larger.

The expansion plan shows the capacity build up based on the planned diesel purchase. The installation dates are modified to be able to compare the two scenarios. The date 2008 represents the period 2005-2008, thus the installation of a unit can take place within this time frame.

The choice is made to take into account the firm installed capacity, this is the installed capacity that is still within the economical lifetime of 20 years. This means for St. Kitts Electricity Department that although the two 34 year old units #1 and #2 are still in operation, they form a too high risk of possible fall out and are therefore excluded from the scenarios.

One can notice in table 6.2 that in the period 2005 to 2015 there will be an increase in capacity shortage from 5% to 29% in case this expansion plan is implemented. Taking in mind that the two currently running 3.6 MW units (#1 and #2) are over their economical lifetime (set on 20 years)

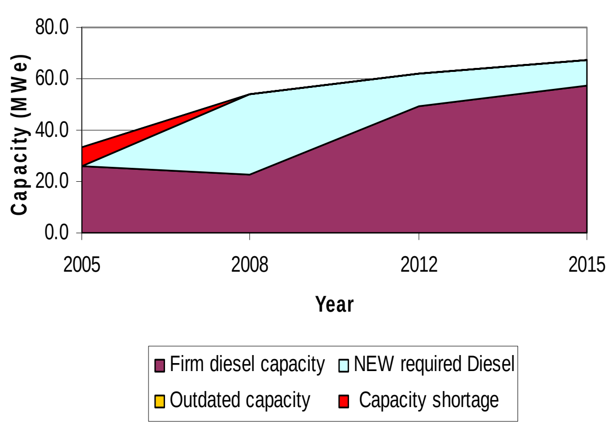
[125] In case of a wind-diesel system, if one considers the required operating reserve to be 10% and a windpower output security of 50% (capacity factor), then for the peakload of for instance 140 kW with an installed wind capacity of 80 kW, HOMER will calculate the required operating reserve to be 14 kW + 40 kW = 54 kW. The diesel generators must therefore provide 60 kW + 54 kW (operating reserve), meaning that the installed diesel capacity should be at least 114 kW.

and that the capacity is then 26.3 MW, the capacity shortage will increase from 23% in 2005 to 41% in 2015. For the business as usual scenario we need to realize that in 2005 the firm capacity is 26.3 MW which means that in the period 2005 to 2008 about 31.1 MW extra diesel capacity is required because the shortage is already 14.2 MW in 2005.

Table 6.2 Comparison between business-as-usual and expansion plan scenario for St. Kitts Electricity Department to comply with peak demand in the period 2005-2015

	2005	2008	2012	2015	Unit
Capacity demand	**24.6**	**32.9**	**37.8**	**41.2**	**MW**
Outdated capacity	0.0	3.5	4.4	4.4	**MW**
Real operating capacity	33.5				**MW**
Capacity shortage	5				**%**
Business-as-Usual St. Kitts					
Firm diesel capacity	**26.3**	22.8	49.5	57.6	**MW**
NEW required Diesel		31.1	12.5	9.9	**MW**
Tot. Installed Diesel[126]	**40.5**	**53.9**	**62.0**	**67.5**	**MW**
Capacity shortage	14.2				**MW**
Capacity shortage	0	0	0	0	**%**
Expansion Plan					
Firm diesel capacity	26.3	22.8	29.9	29.5	**MW**
Planned Diesel installation	0.0	11.5	4.0	4.0	**MW**
Tot. Installed diesel	**33.5**	**41.5**	**41.1**	**40.7**	**MW**
Capacity shortage[127]	5	10	21	29	**%**
Capacity within economical lifetime	**26.3**	**34.3**	**33.9**	**33.5**	**MW**
Capacity shortage	23.0	25.0	35.0	41.0	**%**

Figure 6.6 shows the future projections of the business-as-usual and the expansion plan scenarios for St. Kitts Electricity Department, when including only diesel units that are within the economical lifetime of 20 years.



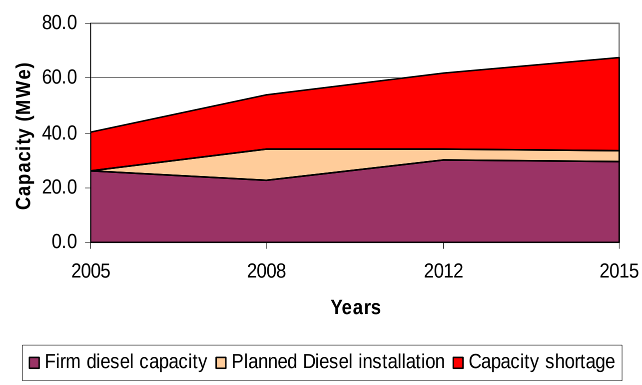


Figure 6.6 Business-as-usual scenario (left) and Expansion Plan St. Kitts (right)

[126] This is the installed capacity required to have a capacity shortage of 0% and giving all the units an economical lifetime of 20 years
[127] Capacity shortage is the shortage in electricity production (kWh) to comply with the annual electric load, calculated based on a load factor of 0.73 and energy efficiency of 38.9%

From table 6.2 and figure 6.6 we can conclude that the current expansion plan is based on the baseline of the annual peak demand projection (figure 6.1). The capacity expansion (expansion plan scenario) is not sufficient to comply with the peak demand for the period 2012-2015[128]. Thus it is recommended to follow the business as usual scenario for St. Kitts to have a security of supply for unforeseen events that can occur with such a power plant. In section 6.3.2 this same approach and starting point is used in all the scenarios for the economical analysis and explained in more detail. Note that the analysis is aiming for the optimal situation, while in reality the lifetime of the diesel units can be extended, other load factors can be applied by operating the plant more efficiently, and the technical efficiency of the units may increase.

Nevis Electricity Company (NEVLEC)

In the case of NEVLEC there is no clear expansion plan. The only information given upon expansion was the plan to purchase 3 MW extra capacity at the end of 2005 or first quarter of 2006, this means that the installed capacity in the period 2005-2008 will have a capacity shortage of 12%[129] to the peak demand of 10.5 MW, see table 6.3. Even in the case we analyze the real operating capacity of 12.8 MW we find a capacity shortage of 1%, see figure 6.7 for an impression of the possible projections. Figure 6.7 illustrates that by expanding with 3.0 MW (expansion plan) there will still be a capacity shortage of 12%, is equivalent to 4.2 MW capacity.

Table 6.3 Comparison between business-as-usual and expansion plan scenario for Nevis Electricity Company to comply with peak demand in the period 2005-2015

	2005	2008	2012	2015	Unit
Capacity demand	**8.8**	**10.5**	**13.3**	**15.9**	**MW**
Outdated capacity	0	0.9	4.5	4.7	**MW**
Real operating capacity	12.8				**MW**
Capacity shortage	1.0				**%**
Business-as-Usual Nevis					
Firm diesel capacity	**11.9**	11.0	13.7	18.4	**MW**
NEW required Diesel	0	7.2	9.4	9.3	**MW**
Tot. Installed Diesel[130]	**13.8**	**18.2**	**23.1**	**27.7**	**MW**
Capacity shortage	1.9				**MW**
Capacity shortage	0	0	0	0	**%**
Tentative Expansion Plan[131]					
Firm diesel capacity	11.9	11.0	9.5	18.4	**MW**
Planned Diesel installation	0	3.0	*13.6*	*9.3*	**MW**
Tot. Installed diesel	**11.9**	**14.0**	**23.1**	**27.7**	**MW**
Capacity shortage	4.0	12.0	0	0	**%**

[128] We have to note that the projections made here are different calculated than the original expansion plan projection, here we consider 26.3 MW (installed diesel within 20 years lifetime) as starting point, also we multiply the load curve with noise factor of 5% deviation that causes the annual peak demand to increase from 22.1 MW to 24.6 MW (to simulate a more realistic projection).

[129] This capacity shortage expressed in %, is the shortage in the electricity production and demand (kWh), using a load factor of 0.74 and an energy efficiency of 34.8%. Taking in mind that the load demand is multiplied with a noise factor of 2% daily and 2% hourly deviation that makes the annual peak demand increase from 8.6 MW to 8.8 MW in 2005

[130] This is the installed capacity required to have a capacity shortage of 0% and giving all the units an economical lifetime of 20 years

[131] This scenario is based on the tentative to maintain the capacity shortage at 0% for the period 2008-2015

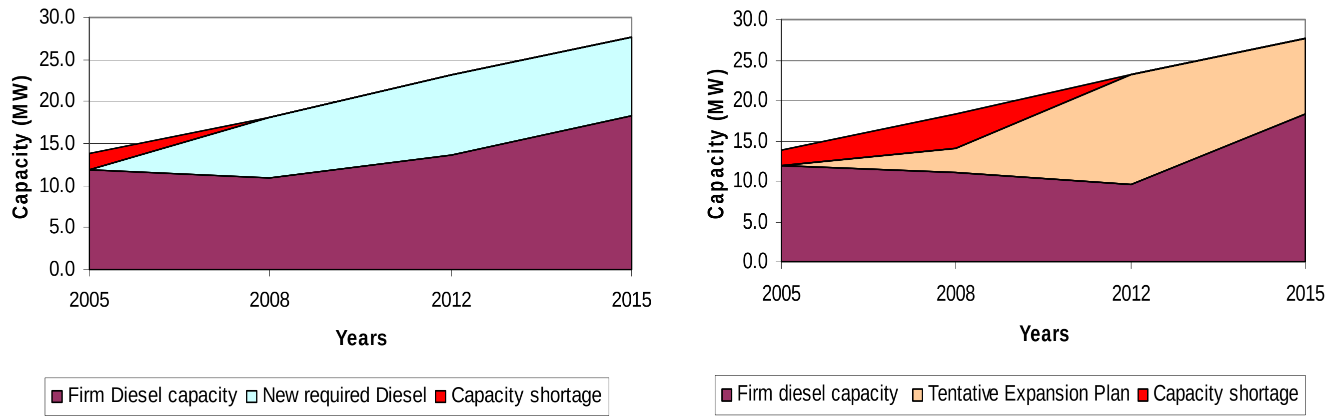


Figure 6.7 Business-as-usual scenario (left)and expansion plan scenario (right)

6.3 Building the electricity supply scenarios

In this section we will construct the electricity supply scenarios that will contain all the pre-selected grid connected RETs as shown in table 5.13.

6.3.1 General scenarios for St. Kitts and Nevis

Table 6.4 gives an overview of the energy supply scenarios for both the island of St. Kitts and of Nevis. In the business as usual scenarios there is no incorporation of renewable energy technologies and they project the continuing development of currently used fossil fuel based energy production technologies. In the best case scenarios we assume that already by the year 2008 a certain amount of RETs are implemented and in operation. Thus the time of implementation and the amount of capacity start up of RETs is the key criteria for the classification of the scenarios. In the next sections each specific scenario will be explained in detail.

Table 6.4 Overview of scenarios for St. Kitts and Nevis

Scenario	Description	Abbreviation	
		St Kitts	Nevis
Business As Usual	No RET	BAUK	BAUN
Fast RET intro / high contribution	RET in 2008	K1	N1
Intermediate RET intro / contribution	RET in 2012	K2	N2
Slow RET intro / contribution	RET in 2015	K3	N3

6.3.2 Scenarios for St. Kitts

The first scenario is the Business-as-Usual scenario for St. Kitts (BAUK), where no RET is included until the year 2015. In the case of the best case scenario, scenario K1, the possible development is shown in table 6.4, when all the stakeholders have a consensus on RET introduction and the project procedures follow the normal trends. Under the worst case scenario

K3 we will consider the option described in the "Generation Expansion Plan of St. Kitts Electricity Department, 2005[132]", where it was concluded that RETs are not seen as viable options on intermediate term, in this case we will interpret intermediate term as the timeframe of 2005 until 2012. For all the three scenarios, K1, K2 and K3, a limited amount of diesel generators will have to be installed as backup capacity to the RETs; this is because RETs have a variation in capacity factor and may require extra capacity to comply with the electricity supply security margin of the energy supply system. The *capacity margin* is the margin of generation capacity beyond the daily system peak demand that is required to cover situations of unexpected failure of generation, or unusual or unanticipated increases in demand. Thus it plays a role in helping to ensure security of electricity supply to the final customer[133]. This factor is especially important in the case of variation in electricity production by wind energy and to a lesser extent solar, biomass and geothermal energy systems.

Table 6.5 gives an overview of the total peak demand for St. Kitts during the period 2005 to 2015. Also the peak demand multiplied by the noise factor of 5% hourly deviation (load of 0.73) is given for the same period. If the capacity margin is low, an increase usually translates to greater relative reliability. Conversely, if the capacity margin is high, an increase will probably not have much or any benefit. The current capacity margin at St. Kitts Electricity Department (including units #1 and #2) is 34%[134]. If we compare it to the capacity margins of the United States it is higher than the average US power plants[135]. But this is not the economically feasible installed capacity thus the capacity margin is relatively not high.

The extra new required capacity is the increase in capacity demand between each time frame, as 2005-2008, 2008-2012, etc. It is also assumed that the currently installed units have a lifetime of 20 years each, and the phasing out indicates how much capacity (or units) will stop operating, based on their date of installation. This means that in the case of year 2005, two currently operating 3.6 MW units are not supposed to be in operation. And in 2008 a 3.5 MW, in 2012 a 4.4 MW and in 2015 another 4.4 MW unit at St. Kitts Electricity Department will reach end of life and stop operating and will be phased out, see table 6.5 for more detail.

Table 6.5 Overview of future required installed capacity for St. Kitts Electricity Department (St. Kitts)

	2005	2008	2012	2015	Unit
Peak demand	22.1	29.5	33.9	36.9	**MW**
Peak demand (5% hourly noise)	24.6	32.9	37.8	41.2	**MW**
Phasing out of current installed capacity	7.2	3.5	4.4	4.4	**MW**
Firm installed capacity	**26.3**	**22.8**	**49.5**	**57.6**	**MW**
Tot. New required capacity	**0**	**31.1**	**12.5**	**9.9**	**MW**
Tot required installed capacity[136]	**40.5**	**53.9**	**62.0**	**67.5**	**MW**
Electricity production[137]	299	399	458	499	**GWh**
Firm capacity at St. Kitts	26.3				**MW**
33.5 MW (0.41 load)	*121.5*				**GWh**
33.5 MW (0.73 load)	*214.2*				**GWh**
26.3 MW (0.53 load)	*122*				**GWh**

[132] Stanley Consultants, Generation Expansion Plan for the St. Kitts Electricity Department (2005-2015), April 2005
[133] Commission for Energy Regulation (CER), Capacity Margin Payments Scheme for 2006, Draft Decision Paper, 2005, source: www.cer.ie/cerdocs/cer05161.pdf
[134] capacity margin = (tot. installed capacity – peak demand) / (tot. installed capacity) * 100
[135] Energy Information Administration (EIA), Performance Issues for a Changing Electric Power Industry, 1995
[136] This is the total required installed capacity to comply with a capacity shortage of 0%
[137] Electricity production is calculated using a load factor of 0.73 and average energy efficiency of 38%

Now we have to clarify the problem that exists on St. Kitts. First of all, in the year 2005 we know from the peak load projections that the level will be 22.1 MWe. We know from information of St. Kitts Electricity Department that there is 33.5 MWe installed. With a load factor of 0.8 this amount would produce a total amount of electricity 234.8 GWh. But in reality the amount of electricity produced was 121.5 GWh. This means that the load factor must have been 0.41 with an installed capacity of 33.5 MWe. On the other hand St. Kitts Electricity Department provided info that the load factor is 0.73. This would have meant that with an installed capacity of 33.5 MWe actually 214.2 GWh should have been produced.

Now we have to highlight the problem in these calculations. First of all we have to look at the firm capacity, this is the capacity installed that is still within their economical lifetime. If we look at the running units, we see that there are two units of 3.6 MW that are running about 14 years longer than their economical lifetime. Thus the risk that they can fall out is considerable. This means that we are not supposed to include them into the number of total installed capacity. The real economic installed capacity (firm capacity) is thus 26.3 MWe. And this makes that the security margin changes from 34% to about 20%. But if we look at the electricity produced (121.5 GWh) we know that the load factor was 0.53 (related to the 26.3 MWe). With this 26.3 MWe an amount of 185.7 GWh should have been produced with a general accepted standard load factor for power plants of 0.8. This 0.53 is lower than the given 0.73 as load factor for the Needmust power plant. The reason for this difference in value is because the calculations done here are based on averages while in reality there is a high variation in demand, also the difference can be due to black outs, mechanical failures or other unexplained reasons. Basically this lower load factor means that during a time frame of a year the units where used on 53% of the 365*24 = 8760 hours/year, thus about 4643 hours/yr.

In table 6.5 we only focus on the period 2005-2015 in the scenario analysis, this is because after 2015 it is too uncertain what developments can occur, especially in the feasibility of new technologies, oil price developments, efficiency improvements and other local/regional political, economic and social developments.

An important note that is valid for all the scenarios is that scenarios are set up in such a way that the diesel expansion and RET introduction is implemented during the time frames, thus for period 2005-2008 it means that a diesel can be implemented in 2006 or 2007. But to facilitate the analysis in the HOMER model, we need to consider that the energy supply systems are all installed and operating at the end of each time frame. For the scenarios we will let HOMER calculate the Required Installed Capacity from the combination of diesel and renewable technologies to comply with the capacity shortage of 0%, and we will take in consideration only the units that are within their economical lifetime (20 years) and also we will calculate the electricity production of the power plants with an energy efficiency of 40% and a load factor of 0.73. This load factor is what St. Kitts Electricity Department officially provided and seems to be feasible if the power plants are maintained and operated adequately.

A schematic overview of the scenarios is shown in figure 6.8, details are described below.

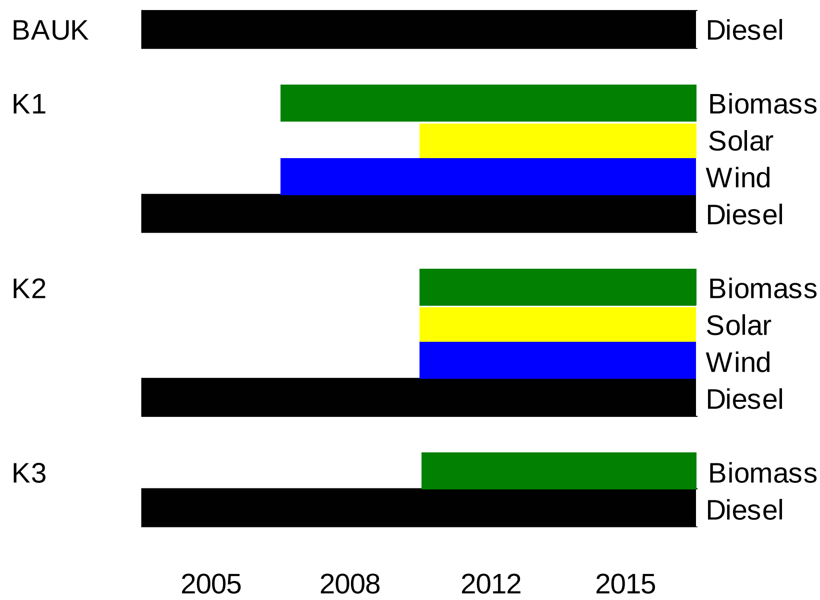


Figure 6.8 Schematic overview of used scenarios for St. Kitts

Business-as-Usual Scenario St. Kitts (BAUK)

This scenario projects the possible development in case no RET is introduced during the timeframe of this study, thus 2005 to 2015. This means that the expansion in diesel generator sets will depend on the capacity demand projection given in table 6.5. In this scenario the expansion process is done by adding 31.1 MW diesel generator sets extra in the period 2005 to 2008, 12.5 MW extra in 2008-2012 and 9.9 MW extra in 2012-2015. Over the period 2005-2015 a total of **53.5 MW** of diesel units will have to be installed to cope with the demand.

Scenario K1 (Fast introduction and high RET contribution Scenario)

Scenario K1 is the best case scenario that represents the possible fast RET introduction in case there is a general consensus formed by the stakeholders involved in the energy development of St. Kitts and Nevis and without occurrences of set backs in the project procedure or development. As one can notice, the geothermal option is left out in all the scenarios. The reason is that from research performed by the OAS it resulted that although there is a geothermal potential on the island of St. Kitts, the geothermal potential on Nevis is much higher, there is more international interest for Nevis and thus is the geothermal development on Nevis more likely to be happen. Solar energy development is set to a later implementation period (2008-2012), because it requires initially higher capital investments than the wind and biomass options. In scenario K1, in 2008 the contribution by bio-energy is 2.9 MW, producing about 2.3 MWe with a capacity factor of 0.8, see table 5.13. The contribution by Wind energy is 14.1 MW, with a capacity factor 0.23, thus producing about 3 MWe. At the end of 2012 the amount of RET capacity has increased to 26.6 MW, because a 5.4 MW PV capacity is added to the energy production mix and will remain like this till the end of 2015.

Scenario K2 (Intermediate RET introduction time and contribution Scenario)

Scenario K2 is considered the intermediate scenario, where the assumption is that the earliest a RET will start its operation will be in the year 2012. This is because no direct consensus is found on which RET to introduce and that there are cases of stagnation in the implementation procedure. In this scenario (K2) we will consider that in 2012, 2.9 MW Bio-energy, 14.4 MW wind energy and 5.4 MW Solar PV energy will be in operation. As in scenario K1 we assume that the RETs will be replaced after 20 years and will in this case operate at least till the year 2032.

Scenario K3 (Slow RET introduction time and low RET contribution Scenario)
Scenario K3 is the worst case scenario and shows a possible development if no consensus is formed by the stakeholders and that causes time delay in feasibility studies or start up of operation up until 2015. For the worst case scenario there will be no RET operation within the time frame of 2005 to 2012 and only bio-energy will be an option in 2012-2015. This scenario matches with the current expansion plans of St. Kitts Electricity Department. In scenario K3 only biomass energy (2.9 MW) will be implemented in the period 2012-2015.

6.3.3 Scenarios for Nevis

As done in the section for St. Kitts, in table 6.6 we give an overview of the demand in capacity for Nevis. The capacity margin is 33% (13.8 MW functioning capacity). As in the case of St. Kitts, there have been problems with the operation of the units. From an interview with representatives of NEVLEC we know that there were problems with unit #2 and it has not operated in the years 2004-July 2005 which means that the actual installed capacity is 12.8 MW. There is one 0.9 MW unit in operation that already passed its economical lifetime and thus the firm installed capacity is 11.9 MW. This means that the security capacity factor is 27.7%.

Table 6.6 Overview of future required installed capacity at NEVLEC (Nevis)

	2005	2008	2012	2015	Unit
Peak demand	8.6	10.3	13.1	15.6	**MW**
Peak demand (2% daily, 2% hourly noise)	**8.8**	**10.5**	**13.3**	**15.9**	**MW**
Phasing out of current installed capacity	0.9	0.9	4.5	4.7	**MW**
Installed firm capacity[138]	**11.9**	**11.0**	**13.7**	**18.4**	**MW**
New required capacity	0	7.2	9.4	9.3	**MW**
Tot required installed capacity	**13.8**	**18.2**	**23.1**	**27.7**	**MW**
Electricity production[139]	103	123	156	187	**GWh**

We will consider the 11.9 MW firm capacity as the starting point in the analysis for Nevis. In all the scenarios bio-energy is left out and instead geothermal energy technology is used in the analysis. On Nevis there are no activities of sugar production for export purposes. And as said before, the geothermal development is likely to be developed on Nevis since the OAS and other international organizations are organizing and doing feasibility studies to go over to the implementation stage of the Geo-Caraibes project.

A schematic overview of the scenarios is shown in figure 6.9, details are described below.

[138] Firm installed capacity based on lifetime of 20 years
[139] Electricity production calculated with a load factor of 0.74 and energy efficiency of 35.1%

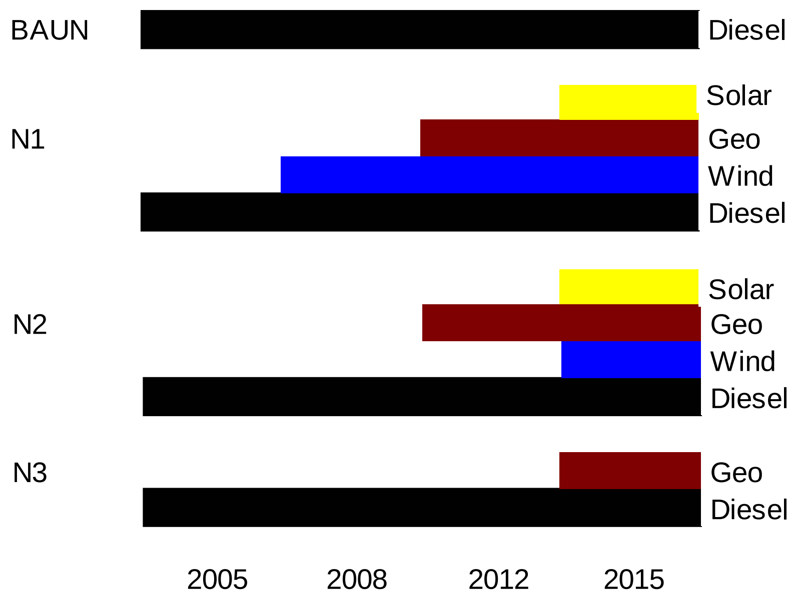


Figure 6.9 Schematic overview of used scenarios for Nevis

Business as Usual scenario for Nevis (BAUN)

In the case of business as usual scenario for Nevis (BAUN), the demand projection for Nevis is as described in table 6.6. In this scenario only diesel generators are seen as expansion option. As described in table 6.6, the amount of new diesels required in the period 2005 to 2008 is 7.2 MW, in 2008-2012 it is 9.4 MW and in 2012-2015, 9.3 MW. In the period 2005-2015 a total amount of 25.9 MW diesel units will have to be installed to comply with the demand.

Scenario N1 (Fast introduction and high RET contribution Scenario)

In scenario N1, Wind energy will start operating in 2008. The reason for this choice is that from interviews with representatives from the OAS, we know that the earliest the geothermal development will come in operation is in 2012. And although feasibility studies are needed for wind and solar energy development, we assume that if all the relevant stakeholders reach a consensus upon developing RETs as soon as possible, these two options are likely to be implemented first. Nevertheless because of the high investment costs for PV compared to wind energy, it is highly probable that wind energy will be implemented first. In 2008, we assume that 9.6 MW wind energy capacity (12x800kW) will be in operation, with a required back up capacity of 6.2 MW (capacity factor 0.35). In the period 2012-2015, the geothermal option will start operating with a capacity of 10.0 MW. The capacity factor is set on 0.9, thus it will produce about 9 MWe of energy. Also 5.4 MW solar energy is introduced in this period.

Scenario N2 (Intermediate RET introduction time and contribution Scenario)

In this scenario the assumption is made that there is no direct consensus upon the urgency for the introduction of RETs. Thus the earliest, wind, geothermal and solar energy will be operational is in the year 2012. The geothermal energy production will start in 2012 and a wind capacity of 9.6 MW will be added in the period 2012-2015, as well as 5.4 MW solar PV.

Scenario N3 (Slow RET introduction time and low RET contribution Scenario)

In this scenario only the geothermal option will be seen as feasible, since Nevis is already engaged in the promotion and development of this option. But the operation will only start in 2015. In 2015, the geothermal technology will produce 9.0 MW with a diesel back up of 1.0 MW.

6.4 Costs related to scenarios

Now the scenarios are known we need to estimate the costs related to each scenario. As price developments are subjected to time and quantity of production we will have to find and adapt the investment costs for the RETs to the year in which they will start operating in each scenario. One way to project future technology price development is by using the experience curve theory.

6.4.1 Global investment cost development of RETs

As starting point we should take into account the global RET price developments, because as a small island state you are dependent on the global availability of the RETs and the global market price development.

To be able to calculate the possible future prices of each RET, the current global prices of the renewable technologies is required. From the World Energy Assessment report data was collected on the investment costs per installed capacity (US$/kW) for each RET in the year 1998. See table 6.7.

Table 6.7 Range of current costs (1998 US Dollars) of renewable electricity production according to the World Energy Assessment, and the arithmetic average used as default in this study (WEA[140])

Renewable electricity source	Turnkey Investment Cost[141] (US$/kW)	Default value use in this analysis (arithmetic average) (US$/kW)	Operating capacity, end 1998 (GWe)
Large hydropower	1,000 – 3,500	2,250	640
Small hydropower	1,200 – 3,000	2,100	23
Biomass	900 – 3,000	1,950	40
Wind	1,100 – 1,700	1,400	10
Solar Photovoltaic	5,000 – 10,000	7,500	0.5
Geothermal	800 – 3,000	1,900	8
Solar Thermal[142]	3,000 – 4,000	3,500	0.4
Marine	1,500 – 3,000	2,250	0.3

For this study an assumption is made to consider the default values in the third column as starting point for the analysis in 2001.

The European Renewable Energy Council (EREC)[143] has published a document containing projections of renewable energy technologies development up until the year 2040. They give an overview of possible annual growth rates in energy supply for each RET until 2040, see table 6.8. Figure 6.10 shows the electricity production development using the annual growth rates given in table 6.8. As initial starting point the global operating capacity (GWe) shown in table 6.7 is used.

[140] World Energy Assessment, UNDP/UNDESA/WEC, United Nations Development Programme, New York, 2000 (Chapter 7), see: http://www.undp.org/seed/eap/activities/wea/drafts-frame.html
[141] Turnkey Investment Costs means the total capital cost for preparation, purchase and installation of the power system
[142] This is Solar Thermal technology for electricity production, low-temperature solar water heaters are in the range of 500 – 1,700 US$/kW.
[143] Source: http://www.erec-renewables.org/documents/targets_2040/EREC_Scenario%202040.pdf

Table 6.8 Annual growth rates for the electricity production by source. The growth rates from 1996 – 2040 are taken from the DCP144 EREC scenario (adapted from EREC)

Period	Large Hydro	Small Hydro	Biomass	Wind	PV	Geo thermal	Solar Thermal	Solar Thermal Electricity	Marine (tidal/wave /ocean)
1996-2001	2%	6%	2%	33%	25%	6%	10%	2%	0%
2001-2010	1%	8%	2%	25%	25%	6%	12%	16%	8%
2010-2020	1%	8%	2.5%	17%	27%	6%	14%	18%	15%
2020-2030	1%	6%	3%	9%	22%	4%	12%	16%	18%
2030-2040	0%	4%	2.5%	4%	15%	3%	8%	13%	16%

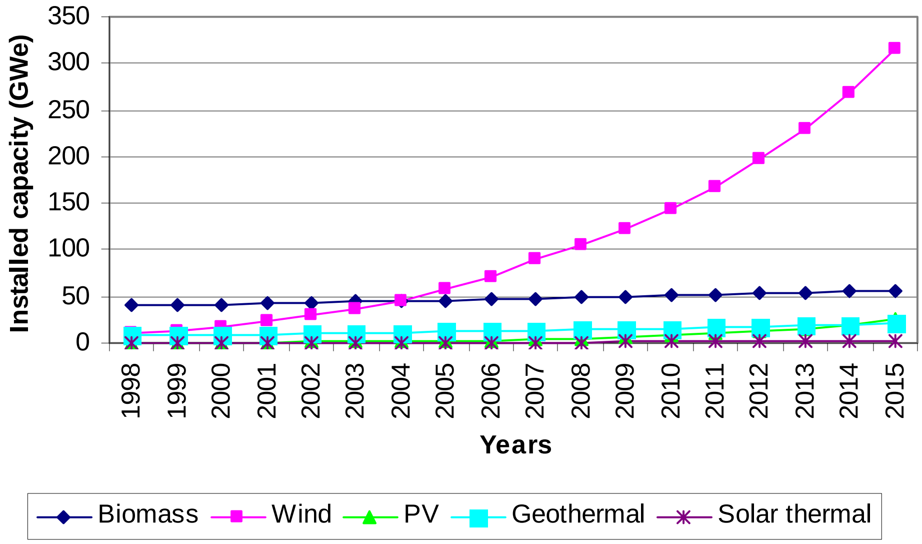


Figure 6.10 Production of global renewable electricity by source in GWe in the DCP/EREC scenario (adapted from EREC)

Now we know the possible development of electricity production by the selected RETs (biomass, wind, geothermal, PV) for this study. Solar thermal is projected along since there is interest in the Caribbean for this technology.

To continue this price development analysis in a correct way, we have to take in mind that we are dealing with two different sets of information and thus will have to combine them in order to know the investment cost reduction per year. Another important factor that has to be taken in mind is the technological energy conversion efficiency improvement of RETs.

Figure 6.10 shows the global electricity production in GWe against time in years. By using the experience curve theory it will be possible to calculate the investment costs development per year. The theory is based on the reduction of the global production cost, in this case in US$/kW against the doubling in growth in electricity production in GWe. See below for a brief description of the experience curve theory.

[144] Dynamic Current Policy (DCP) scenario. This scenario can be considered as intermediate and is based on less international co-operation than the Advanced International Policy (AIP) scenario, see EREC.

The experience curve theory

$$C_{Cum} = C_0 * Cum^b \tag{7.1}$$
$$\log C_{Cum} = \log C_0 + b * \log Cum \tag{7.2}$$
$$PR = 2^b \tag{7.3}$$

With

C_{Cum} = Cost per unit
Cum = Cumulative (unit) production
PR = Progress Ratio
C_0 = Cost of the first unit produced
b = Experience factor

The parameter *Cum* in this context, means the energy operating capacity of a PV panel, wind turbine, etc. The progress ratio (*PR*) is a parameter that expresses the rate at which costs decline each time the cumulative production doubles. For example, a progress ratio of 0.8 (80%) equals a learning rate of 0.2 (20%) and thus a 20% costs reduction for each doubling of the cumulative capacity.

In this study, as progress ratios (*PR*) we use 90% for wind energy and 80% for solar photovoltaic. These data are derived from Neij[145]. For the rest of the RETs progress ratio of 80% will be used, this is the general accepted PR for RETs[146].

Table 6.9 Overview of input data for the calculation of the experience curves

RET	PR	*b*	Ccum ($US\$_{2005}$/kW)[147]	Cum (GW)	*Co*
Biomass	0.80	-0.32	2415	40	7918
Wind	0.90	-0.15	1734	10	2460
PV	0.80	-0.32	9287	0.5	7430
Geothermal	0.80	-0.32	2353	8	4595
Solar thermal	0.80	-0.32	4334	0.4	3227

In table 6.9 the input data for the calculation of future investment costs are shown. Using the parameters C_{Cum} and *Cum* that are known from the table 6.5 and figure 6.10, the constant C_0 can be calculated. Since the values in table 6.5 are shown in $US\$_{1998}$ this is corrected for inflation by using an average inflation rate of 3% for OECD[148].

By filling in the growth development of the energy supply of each RET from figure 6.10 in formula 7.2 we can calculate the decrease in investment costs per year, see figure 6.11 for the results.

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[145] In her thesis, Lena Neij found a progress ratio for wind energy in the following ranges 0.89 – 0.98 and 0.88 – 0.91 (Table 4.3). This percentage is the progress ratio for the costs per kWh, i.e. it takes all factors that lead to cost reduction into account, including higher capacity factors and lower O&M costs. For photovoltaic solar she found progress ratio of 0.79 – 0.82. See L. Neij, Dynamics of Energy Systems, Ph.D. Thesis, Lund University, 1999.
[146] Experience Curves for Energy Technology Policy, International Energy Agency, Paris, 2000. See: http://www.iea.org/textbase/nppdf/free/2000/curve2000.pdf
[147] This is calculated as follows: $US\$_{1998}$ value* (1+0.03)^$^{(2005-1998)}$
[148] Ciccarelli, M. and Mojon, B., Global Inflation, European Central Bank, Working Paper Series no 537, October 2005

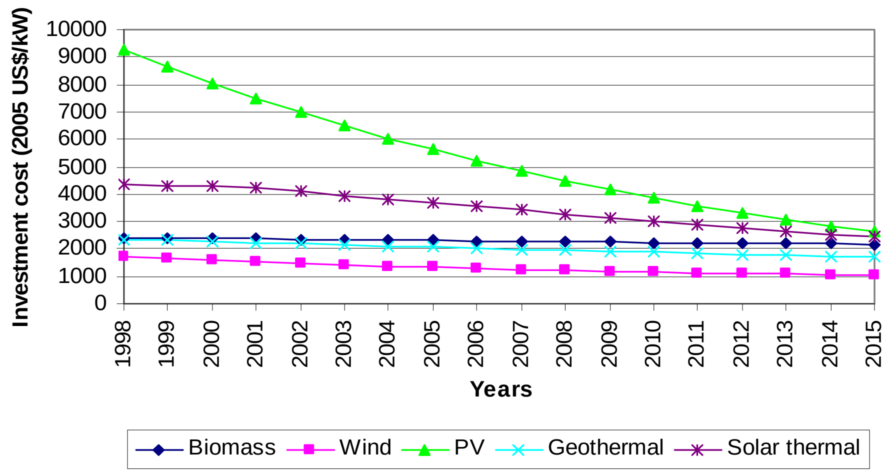


Figure 6.11 Investment cost development of RETs in the period 1998-2015

Now we can have a reasonable assumption of the investment costs for the years of start-up operation of the scenarios discussed in section 6.3. For an overview of the global investment cost development for the specific years 2005, 2008, 2012 and 2015, see table 6.10.

Table 6.10 Global investment cost development per RET

	Turn key investment cost (US$$_{2005}$/kW)			
	2005	2008	2012	2015
Biomass	2309	2265	2208	2167
Wind	1329	1213	1102	1026
PV	5617	4505	3311	2629
Geothermal	2063	1950	1809	1710
Solar thermal	3674	3275	2766	2438

Based on the data provided in table 6.10 we now have an idea of the relative differences between the investment costs of RETs for the islands. In a later stage of this study an uncertainty analysis will be performed to find the variations in these data and investment costs of sub-technologies applied in other studies under similar conditions.

6.4.2 Financial data of the Diesel generator sets

To have a good comparative analysis we have to find the turn key investment costs of the diesel engines installed at both utilities. Also we need to know the financial information for the projected diesel units in the expansion plans of both utilities.

Investment cost development of installed Diesel

Because the HOMER model calculates the levelized cost of electricity (COE) based on the inputted investment costs and considers this as year zero and calculates on forward, it is in this study required to depreciate the investments of the existing diesel engines over the period they were installed till 2005. As described in section 4.2, at the St. Kitts Electricity Department a total of 7 diesel engines are installed with a total capacity of 33.5 MWe. For Nevis a total of 7 diesel engines are installed with a total capacity of 13.8 MWe. Each diesel engine or unit has its own capacity and was installed in a different year and with variation in capital investment costs. Another thing to keep in mind is that the value of a US$ in the past is not equal to the US$ now. Due to lack of financial information for the diesel units installed at NEVLEC we will use the

information available from St. Kitts Electricity Department for both islands and afterwards run a sensitivity analysis to cover the deviation in costs.
Table 6.11 shows the available information about the installed diesel units at St. Kitts Electricity Department. The investment costs are given for the year the units were installed. The US$ values in the sixth column were corrected using an average inflation rate of 3.1%[149] to the US$$_{2005}$.

Table 6.11 Overview of techno-financial data on installed diesel units at St. Kitts Electricity Department[150]

Unit	Diesel type	Capacity (MWe)	Installation year	US$/kW (in installation year)	US$/kW (in installation year with 2005 US$ value)	NPV in US$$_{2005}$/kW
#1	Mirrlees KV12	3.6	1971	*556*	*1570*	*61*
#2	Mirrlees KV12	3.6	1971	*556*	*1570*	*61*
#3	Mirrlees K8	3.5	1987	*571*	*989*	*178*
#4	Caterpillar 3616 (#1)	4.4	1989	417	680	148
#5	Caterpillar 3616 (#2)	4.4	1995	636	863	333
#6	Mirrlees 12MB430	7.9	1999	*688*	*826*	*466*
#7	Mirrlees 8MB430	6.1	1999	*833*	*1000*	*564*
	Total	**33.5**			**Average**	**259**

These investment costs in US$$_{2005}$ are then depreciated using an interest rate of 10% to calculate the net present value (NPV) in the year 2005 using the following equation.

$$NPV = \frac{PV}{(1+r)^t} \tag{7.4}$$

Where
NPV = the current value of a future amount of money, the net present value
PV = the value of an amount of money in year t
r = the discount rate
t = time in years

Figure 6.12 shows the result of the NPV calculations for each installed diesel unit.

[149] Average taken over the period 1993-2003, source: Statistical Review 2004, Statistics Division, Planning Unit, Ministry of Finance, Technology & Sustainable Development, St. Kitts and Nevis Federal Government
[150] The *italic* fonts are assumptions made by representatives of St. Kitts Electricity Department (July, 2005)

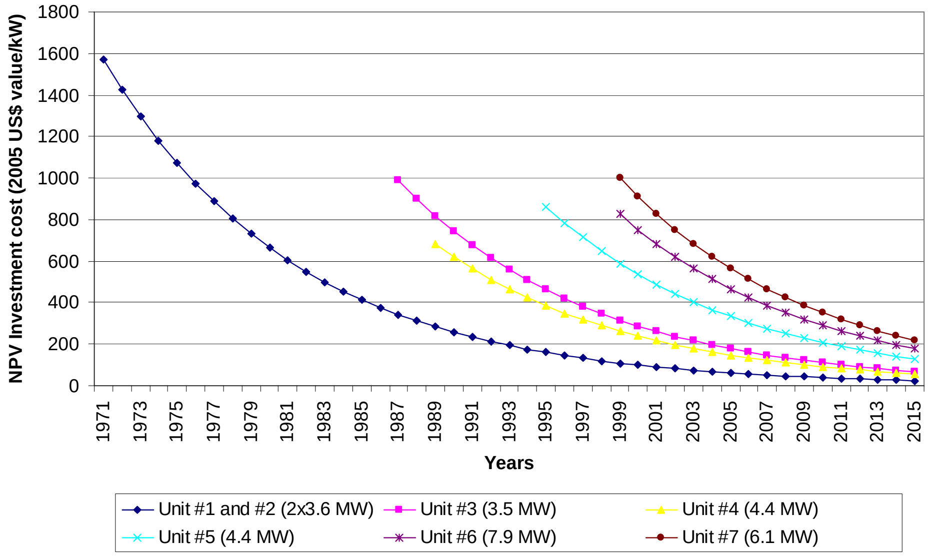


Figure 6.12 NPV Investment costs (US$$_{2005}$/kW) per year of diesel units installed at St. Kitts Electricity Department

In figure 6.12 one can see that the development in investment costs is not equal to the cost development of RETs. If you compare the two 4.4 MW units (unit #4 and #5, both Caterpillar), they where installed in different years, one in 1989 and the other in 1995. Instead of an expected decrease of the investment cost per unit it actually increased over the years. The reasons behind this difference in investment costs are not directly explainable; it can be due to difference in Free on Board charge for the transport, import taxes or other not to overlook issues, therefore in this study the assumption is made that the provided data is correct.

Investment cost development of future Diesel units

Table 6.12 shows the gathered financial information for the planned diesel units at St. Kitts Electricity Department. The investment costs are expressed in US$$_{2005}$.

Table 6.12 Overview of investment costs for future diesel generators (Stanley Consultants, 2005)

Fuel type	Capacity (MWe)	Investment (US$$_{2005}$/kW)
Fuel oil	2.5	688-1143
Fuel oil	4	882

To calculate the turn key investment of the units shown in table 6.12, we need to add the costs for site preparation and building. Based on information gathered from St. Kitts Electricity Department about expansion plan 1 (see section 6.2) we know the following information.

Cost 4 x 2.5 MW diesel units[151]	US$ 6,880,000.- (low) or US$ 11,430,000.- (high)
Site preparation	US$ 177,100.-
Mechanical installation	US$ 52,700.-
Building	US$ 1,296,600.-
Total	**US$ 8,406,400.- (low) or US$ 12,956,400.- (high)**

[151] Investment costs include labor, material, undeveloped design details, overhead and profit, source Generation Expansion Plan for St. Kitts Electricity Department (2005)

This means that the turn key investment cost for a 2.5 MW diesel unit (under conditions at St. Kitts and Nevis) is in the range of 841-1296 US$$_{2005}$/kW. The mean turn key investment cost for a 2.5 MW diesel unit is thus about 1069 US$$_{2005}$/kW. Also for the 4 MW diesel units the turn key investment costs is calculated and is about 1035 US$$_{2005}$/kW.

The capacity range of the diesel units installed at St. Kitts Electricity Department is between 3.5-7.9 MW. In all the scenarios we will continuously add diesel units of either 2.5 or 4 MW size range to comply with the projected demands. But as in the case of the future turn key investment costs of the RETs (see table 6.8) we need to know the value of a diesel unit in the projected years, 2008, 2012 and 2015. Although we know from figure 6.12 that the investment cost development is not straightforward, we will assume that the investment costs will decrease according to the NPV equation (eq. 7.4) with a discount rate of 10%.

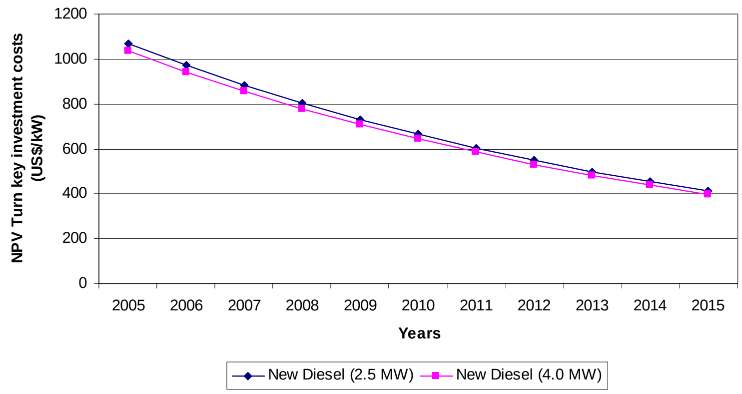


Figure 6.13 NPV Turn key investment cost for new diesel units to be installed at St. Kitts Electricity Department

Figure 6.13 shows the decrease in turn key investment cost for 2.5 and 4.0 MW new diesel units. This net present value will be added to the NPV value of the already installed diesel units at each utility to know roughly the NPV value of the total installed diesel in the years 2005, 2008, 2012 and 2015 according to the scenarios.

Based on the previous sub sections a summary is given in table 6.13 of the turn key investment costs for the currently installed diesel units and future investments in diesel units for both St. Kitts Electricity Department as NEVLEC. The new diesel investment values will be used for both the scenarios of St. Kitts as of Nevis.

Table 6.13 Turn key investment costs of diesel units on St. Kitts and Nevis

	Turn key investment cost (US$$_{2005}$/kW)			
	2005	2008	2012	2015
NPV of Installed diesel (St. Kitts & Nevis)	259	195	133	100
New diesel (2.5 MW)	1069	803	549	412
New diesel (4.0 MW)	1035	778	531	399

Now we are able to estimate the initial NPV of the total diesel investment costs for the years 2005, 2008, 2012 and 2015 for St. Kitts and for Nevis. This is done by calculating the average turn key investment cost based on the amount of installed diesel units (installed and new) with each new diesel having a size that matches roughly either the 2.5 or the 4.0 MW diesel units.

In order to calculate the NPV of the total installed diesel capacity for each scenario, the option is made to consider the minimal required diesel capacity to comply with the peak load demand, as described in the business as usual (BAUK) scenario, see table 6.5. The reason for doing this is that at this moment in the research it is not possible to identify the total required diesel capacity for each scenario, this is because the HOMER model calculates the optimal hybrid system where the NPV of the initial capital investment of the diesel plays an important role in the cost of electricity production (US$/kWh) and the minimal required diesel capacity (MW) to comply with a 0% annual capacity shortage.

Thus as an alternative approach, the diesel power capacity that complies with the peak demand is taken in account, including the phasing out of outdated diesel units. For the other scenarios the minimal required diesel capacity for each time frame (2005-2008, 2008-2012, 2012-2015) is calculated based on the total installed RET capacity, their required diesel back up capacity and the phasing out of outdated diesel capacity. See equation 7.5 for a better explanation.

$$C_{\min,req(year1)} = C_{demand(year1)} - (C_{inst(year0)} - C_{phas(year1)}) - C_{RET(year1)} + C_{Backup(year1)} \quad (7.5)$$

$C_{\min,req(year1)}$: Minimal required extra diesel capacity in year 1

$C_{demand(year1)}$: Total capacity demand to comply with the peak load in year 1

$C_{inst(year0)}$: Total installed diesel capacity in year 0

$C_{phas(year1)}$: Diesel capacity phased out in year 1

$C_{RET(year1)}$: Total installed renewable energy technology capacity in year 1

$C_{Backup(year1)}$: Total required diesel back up capacity for the RETs in year 1

As example we take scenario K1. Scenario K1 is the best case scenario for St. Kitts, that represents the possible fast RET introduction in case there is a general consensus formed by the stakeholders involved in the energy development of St. Kitts and Nevis and without occurrences of set backs in the project procedure or development. In 2008 the contribution by bio-energy is 2.9 MW, producing about 2.3 MWe with a capacity factor of 0.8. The contribution by wind energy is 14.4 MW, with a capacity factor 0.23, thus producing about 3.3 MWe. At the end of 2012 the amount of RET capacity has increased to 22.7 MW, because a 5.4 MW PV capacity (capacity factor 0.15) is added to the energy production mix and will remain like this till the end of 2015.

Table 6.14 Overview of required diesel capacity for scenario K1

K1	2005	2008	2012	2015	Unit
Tot required capacity	26.3	53.9	62.0	67.5	**MW**
Outdated capacity	0.0	3.5	4.4	4.4	**MW**
Firm Diesel capacity	**26.3**	**22.8**	**43.9**	**51.2**	**MW**
RET capacity					
Biomass	0.0	2.9	2.9	2.9	**MW**
Wind	0.0	14.4	14.4	14.4	**MW**
Solar	0.0	0.0	5.4	5.4	**MW**
Tot. RETs capacity	**0.0**	**17.3**	**22.7**	**22.7**	**MW**
Required back up					
Biomass	0.0	0.6	0.6	0.6	**MW**
Wind	0.0	11.1	11.1	11.1	**MW**
Solar	0.0	0.0	4.6	4.6	**MW**
Tot. Req. Back up RETs	**0.0**	**11.7**	**16.3**	**16.3**	**MW**
New required Diesel	**0.0**	**25.5**	**11.7**	**9.9**	**MW**
Tot installed diesel	26.3	48.3	55.6	61.1	**MW**
Tot installed capacity	26.3	65.6	78.3	83.8	**MW**

For the year 2005 we know that the firm capacity is 26.3 MW, and thus the required extra capacity has to be introduced in the period 2005-2008. This is why in 2008 a total of 25.5 MW extra diesel capacity is required. For the period 2008-2012 a total of 11.7 MW extra diesel capacity is required. As shown in equation 7.5, in order to calculate this extra diesel capacity we have to calculate this as follows:

62.0 MW – (48.3 MW – 4.4 MW) – 22.7 MW + 16.3 MW = 11.7 MW new required diesel

This same method is applied to all the scenarios, in this way we can find the required extra diesel capacity for each period. By adding new diesel units knowing their NPV (described in table 6.13) that correlate with the required extra diesel capacity we can estimate the NPV of the total new diesel capacity installed in each period. See table 6.15 for an overview of this.

Table 6.15 Overview of the NPV estimate for the new required diesel units for scenario K1

K1	2005	2008	2012	2015	Unit
Installed diesel	5	4	3	3	**Nr.**
new 2.5	0	0	0	1	**Nr.**
new 4	0	6	9	11	**Nr.**
Installed diesel	1689	1136	700	526	**US$/kW**
new 2.5	0	0	0	412	**US$/kW**
new 4	0	4666	4780	4389	**US$/kW**
NPV	**338**	**580**	**457**	**355**	**US$/kW**
New diesel required	0.0	25.5	11.7	9.9	**MW**

In the upper part of table 6.15 the amount of diesel units (taking in mind each unit size and related NPV value) is shown, in 2005 a total of 5 diesel units are within the economical lifetime of 20 years summing a total NPV value of 1689 US$/kW. In 2008 one 3.5 MW unit is phased out, thus making it 4 installed diesel units with a total NPV value of 1136 US$/kW. And to comply with the demand capacity an extra new diesel capacity of 25.5 MW is needed. Thus the utility can opt to invest in 6 new 4.0 MW diesel units with a total NPV value of 4666 US$/kW. The average

NPV value for total installed diesel capacity in 2008 is then 580 US$/kW (1136 US$/kW + 4666 US$/kW divided by 10 diesel units).

This same approach is followed for all the scenarios and table 6.16 shows the overview of the results for the NPV estimation for all the scenarios for St. Kitts and in each time frame.

Table 6.16 Net present value of the total installed diesel capacity in each period in the four scenarios for St. Kitts

	Net Present Value Tot. installed Diesel (US$$_{2005}$/kW)			
	2005	2008	2012	2015
BAUK	338	615	469	361
K1	338	580	457	355
K2	338	615	465	360
K3	338	615	469	359

From table 6.16 one can see that the NPV value of the total installed diesel capacity decreases more for scenario K1 compared to the other scenarios that contain less RET capacity. See appendix A3-13 for info about Nevis.

6.4.3 Fuel cost development

The global oil price development is briefly analyzed to be able to give a short overview of mechanisms that play a role on the diesel fuel oil price developments. The price development of diesel fuel and fuel oil is different than the crude oil price development and is regionally bounded which makes it difficult for Caribbean utilities to make estimates in possible future costs for import of diesel fuel. The focus will be on analyzing the diesel fuel oil production, supply and price development in or for the Caribbean region. The costs for the import of this fuel oil to the Caribbean islands forms a considerable part of the operational costs of the diesel fuel generator units and it is important to have a future fuel oil price projection baseline when performing the economical analysis for electricity supply scenario for St. Kitts and Nevis.

Global Oil Market

First we take a look at the global crude oil market. Several factors have influence on the world crude oil prices in the near term. First, world petroleum demand grew at a robust 3.4 percent[152] (2.7 million barrels per day) in 2004, reflecting dramatic increases in China's demand for oil-generated power and oil-based transportation fuels, as well as a rebound in U.S. oil demand. Second, oil prices typically are sensitive to any incremental tightening of supply during periods of high economic growth. On the supply side, there was very little spare upstream capacity, and the spare downstream capacity was not always properly configured to produce the required line up of products. World oil inventories, in terms of "days of supply," were unusually low. Next, geopolitical tensions in major oil-producing countries— including the continuing war in Iraq and uncertain prospects for a return to normalcy in Iraq's oil sector— and potential unrest in Nigeria and Venezuela contributed to the volatility in world oil markets.

Difference between Global Petroleum and Diesel Fuel Prices

In 2004 the crude oil prices averaged 36 US$/barrel[152] and in June 2005, crude oil featured prices exceeding 60 US$ per barrel, a record high price in nominal dollars. See figure 6.14 for the historical development of the global crude oil prices and possible future price developments up to the year 2025, created by the EIA (2005).

[152] International Energy Outlook 2005, Energy Information Administration (EIA), US Government, source: http://www.eia.doe.gov/oiaf/ieo/oil.html

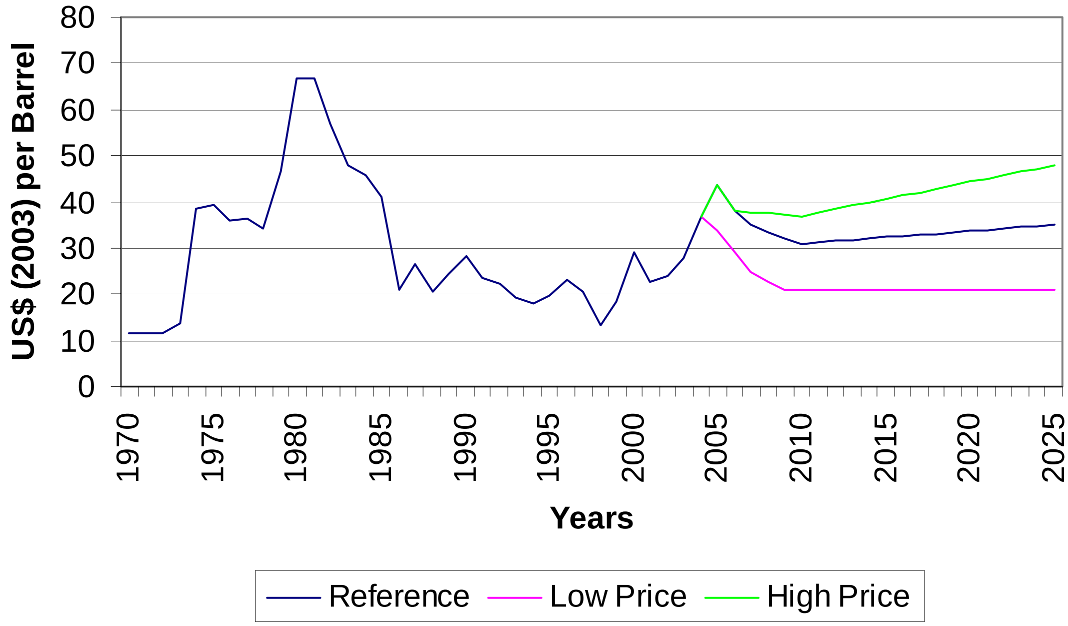


Figure 6.14 World Oil Prices in three Cases for the period 1970 to 2025[152]

If we look at table 6.17, which shows the diesel fuel price development in the US over the period 2003-2006, we can see different percentual changes from year to year which indicates a different pattern than the crude oil price development. This is because the retail price always has a retention time before the changes in crude oil prices are expressed, also other market forces influence this price.

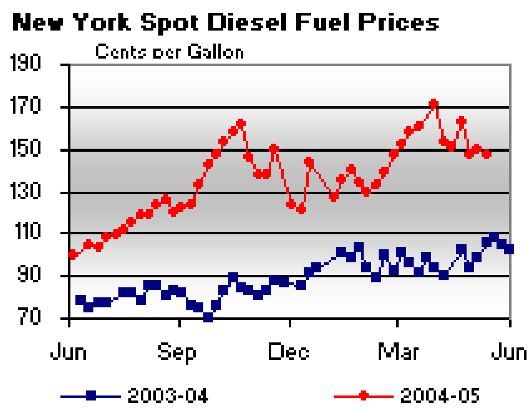
Table 6.17 Price summary of crude and petroleum product for the US [153]

	Year				Percentual Change (%)		
	2003	2004	2005	2006	2004/2003	2005/2004	2006/2005
WTI Crude[a] ($/barrel)	31.12	41.44	56.54	63.33	33.2	36.4	12
Gasoline[b] ($/gal)	1.56	1.85	2.27	2.42	18.8	22.6	6.4
Diesel[c] ($/gal)	1.5	1.81	2.41	2.54	20.3	33.3	5.3
Heating Oil[d] ($/gal)	1.36	1.54	2.03	2.25	13.5	31.7	11.2
Natural Gas[d] ($/mcf)	9.51	10.74	12.77	14.52	12.9	18.9	13.7

[a] West Texas Intermediate. [b] Average regular pump price.
[c] On-highway retail. [d] Residential average.

In the US, diesel fuel and heating oil are used for activities as power generation and heating, and mainly because of the last function their respective prices are on a short term base strongly influenced by winter heating oil demand, see figure 6.18 a and b.

153 Source: http://www.eia.doe.gov/emeu/steo/pub/contents.html



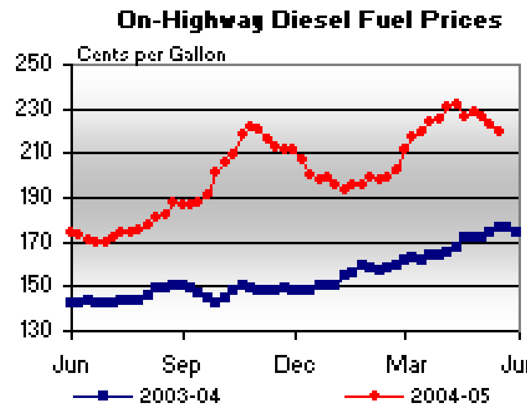


Figure 6.15 a **Figure 6.15 b**

An important thing to highlight is that there is a difference in SPOT and retail prices. As one can see in figures 6.15 a. and b. there is a clear difference in price. The SPOT price indicates the actual international price on that given day for the diesel or fuel oil and is dependent on the location of the market exchange centre and the global diesel/fuel oil availability and quality[154]. For distillate or fuel oil #2 there are four major exchange markets located in New York, Texas, Rotterdam and Singapore. In figure 6.15 a. we see the international SPOT diesel fuel prices at the New York Mercantile Exchange (NYMEX) that covers the US Atlantic Coast. The retail price includes next to this SPOT price also the FOB charge and the possible taxes in a country.

In general the diesel fuel price per gallon exists of four components, the crude oil price, refining costs, the distribution and marketing costs and last the possible taxes, depending on variation of policies in different countries or states. As an example, in the US in November 2005 a Gallon of Diesel (on road[155], with a retail price of US$ 2.57 per US Gallon[156] or US$ 0.679 per liter) consisted for 50% of crude oil prices, 17% was accounted for refining costs, 13% for distribution and marketing costs and taxes accounted for 20% of the retail price.

Diesel fuel oil price projections for St. Kitts and Nevis

For St. Kitts and Nevis or the Eastern Caribbean region it is important to analyze the refined SPOT markets at the US Atlantic Coast (nearest located) and the Free on Board (FOB)[157] price calculation as the international element of the diesel fuel or fuel oil #2 price. Next to this the national or domestic pricing components as capital recovery charges or taxes need to be analyzed and included in the price. The definition and methodology for the FOB price calculation varies per country or region and is often negotiated between the governments and oil companies.

In 2004 the average delivered fuel (fuel oil #2) cost to St. Kitts Electricity Department was EC$ 4.152 per imperial gallon[158] (US$ 0.338 per liter). See table 6.18 for a historic development of the fuel oil price at St. Kitts Electricity Department. This price includes three components, the FOB charge which is the arithmetic mean of the PETROTRIN and SHELL WEST CURACO postings, a freight/insurance charge and a capital charge for a repayment of a US$ 300.000.,- loan by

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[154] SASOL Ltd., How South African fuel prices are calculated, October 2005, source: http://www.sasol.co.za/sasol_internet/frontend/navigation.jsp?navid=8700003&rootid=4
[155] On road diesel fuel is a higher quality refined product compared to fuel oil #2 and this also means that on average it costs more per liter or gallon.
[156] Source: http://tonto.eia.doe.gov/oog/info/gdu/gasdiesel.asp
[157] F.O.B. literally means "Free on Board." It denotes a transaction whereby the seller makes the product available with an agreement on a given port at a given price; it is the responsibility of the buyer to arrange for the transportation and insurance
[158] St. Kitts Electricity Department Expansion Plan 2005-2015

Texaco to the Department for a Warehouse facility. From a meeting with representatives of St. Kitts Electricity Department in July 2005, they provided the information that the current fuel price was EC$ 5.11 per imp. gallon. At NEVLEC the fuel oil #2 price in 2005 was on average about EC$ 5.96/imp. gallon[159] (US$ 0.486 per liter). Unfortunately no data is provided on the historical fuel cost development at NEVLEC but the analysis is performed from 2005 on forward.

Table 6.18 Overview of fuel price development at St. Kitts Electricity Department

Year	Spend Fuel costs (Million EC$)	Imported Fuel (Million Imp. Gallons)	Fuel cost (EC$/Imp. Gallon	Fuel cost (US$/Liter)	Percentual change (%)
2002	16.67	6.19	2.69	0.22	20
2003	20.93	6.45	3.24	0.26	25
2004	24.81	6.61	3.75 - 4.15[160]	0.31 - 0.34	26
2005			5.11	0.42	

Table 6.18 shows that the fuel cost has increased during the period 2002 to 2005 with an average percentual growth of 24% per year.

If we compare the fuel oil costs for St. Kitts Electricity Department with the Fuel Oil #2 SPOT prices of New York (US Atlantic Coast) and of Texas (US Golf Coast), we see that there is a correlation between the prices (Fig. 6.16). They all relatively have a similar trend in price development. This means that up until 2004 there is was no clear disconnection between the SPOT and the retail price of the fuel oil delivered at St. Kitts Electricity Department. The price in 2005 given by St. Kitts Electricity Department was the price for July, while the values for the SPOT prices are the average prices for the year 2005. This may explain the deviation in 2005 from the parallel trend.

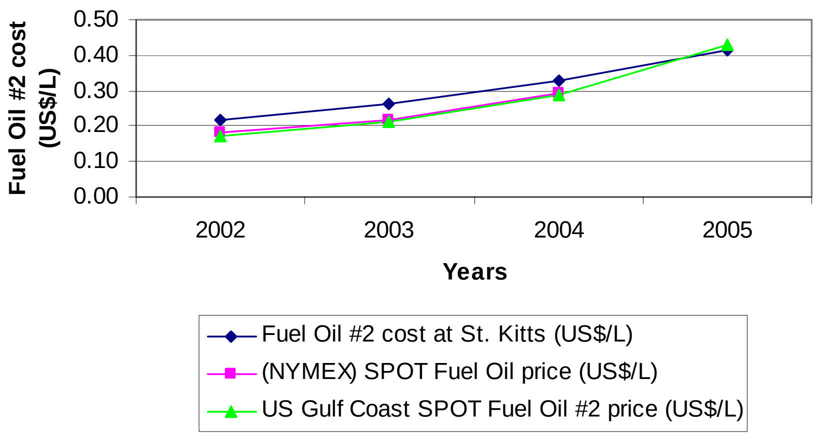


Figure 6.16 Comparison Fuel Oil SPOT prices with fuel cost prices at St. Kitts Electricity Department for the period 2002 to 2005[161]

Now the difficulty is to forecast the possible fuel oil price development. This is as explained before a complicated process that depends on a high number of variables. One important variable

[159] Information gathered from meeting with representatives of NEVLEC (Charlestown, Nevis, July, 2005)
[160] The value 4.15 EC$/Imp. Gallon is the average price provided by St. Kitts Elec. Dep. and the value 3.75 EC$/Imp. Gallon is calculated based on the information available on the amount of imported fuel and the spend fuel costs for year 2004. This difference can be explained due to frequency of change in import costs and of international prices.
[161] Fuel Oil St. Kitts, source: St. Kitts Electricity Department (2005) and the NYMEX Fuel Oil #2 SPOT prices, EIA(2006), source: http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_a.htm

that is currently impacting the energy sector in the Caribbean region is the political response to the increase of price. In recent years, the Caribbean countries, with the exception of Trinidad and Tobago, have been worried that higher global oil prices will limit their efforts to expand economically. In response, the island nations have been discussing ways to integrate oil and natural gas operations in order to reduce costs of energy, which is affecting their prospective economies.

As one of the biggest suppliers to the Caribbean Islands, Venezuela has proposed creating "Petrocaribe," a state oil company representing all the Caribbean nations which would centralize refining, procurement and marketing. On the 29th of June 2005 at Puerto la Cruz in Venezuela, the energy cooperation agreement "Petrocaribe" was signed by Venezuela and 13 Caribbean States, including St. Kitts and Nevis[162]. Another interesting development is the "Free Trade Area of the Americas" (FTAA) process that has initiated the development of an energy policy for all members. One focus of a proposed energy policy is to increase collaboration among members in order to ensure energy security and supply in the region. Other possibilities currently on the table include constructing a natural gas pipeline linking Trinidad's natural gas reserves to many of the Caribbean islands, as well as encouraging the development of alternative energy sources, such as wind, solar and geothermal[163].

The interesting aspect of the above named energy cooperation is that Venezuela will create a fund (ALBA Caribe) and initially subsidize this initiative with US$ 50 million and will be used for the development of common energy policies, financing socio-economic programs and energy projects. Next to this the PDV Caribe will take care of the intermediation and distribution operations, that also includes creating logistical plans and where possible increasing refinery and storage capacity in the Caribbean region. The agreement entails Venezuela financing the price per barrel of crude and petroleum products with the following rates, see table 6.19.

Table 6.19 Financing scheme for petroleum delivered by "Petrocaribe"[162]

Price of Petroleum (US$/Barrel)	Percentage to finance (%)	Pay back time (Years)
15	5	15
20	10	15
22	15	15
24	20	15
30	25	15
40	30	25 (+ 1%)
50	40	25 (+ 1%)
100	50	25 (+ 1%)

The above means that of the current average petroleum price of US$ 55.61 per barrel[164] (in 2005) about US$ 22.2 per barrel (40%) will be financed by Venezuela and thus the receiving Caribbean state pays US$ 33.4 per barrel that still needs to be processed into petroleum products as gasoline or fuel oil and be delivered. In the agreement is stated that the importing state will have to pay back Venezuela this 40% financed price (US$ 22.2 per barrel) in the period of 25 years with a 1% interest rate. As an extra thing, in the first two years the importing states are exempted from the pay back for the financing of the crude oil price.

[162] Ministry of Foreign Affairs of the Government of Venezuela, source: http://www.mre.gov.ve/Petrocaribe2005/acuerdo_final.htm
[163] EIA website, Caribbean Fact Sheet: http://www.eia.doe.gov/emeu/cabs/carib.html
[164] Average crude oil price of WTI and Brent Crude Oil, source: http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_a.htm

As described previously the fuel oil price development does not directly correlate to the crude oil price development and that makes it difficult to make projections based on crude oil price forecasts. Nevertheless it gives a rough indication of the possible development of the fuel oil price. For the specific diesel fuel price for St. Kitts and Nevis we limit ourselves to use the available fuel oil prices and extrapolate this data to the future taking in mind the projections shown in figure 6.14. Then we estimate the possible deviation from the extrapolated reference forecast by taking in account the pricing mechanism of Petrocaribe.

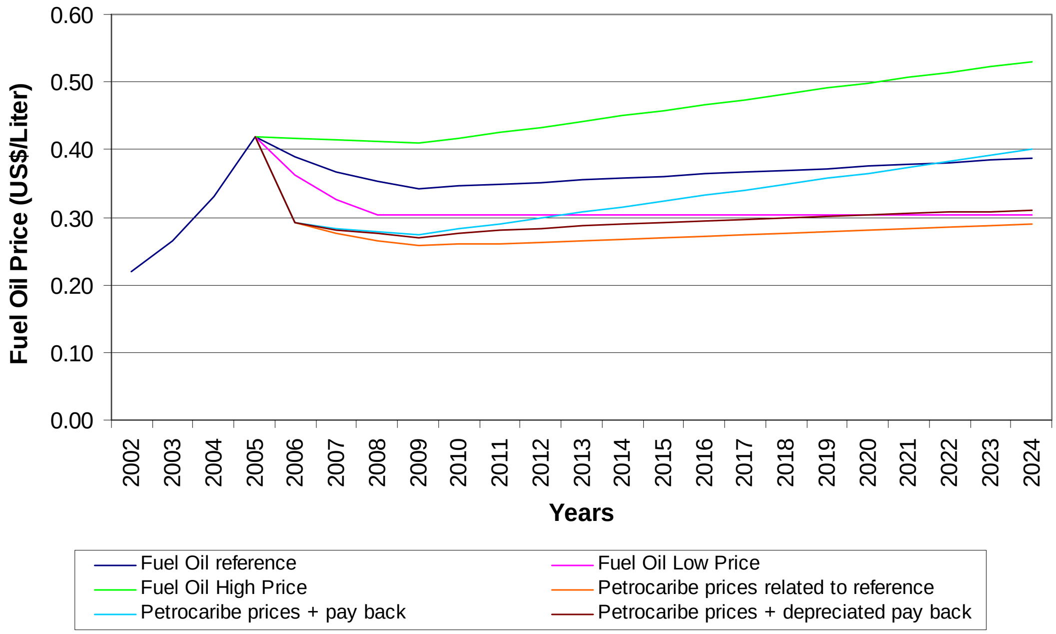


Figure 6.17 Fuel Oil #2 price forecast for St. Kitts over the period 2002 to 2015

Figure 6.17 shows the possible fuel oil #2 price development for St. Kitts and Nevis. The prices provided by Petrocaribe will be considerably lower on short term, but the fact stays that all this set aside money will have to be paid back within 15 or 25 years. And on long term a Caribbean state will have to add this loan (+ eventual 1 % interest rate) on the to be purchased fuel price. The question is how this pay back is being calculated. Figure 6.20 shows that there is a considerable difference in price if the pay back is simply the yearly cumulative value of 1/15 of the payback (Petrocaribe + payback) or if this payback is depreciated with an depreciation rate of 10% (Petrocaribe + depreciated payback). In the case of the "Petrocaribe + payback" projection this may on the long run even result in higher fuel oil prices than the "reference" projection.

Table 6.20 gives the overview of the fuel cost development related to the scenarios for St. Kitts. For the reference projection the price may decrease or fluctuate between the range of 0.36-0.42 US$/L for the period 2005 to 2015. In the case of the low price projection the fuel price may fluctuate between 0.30-0.42 US$/L.

Table 6.20 Forecasts for the fuel cost development for St. Kitts

	Fuel Oil #2 price in (US$/L)			
	2005	2008	2012	2015
Reference	0.42	0.35	0.35	0.36
Low Price	0.42	0.30	0.30	0.30
High Price	0.42	0.41	0.43	0.46
Petrocaribe price	0.42	0.27	0.26	0.27
Petrocaribe price + payback	0.42	0.28	0.30	0.32
Petrocaribe price + depreciated payback	0.42	0.28	0.28	0.29

The petrocaribe price development depends on the manner the payback is calculated, for the petrocaribe price without depreciated payback the fuel price will range between 0.32-0.42 US$/L and in case of depreciated payback the price will range between 0.29-0.42 US$/L.
The same methodology is used to calculate the fuel cost development for Nevis and the results are shown in table 6.21.

Table 6.21 Forecast for the fuel cost development for Nevis

	Fuel Oil #2 price (US$/L)			
	2005	2008	2012	2015
Reference	0.49	0.41	0.41	0.42
Low Price	0.49	0.35	0.35	0.35
High Price	0.49	0.48	0.50	0.53
Petrocaribe price	0.49	0.31	0.31	0.31
Petrocaribe price + payback	0.49	0.32	0.35	0.37
Petrocaribe price + depreciated payback	0.49	0.32	0.33	0.34

In the case of Nevis, the reference projection indicates a decrease of fuel price from 0.49 to 0.42 US$/L. Contrary to the situation on St. Kitts, the calculation method for the payback related to the petrocaribe prices will cause the fuel prices to remain under the reference projection.

6.4.4. Biomass feedstock price

Next to the fuel price development we need to identify the possible biomass feedstock price. It is hard to determine an average biomass feedstock price, because it differs per location and circumstances. From section 5.1.1 we know that the sugar cane cultivation area of about 7,000 acres (2833 ha) yielded about 170,000 tons of sugarcane. This means that the yield in 2004 was about 24.3 ton/acre (60.0 ton/ha) sugar cane cultivation.

To get a best estimate of the costs related to the production of sugarcane, some sources from the literature indicate a price range on Brazilian fields between 18-22 US$/ton of biomass feestock price (in the form of sugarcane *trash*[165]), under varying transport distances[166]. Data collected over 2 years in a sugarcane growing area for a study in India shows that the landed, sized and dried cost of sugarcane *leaves* is between 29-36 $US\$_{1995}$ per ton of biomass, if the material is procured from within a 20-30 km radial distance[167]. In case of an *eucalyptus* plantation in Thailand the biomass feedstock price varied between 13.5-16.2 $US\$_{1999}$/ton[168]. Another study done by

[165] This is 15% of dry matter of the produced sugarcane
[166] Rodrigues, M. et al., Techno-economic analysis of co-fired biomass integrated gasification/combined cycle systems with inclusion of economies of scale, 2003, page 1248
[167] Jorapur, R. and Rajvanshi, A.K., Sugarcane leaf-bagasse gasifiers for industrial heating applications, Nimbkar Agricultural Research Institute (NARI), 1997, India, page 145
[168] Junginger et al., Fuel supply strategies for large scale bio-energy projects in developing countries. Electricity generation from agricultural and forests residues in Northeastern Thailand, 2001, page 267

Hamelinck et al (2003), shows a range of 12.3-20.6 US$$_{2003}$ per ton of *eucalyptus* collected and transported.

St. Kitts is a small island and the distances are not large, but on the other hand there are outdated equipments (collection and transportation), and one has to account also for the labour and operation costs that may lead costs between 30-40 US$/ton of sugarcane, comparable to the situation in India as described above. When we allocate 30% of these costs to baggase we find a range of 9-12 US$/ton for sugarcane bagasse. Thus a price of 10 US$/ton is used as input for further analysis. In the sensitivity analysis we will look at the influence of the biomass feedstock price on the COE and NPC.

6.4.5 Emissions (CO_2)

As part of the economic analysis, we will take the CO_2 emissions related to each scenario into consideration, these are compared to the business as usual scenarios (BAUK and BAUN scenarios) to estimate the CO_2 emission reduction and this will be quantified in money value. As described in chapter 2, since the ratification of the Kyoto Protocol by Russia[169] to combat the global warming, the Carbon credit market is official and has boomed and forms an important parameter for costsavings in investment costs for renewable energy projects within the Clean Development Mechanism (CDM) or Joint Implementation (JI) schemes where to St. Kitts and Nevis is entitled to.

In general RETs can be considered to have zero carbon emissions. If one consideres the life cycle of a RET, emissions can be identified related to the mining, collection, transportation, processing of the primary materials used to build the RETs, but this is in general considered to be limited[170].

On the other hand, in the case of bio-energy, one has to think of the carbon emissions related to the harvesting, processing/transportation, and consumption of the biomass feedstock. The carbon content in the feedstock in this case is considered to be originally present in the atmosphere, thus for biomass energy technologies it is the net amount of carbon emission reduction (carbon content in feedstock – carbon emission of activities, as harvesting and transportation) that can be considered valuable for the carbon market.
The amount of carbon contained in the biomass feedstock, expressed as a mass-based percentage is used in HOMER to calculate the emissions of CO_2, CO, and unburned hydrocarbons. Since there is no information available on the machinery used, the fuel consumption and other important data to analyze the emissions related to the harvesting, processing and transportation of the biomass feedstock, we will consider the devault value of 5% carbon content provided in the model. This amount in CO2 emissions will have to be deducted from the total mitigated CO2 emission of each scenario that includes bioenergy as part of the electricity production system.

6.5 General overview of input data for the HOMER Model

To be able to attain the overview, in this section we will show the general technical and financial input data or estimations made for each scenario based on the calculations done in the previous sections. Also the environmental considerations are discussed.

6.5.1 Input data for scenarios St. Kitts

Tables 6.22 till 6.25 show the general input data for the four scenarios related to St. Kitts. They contain information about the diesel and RET capacity expansion, the turn key investment costs,

[169] The Kyoto Protocol took effect in February 16, 2005, source: UNFCC website http://unfccc.int/2860.php/
[170] Ramana, V.P. et al., Renewable Energy Technologies and climate change policies in India, International Journal of Global Energy Issues, Vol. 15, Nos. ½, 2001

the operation and maintenance costs (O&M), the fuel costs, and some technical and financial parameters. These all form the main input data for the economical analysis to come to the levelized cost of electricity production (US$/kWh) and the net present cost (US$) which form the economical indicators to evaluate the scenarios.

The O&M costs are estimated to be 4% of the turn key investment costs for the years 2008 on forward. The O&M cost showed in tables 6.22 till 6.25 for the year 2005 are the real O&M costs at St. Kitts Electricity Department, which is about 4% of the key investment costs as well.

Table 6.22 General input data Business as Usual Scenario for St. Kitts

Business-as-Usual St. Kitts (BAUK-scenario)					
Parameter	**Value (2005)**	**Value (2008)**	**Value (2012)**	**Value (2015)**	**Unit**
Annual Peak demand	24.6	32.9	37.8	41.2	**kW**
Diesel Electricity capacity	**26.3**	**53.9**	**62.0**	**67.5**	**MWe**
Turn key investment (NPV)	338	615	469	361	**US$/kW**
Replacement costs	304	554	422	325	**US$/kW**
O&M costs	0.36	1.33	1.16	0.97	**US$ (xMillion)**
Fuel costs	0.42	0.35	0.35	0.36	**US$/l**
Fuel type	Fuel Oil #2				
Fuel density	890.1				**g/l**
Carbon content	88				**%**
Electric efficiency (LHV)	40				**%**
Load factor	73				**%**
Lifetime power plant	20				**yr**
Discount rate	10				**%**

Table 6.23 General input data Scenario K1 for St. Kitts[171]

Scenario K1					
Parameter	**Value (2005)**	**Value (2008)**	**Value (2012)**	**Value (2015)**	**Unit**
Annual peak demand	**26.3**	**32.9**	**37.8**	**41.2**	**MWe**
Turn key investment (NPV)	338	580	457	355	**US$/kW**
Replacement costs	304	522	411	320	**US$/kW**
O&M costs	13.5	23.2	18.3	14.2	**US$/kW**
Fuel costs	0.42	0.35	0.35	0.36	**US$/l**
Biomass	**0**	**2.9**	**2.9**	**2.9**	**MW**
Turn Key investment	0	2265	2208	2167	**US$/kW**
Replacement costs	0	2039	1987	1950	**US$/kW**
O&M costs	0	0.26	0.26	0.25	**US$ (x Million)**
Load factor	90				**%**
Lifetime power plant	20				**yr**
Scaled annual average feed	515				**ton/day**
Average feedstock price	10				**US$/ton**
Wind	**0**	**14.4**	**14.4**	**14.4**	**MW**
Turn Key investment	0	1213	1102	1026	**US$/kW**
Replacement costs	0	1092	992	923	**US$/kW**
O&M costs	0	0.70	0.63	0.59	**US$ (x Million)**
DC-AC Converter investment	0	649	80	6	**US$/kW**
Turbine type	Nordex N50/800				
Amount	18				
Lifetime power plant	20				**yr**
Capacity factor	35				**%**
Hub height	48				**m**
Rotor diameter	50				**m**
Cut in speed	3				**m/s**
Cut out speed	25				**m/s**
Weibull factor	2				
Scaled average windspeed	5.14				**m/s (10 m height)**
Solar	**0**	**0**	**5.4**	**5.4**	**MW**
Turn Key investment	0	0	3311	2629	**US$/kW**
Replacement costs	0	0	2980	2366	**US$/kW**
O&M costs	0	0	0.72	0.57	**US$ (x Million)**
Lifetime power plant	20				**yr**
Capacity factor	20				**%**
Energy conversion efficiency	12.5				**%**
Derating factor	80				**%**
Tot. RETs capacity	**0**	**17.3**	**22.7**	**22.7**	**MW**

[171] The extra information for each RET in this table also counts for tables 6.19 and 6.20

Table 6.24 General input data Scenario K2 for St. Kitts

Scenario K2					
Parameter	**Value (2005)**	**Value (2008)**	**Value (2012)**	**Value (2015)**	**Unit**
Annual peak demand	**26.3**	**32.9**	**37.8**	**41.2**	**MWe**
Turn key investment (NPV)	338	615	465	360	**US$/kW**
Replacement costs	304	554	419	324	**US$/kW**
O&M costs	13.5	24.6	18.6	14.4	**US$/kW**
Fuel costs	0.42	0.35	0.35	0.36	**US$/l**
Biomass	**0**	**0**	**2.9**	**2.9**	**MWe**
Turn Key investment	0	0	2208	2167	**US$/kW**
Replacement costs	0	0	1987	1950	**US$/kW**
O&M costs	0	0	0.26	0.25	**US$ (x Million)**
Wind	**0**	**0**	**14.4**	**14.4**	**MWe**
Turn Key investment	0	0	1102	1026	**US$/kW**
Replacement costs	0	0	992	923	**US$/kW**
O&M costs	0	0	0.63	0.59	**US$ (x Million)**
Solar	**0**	**0**	**5.4**	**5.4**	**MWe**
Turn Key investment	0	0	3311	2629	**US$/kW**
Replacement costs	0	0	2980	2366	**US$/kW**
O&M costs	0	0	0.72	0.57	**US$ (x Million)**
Tot. RETs capacity	**0**	**0**	**22.7**	**22.7**	**MWe**
Tot installed capacity	**26.3**	**32.9**	**60.5**	**63.9**	**MWe**

Table 6.25 General input data Scenario K3 for St. Kitts

Scenario K3					
Parameter	**Value (2005)**	**Value (2008)**	**Value (2012)**	**Value (2015)**	**Unit**
Annual peak demand	**26.3**	**32.9**	**37.8**	**41.2**	**MWe**
Turn key investment (NPV)	338	615	469	359	**US$/kW**
Replacement costs	304	554	422	323	**US$/kW**
O&M costs	13.5	24.6	18.7	14.3	**US$/kW**
Fuel costs	0.42	0.35	0.35	0.36	**US$/l**
Biomass	**0**	**0**	**0**	**2.9**	**MWe**
Turn Key investment	0	0	0	2167	**US$/kW**
Replacement costs	0	0	0	1950	**US$/kW**
O&M costs	0	0	0	0.25	**US$ (x Million)**
Load factor	80				**%**
Lifetime power plant	20				**yr**
Tot. RET capacity	**0**	**0**	**0**	**2.9**	**MWe**

6.5.2 Input data for scenarios for Nevis

The general input data for the scenarios related to Nevis are shown in tables 6.26 till 6.29. They contain information about the diesel and RET capacity expansion, the turn key investment costs, the operation and maintenance costs (O&M), the fuel costs, and some technical and financial parameters. These all form the main input data for the economical analysis to come to the levelized cost of electricity production (US$/kWh) and the net present cost (US$) which form the economical indicators to evaluate the scenarios, see chapter 2 for more detail.

Table 6.26 General input data Business as Usual Scenario and N1 for Nevis

Business-as-Usual Nevis (BAUN-scenario)					
Parameter	**Value (2005)**	**Value (2008)**	**Value (2012)**	**Value (2015)**	**Unit**
Diesel Electricity capacity	**11.9**	**18.2**	**23.1**	**27.7**	**MWe**
Turn key investment (NPV)	338	512	439	350	**US$/kW**
Replacement costs	304	461	396	315	**US$/kW**
O&M costs	0.16	0.37	0.41	0.39	**US$ (xMillion)**
Fuel costs	0.49	0.41	0.41	0.42	**US$/l**
Electric efficiency (LHV)	40				**%**
Load factor	73				**%**
Lifetime power plant	20				**yr**
Discount rate	10				**%**

Table 6.27 General input data N1 Scenario for Nevis

Scenario N1					
Parameter	**Value (2005)**	**Value (2008)**	**Value (2012)**	**Value (2015)**	**Unit**
Diesel Electricity capacity	**11.9**	**18.2**	**23.1**	**27.7**	
Turn key investment (NPV)	338	539	412	336	**US$/kW**
Replacement costs	304	485	370	302	**US$/kW**
O&M costs	13.5	21.6	16.5	13.4	**US$/kW**
Fuel costs	0.49	0.41	0.41	0.42	**US$/l**
Geothermal	**0.0**	**0.0**	**10.0**	**10.0**	**MW**
Turn Key investment			1809	1710	**US$/kW**
Replacement costs			1628	1539	**US$/kW**
O&M costs			0.72	0.68	**US$ (x Million)**
Lifetime power plant	20				**yr**
Capacity factor	0.9				**%**
Solar	**0.0**	**0.0**	**0.0**	**5.4**	**MWe**
Turn Key investment	0	0	0	2629	**US$/kW**
Replacement costs	0	0	0	2366	**US$/kW**
O&M costs	0	0	0	0.57	**US$ (x Million)**
Lifetime power plant	20				**yr**
Capacity factor	20				**%**
Energy conversion efficiency	12.5				**%**
Derating factor	80				**%**
Wind	**0.0**	**9.6**	**9.6**	**9.6**	**MW**
Turn Key investment		1213	1102	1026	**US$/kW**
Replacement costs		1092	992	923	**US$/kW**
O&M costs		0.47	0.42	0.39	**US$ (x Million)**
Amount	12 x Nordex N50/800				
Lifetime power plant	20				**yr**
Capacity factor	25.1				**%**
Hub height	48				**m**
Rotor diameter	50				**m**
Cut in/out speed	3-25				**m/s**
Weibull factor	2				
Scaled average windspeed	6.18				**m/s (10 m height)**
Tot. RET capacity	**0.0**	**9.6**	**19.6**	**25.0**	**MW**

Table 6.28 General input data N2 Scenario for Nevis

Scenario N2					
Parameter	**Value (2005)**	**Value (2008)**	**Value (2012)**	**Value (2015)**	**Unit**
Diesel Electricity capacity	**11.9**	**18.2**	**23.1**	**27.7**	**MWe**
Turn key investment (NPV)	338	512	403	336	**US$/kW**
Replacement costs	304	461	362	302	**US$/kW**
O&M costs	13.5	20.5	16.1	13.4	**US$ (xMillion)**
Fuel costs	0.49	0.41	0.41	0.42	**US$/l**
Geothermal	**0**	**0**	**10**	**10.0**	**MW**
Turn Key investment			1809	1710	**US$/kW**
Replacement costs			1628	1539	**US$/kW**
O&M costs			0.72	0.68	**US$ (x Million)**
Solar	**0**	**0**	**0.0**	**5.4**	**MWe**
Turn Key investment	0	0	0	2629	**US$/kW**
Replacement costs	0	0	0	2366	**US$/kW**
O&M costs	0	0	0	0.57	**US$ (x Million)**
Wind	**0**	**0**	**0.0**	**9.6**	**MW**
Turn Key investment				1026	**US$/kW**
Replacement costs				923	**US$/kW**
O&M costs				0.39	**US$ (x Million)**
Tot. RET capacity	**0.0**	**0.0**	**10.0**	**25.0**	**MW**

Table 6.29 General input data N3 Scenario for Nevis

Scenario N3					
Parameter	**Value (2005)**	**Value (2008)**	**Value (2012)**	**Value (2015)**	**Unit**
Diesel Electricity capacity	**11.9**	**18.2**	**23.1**	**27.7**	
Turn key investment (NPV)	338	512	439	341	**US$/kW**
Replacement costs	304	461	396	307	**US$/kW**
O&M costs	13.5	20.5	17.6	13.6	**US$/kW**
Fuel costs	0.49	0.41	0.41	0.42	**US$/l**
Geothermal	**0**	**0**	**0**	**10**	**MW**
Turn Key investment				1710	**US$/kW**
Replacement costs				1539	**US$/kW**
O&M costs				0.68	**US$ (x Million)**
Tot. RET capacity	**11.9**	**18.2**	**23.1**	**37.7**	**MW**

Now the general input data for all the scenarios is known we can use the HOMER model to calculate the total amount of required diesel capacity to comply with the load demand of each island. HOMER will search for the optimal combination of energy technologies based on costs and compliance to the energy demand. The results are discussed in chapter 7.

7. Results of Energy and Economical Analysis

In this chapter we will analyze the results of the energy and economic analysis. The main parameters or indicators are the amount of required diesel capacity, the renewable fraction, the levelized cost of electricity production (COE), the net present value (NPC), the total electricity production and the CO2 emissions. The business as usual scenario (BAUK and BAUN scenarios) are projected and the best performing RET scenario described. With a multi criteria analysis the best case scenario is selected for further sensitivity analysis.

7.1 Scenarios for St. Kitts

Business as Usual scenario (BAUK-scenario)

Figure 7.1 gives the overview of the results related to the BAUK scenario. In 2005 there is a capacity shortage of 23% (lack of operating reserve[172]), this means that a considerable capacity is needed in the period 2005 to 2008 to comply with the load demand. By installing additional diesel capacity to 53.9 MW, will reduce the capacity shortage to 0%. After this the increase in capacity will parallel follow the projected load demand.

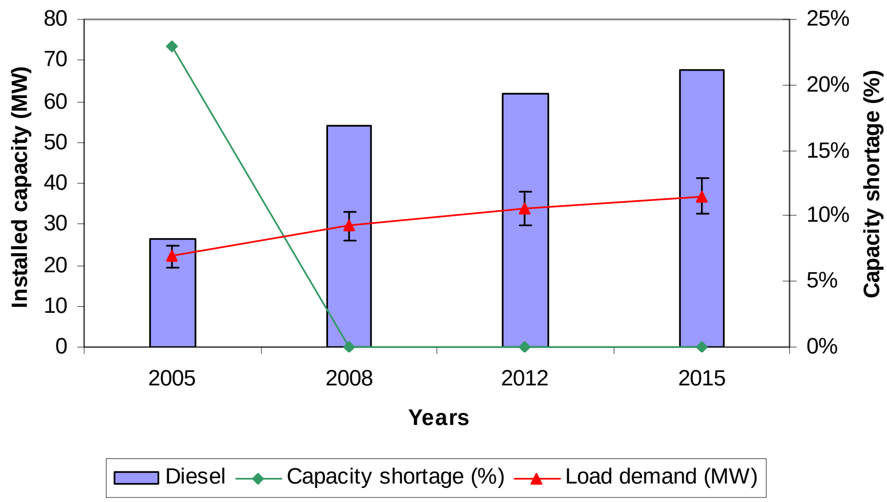


Figure 7.1 Results of the Business as Usual (BAUK) scenario for St. Kitts

K1 scenario

The HOMER model searched for the optimal hybrid combination of electricity production systems. And in this case the system architecture for period 2008-2015 is 4 x 800kW Nordex wind turbines, 2.9 MW Bio energy, an inverter/rectifier capacity of 3.5 MW and an increasing

[172] Operating reserve provides a safety margin that helps ensure reliable electricity supply despite variability in the electric load and the renewable power supply. Virtually every real micropower system must always provide some amount of operating reserve, because otherwise the electric load would sometimes fluctuate above the operating capacity of the system, and an outage would result. Each hour, HOMER calculates the required amount of operating reserve as a fraction of the primary load that hour, plus a fraction of the annual peak primary load, plus a fraction of the PV power output that hour, plus a fraction of the wind power output that hour. The modeler specifies these fractions by considering how much the load or the renewable power output is likely to fluctuate in a short period (in this study the capacity factor is the indicator for the RET fraction), and how conservatively he or she plans to operate the system. The more variable the load and renewable power output, and the more conservatively the system must operate, the higher the fractions the modeler should specify. HOMER does not attempt to ascertain the amount of operating reserve required to achieve different levels of reliability; it simply uses the modeler's specifications to calculate the amount of operating reserve the system is obligated to provide each hour. See table 5.9 for an overview of the capacity factors related to the RETs selected for this analysis.

diesel capacity over the years from 50.6 to 63.4 MW in period 2005-2015. This means less diesel is required compared to the business as usual scenario, and thus less fuel usage, a lower COE and lower CO_2 emissions. Figure 7.2 gives the overview of the required installed diesel and RETs capacities and the renewable energy fraction for scenario K1. The other indicators are discussed in section 7.2 on comparative results.

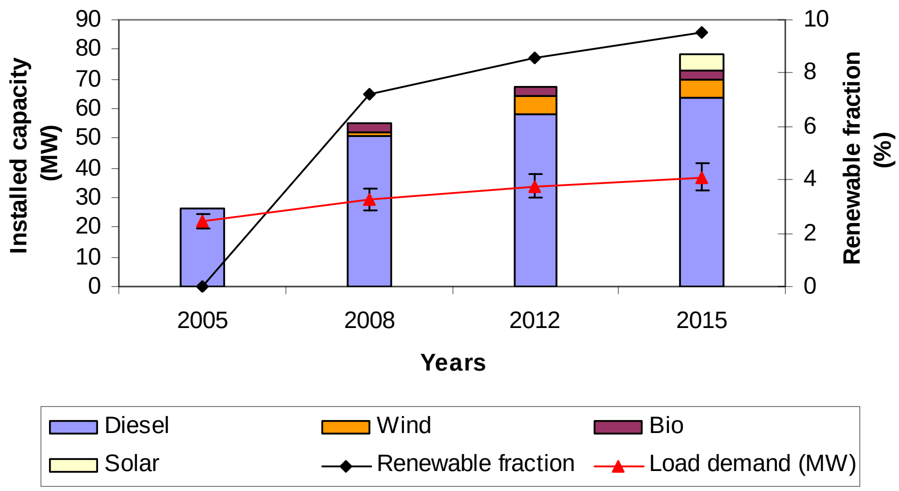


Figure 7.2 Results of the K1 scenario for St. Kitts

K2 scenario

Figure 7.3 shows the results of scenario K2. In this scenario HOMER found as best hybrid system to be introduced in the period 2008-2012, the combination of 5.4 MW PV, 2.9 MW Bio, Inverter/rectifier of 3.5 MW and an increasing diesel capacity over the period 2005-2015.

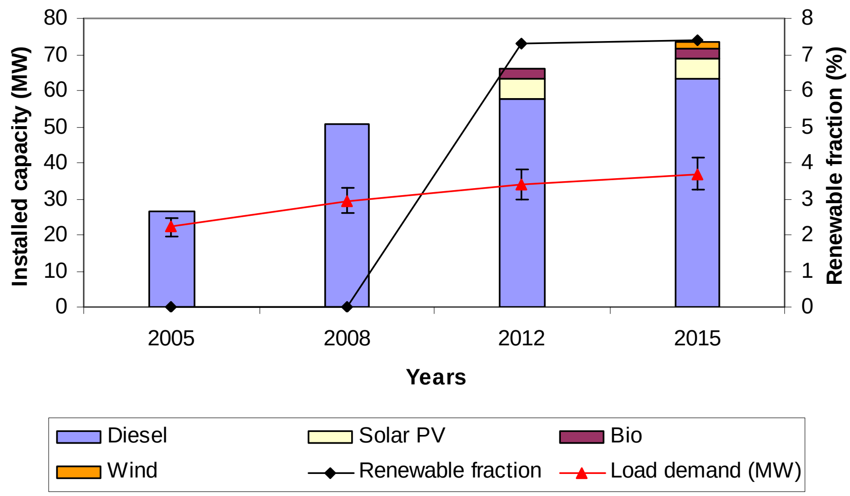


Figure 7.3 Results of the K2 scenario for St. Kitts

K3 scenario

Figure 7.4 gives an overview of the results for the K3 scenario for St. Kitts. In this scenario the only RET that is introduced is the bio-energy technology and this occurs late in the period 2012-2015.

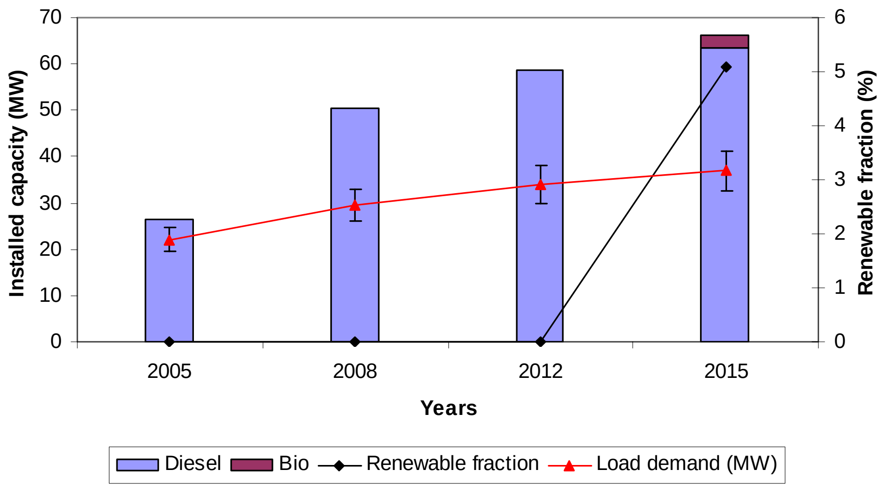


Figure 7.4 Results of the K3 scenario for St. Kitts

One can also see the difference in installed diesel capacity for the specific periods, scenario K3 requires more installed diesel than scenario K1 over the period 2005-2008 and 2008-2012. This means more fuel consumption and larger CO_2 emissions.

7.2 Comparative results of scenarios for St. Kitts

In figure 7.5 the results for all the scenarios related to St. Kitts are shown. The levelized cost of electricity (COE) does decrease for all the scenarios BAUK, K1, K2 and K3 during the period 2005-2015. The reason for this is that there is a general trend that the turnkey investment costs for the diesel units and the RETs will decrease in the future. Also the fuel price forecasts used for this analysis indicate that the fuel price may decrease on the long run.

The results in figure 7.5 are trend lines, with 4 measurement moments on 2005, 2008, 2012 and 2015. This means that the results for the intermediate periods are interpolated and are only qualitative in essence.

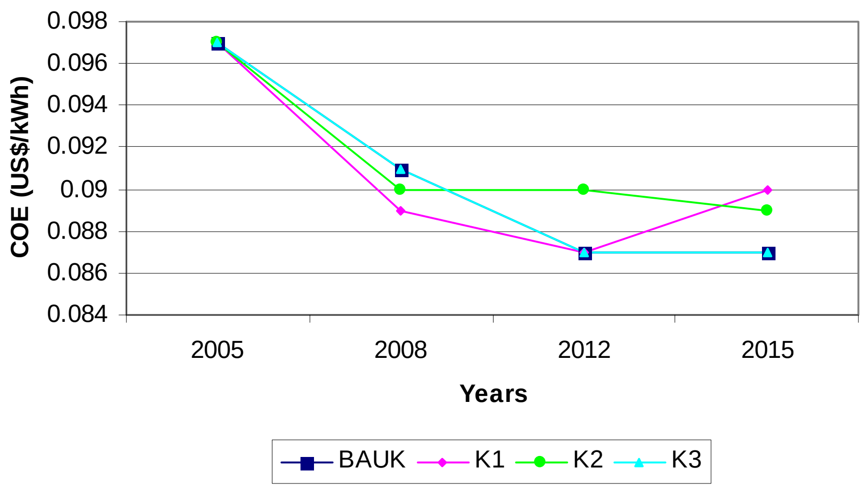


Figure 7.5 Levelized cost of electricity per scenario for St. Kitts

The cost of electricity production (COE) development for the Business-as-Usual scenario in 2005 is 0.097 US$/kWh and will decrease to 0.087 US$/kWh over the period 2005-2015. The best case scenario (K1), with the highest RET contribution and quickest introduction causes a decrease in the COE from 0.097 US$/kWh to 0.089 US$/kWh in the period 2005-2008. The COE decreases by 8.2% per annum (2005-2008), 2.2% per annum (2008-2012) and 2.3% per annum (2012-2015). For the scenario K2, the COE decreases from 0.097 US$/kWh to 0.088 US$/kWh over the period 2005-2015 with a small addition of diesel capacity. For scenario K3, the COE will decrease from 0.097 US$/kWh in 2005 to 0.085 US$/kWh in 2015 as it does in scenario K1. But the difference between the two is that here the decrease in COE for the periods 2005-2008 is 6.2% per annum, in period 2008-2012 a decrease of 4.4% and 2.3% per annum in the period 2012-2015.

Based on the COE development of the scenarios we can consider scenario K1 as the best scenario for the cost of electricity production, this is because by introducing RETs as early as in period 2005-2008 the COE in 2008 will decrease the most and this low average COE can be decreased even further till the year 2015. Also the renewable fraction is on average 11.7% over the period 2005-2015.

When we look at the net present costs for each scenario related to St. Kitts, we find very high values. There is an uncertainty in the NPC values, this is because input data as the NPV of the capital investments of the diesel units are estimated (see section 6.4.2). Also the operation and maintenance costs are considered to be 4% of the capital investments.

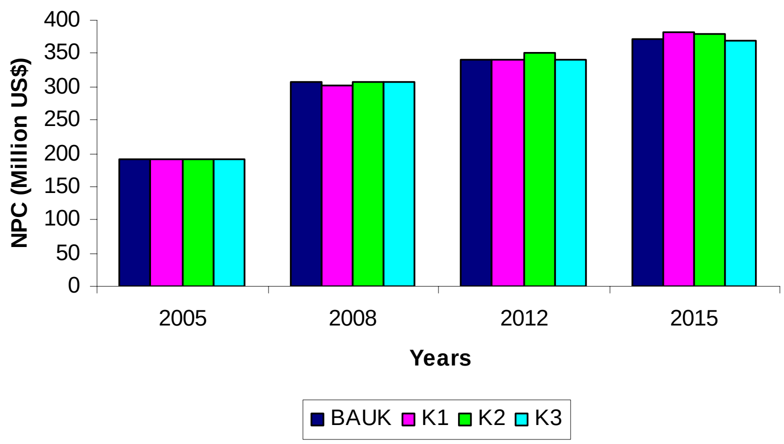


Figure 7.6 Net Present Cost per scenario for St. Kitts

In general the NPC increases drastically for all the scenarios in the period 2005 to 2008. The reason is that in 2005 there is a capacity shortage of 23%, thus in this period a large amount of extra new diesel capacity is required to come to a capacity shortage of 0%.

The electricity production based on the BAUK scenario is shown in figure 7.7. One of the considerations taken for this analysis is that all the RET scenarios should minimally comply to this electricity production, this is because at this level there is a 0% capacity shortage. The electricity production will increase from 230.4 GWh to 499.3 GWh in period 2005-2015.

If we look at the CO_2 emissions, we see that as expected the BAUK scenario emits the largest amounts of CO_2 over the period 2005-2015, see figure 7.7. Also in this case the K1 scenario scores the best, thus by introducing RETs in the early stage you can prevent a considerable amount of CO_2 emissions over the period 2005-2015 when it is compared to the BAUK scenario.

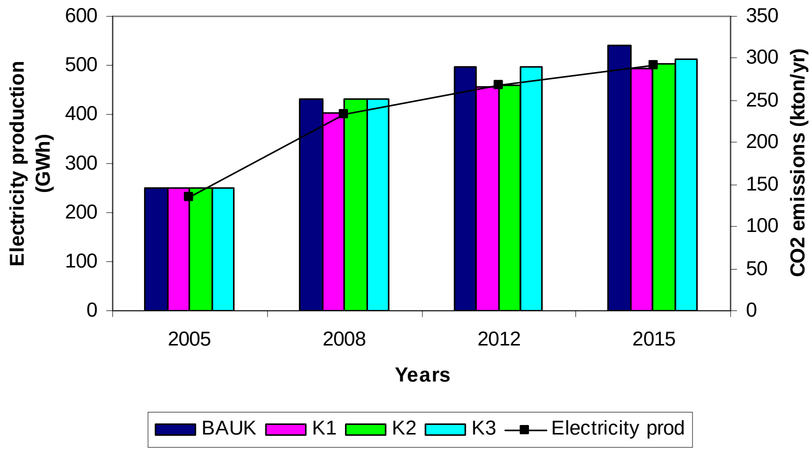


Figure 7.7 Electricity production and CO_2 emissions per scenario for St. Kitts

The difference between the amount of emitted CO_2 between the RET scenarios and the BAUK scenario are considered the avoided CO_2 emissions. With a current carbondioxide price of 26.7 US$/ton[173] on the Carbon Credit Market we are able to estimate the value of CO_2 emission avoidance. See the results in table 7.1.

Table 7.1 Overview of carbon credit calculations for scenarios of St. Kitts

		2005	2008	2012	2015	
BAUK	CO2 emissions	145.2	252.3	289.4	315.5	kton/yr
	NPC	**190.0**	**308.1**	**339.9**	**370.5**	US$ (Million)
K1	CO2 emissions	145.2	234.3	266.4	287.3	kton/yr
	Avoided CO2	0.0	18.0	23.0	28.2	kton/yr
	CO2 credit value	0.0	480.6	614.1	752.9	x10^3 US$/yr
	NPC	190.0	301.3	339.4	383.0	US$ (Million)
	NPC (net)	**190.0**	**300.8**	**338.8**	**382.2**	US$ (Million)
K2	CO2 emissions	145.2	252.3	268.8	293.2	kton/yr
	Avoided CO2	0.0	0.0	20.6	22.3	kton/yr
	CO2 credit value	0.0	0.0	550.0	595.4	x10^3 US$
	NPC	190.0	308.1	351.0	380.5	US$ (Million)
	NPC (net)	**190.0**	**308.1**	**350.4**	**379.9**	US$ (Million)
K3	CO2 emissions	145.2	252.3	289.4	299.4	kton/yr
	Avoided CO2	0.0	0.0	0.0	16.1	kton/yr
	CO2 credit value	0.0	0.0	0.0	429.9	x10^3 US$
	NPC	190.0	308.1	339.9	368.6	US$ (Million)
	NPC (net)	**190.0**	**308.1**	**339.9**	**368.2**	US$ (Million)
CO2 price		26.7				US$/ton CO2

The CO_2 emissions related to the BAUK scenario increase with fluctuations from 145.2 to 315.5 kton/yr over the period 2005-2015.

Note that the results for the CO2 emissions are expressed in kton per year. While the NPC expresses the sum of the annualized costs over the whole project lifetime (in this case 20 years). When one wants to calculate the real payback by carbon reduction credit, the CO2 emissions need

[173] Source: http://community.newvalues.net/international/000909.shtml

to be treated as a net present value (see equation 7.4). Thus the CO2 credit value needs to be depreciated over the years of the project lifetime and annually deducted from the total annual costs in order to find the real net present costs and finally come to a new net present cost for the whole project.

As general conclusion we can say that scenario K1, with the high and fast renewable energy technology contribution scores best on the development of the levelized cost of electricity production (COE), the CO_2 emission avoidance, less diesel capacity requirement, which means less fuel consumption, thus less dependency on external fossil fuel markets.

In chapter 8, a sensitivity analysis is performed to identify the parameters or input data that has the most influence on the COE. Then we will see how reliable this identified parameter is in this analysis to be able to come to conclusions and recommendations.

7.3 Scenarios for Nevis

Business as Usual (BAUN) scenario
As for the scenario for St. Kitts the analysis is done for the situation on Nevis. The power capacity requirement for Nevis is much smaller compared to St. Kitts. The required capacity to comply with the demand load to maintain a capacity shortage of 0% is for the period 2005-2008 an increase till 18.2 MW, in period 2008-2012 investments have to be made in additional capacity up to 23.1 MW and continue this to a total installed capacity of 27.7 MW in the year 2015. Figure 7.8 shows the overview of the results of the analysis for the scenarios for Nevis.

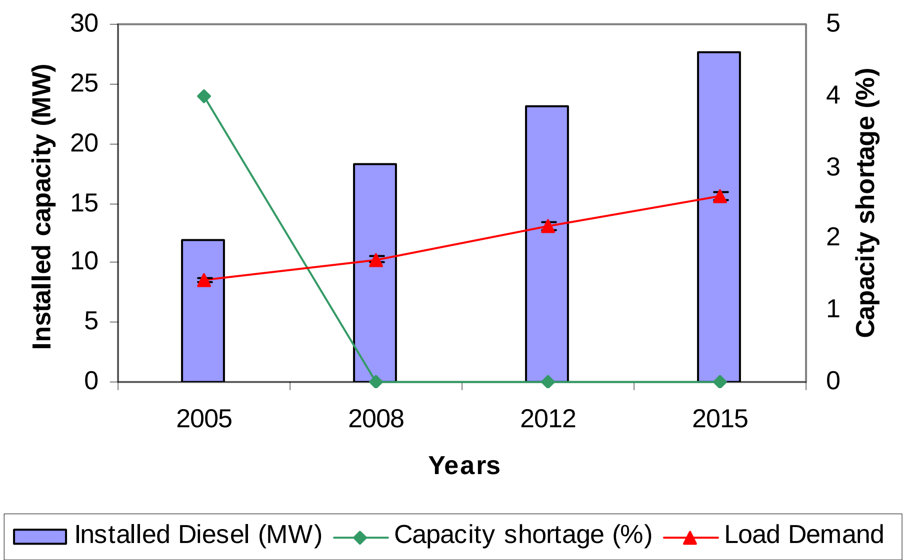


Figure 7.8 Overview of results of the BAUN scenario for Nevis

The current installed capacity at NEVLEC that is within the economical lifetime of 20 years is 11.9 MW, with this capacity there is a 4% capacity shortage to deal with the demand load. The COE calculated for all the scenarios of Nevis are based on NPV of the installed capacity at St. Kitts Electricity Department, this is because NEVLEC did not provide investment data on the units installed at NEVLEC. Therefore, the outcomes of the analysis may not reflect the real situation for Nevis. Nevertheless, since the idea of this study is to give a qualitative analysis of the impact of possible RET introduction on the costs for electricity production, the results can still be of great value for further research and evaluation.

N1 scenario
In the case of the N1 scenario, with fast and high contribution of RETs, the system architecture was based on an varying diesel capacity, 6 x 800 kW Nordex wind turbines and 10 MW geothermal energy. The renewable fraction increases drastically in 2012 because the geothermal energy technology will start operating. In period 2012 to 2015 this geothermal influence will decrease steadily since the load demand will continue to grow and more diesel capacity is required, with higher operational costs that causes the COE to increase.

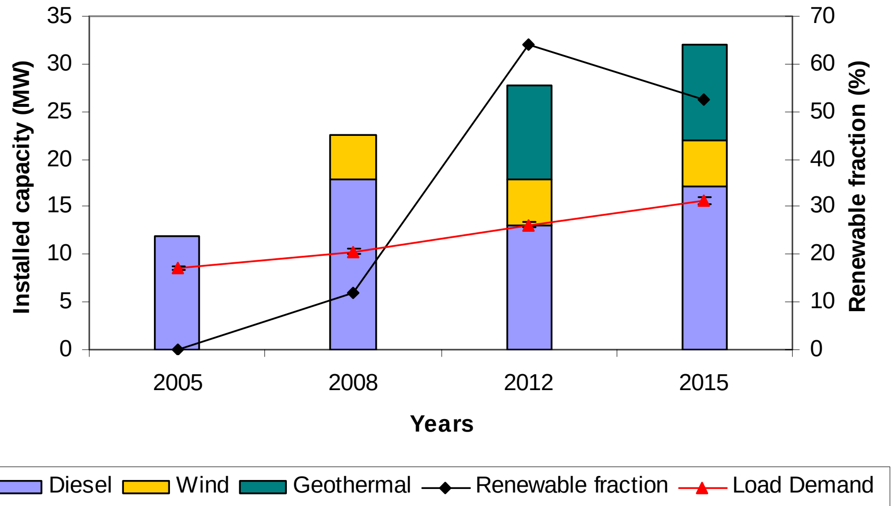


Figure 7.9 Overview of results of the N1 scenario for Nevis

N2 Scenario
In the case of the N2 scenario a 10 MW geothermal technology development will be in operation in 2012 and will cause an increase in the renewable fraction from 0 to 56%, see figure 7.10.

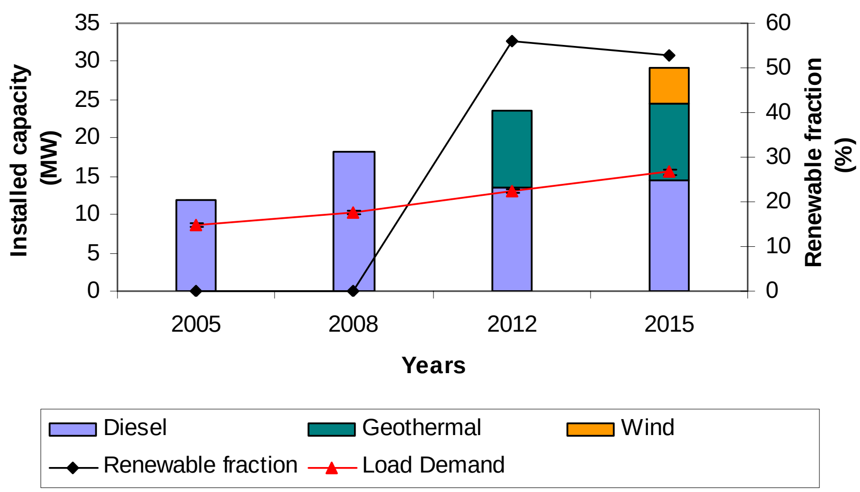


Figure 7.10 Overview of results of the N2 scenario for Nevis

As in scenario N1, here the geothermal technology has a great impact on the fuel usage and thus also the COE, next to this the CO_2 emissions are reduced considerably.

Scenario N3

Figure 7.11 shows the results of the analysis for scenario N3. In this scenario the geothermal technology development will be introduced in the period 2012-2015, with a full 10 MW operating plant in 2015.

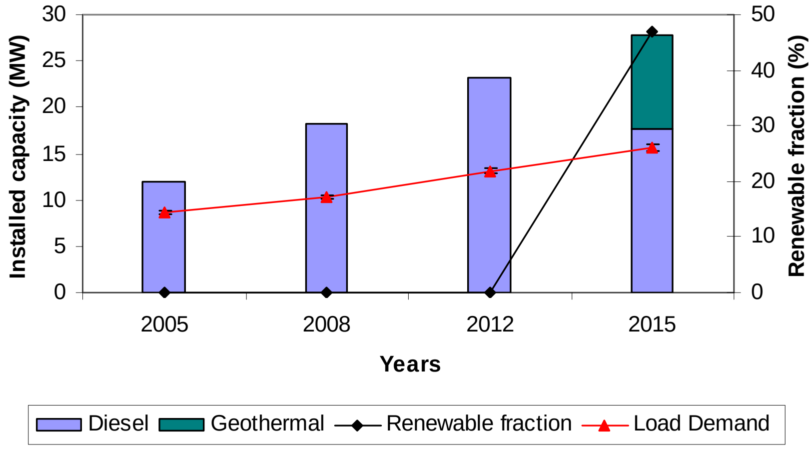


Figure 7.11 Overview of results of the N3 scenario for Nevis

7.4 Comparative results of scenarios for Nevis

In figure 7.12 the COE for the four scenarios for Nevis, BAUN, N1, N2 and N3 are shown. One can see directly that there are large reductions possible in COE. This is caused by the introduction of geothermal capacity of 10 MW in the different time frames of each scenario. The scenarios N1 and N2 seem to overlap eachother, the reason for this is that the contribution of the installed wind capacity in scenario N1 is limited and causes it to be negligible to the COE, when the geothermal capacity is introduced. Thus eventhough the renewable fraction for N1 in 2012 is higher (64%) compared to the renewable fraction of scenario N2 (56%), the cost of electricity production will differ only by 0.001 US$/kWh (0.065 – 0.064 US$/kWh). In the case of scenario N3 the COE drops from 0.109 US$/kWh in 2012 to 0.072 US$/kWh in 2015 due to the introduction of the geothermal option.

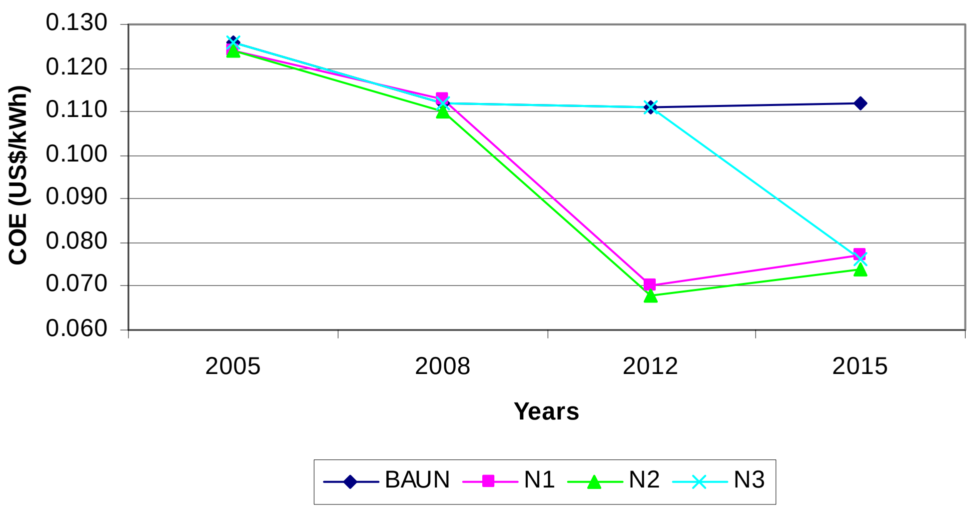


Figure 7.12 Levelized cost of electricity per scenario for Nevis

For the scenarios N1 and N2 related to Nevis the net present cost decreases considerable in the years 2012 and 2015, see figure 7.13. The reason is that the geothermal energy system is introduced and because of its large energy production ratio to the turnkey investments it is cheaper to operate than other renewable technologies and causes the NPC to drop.

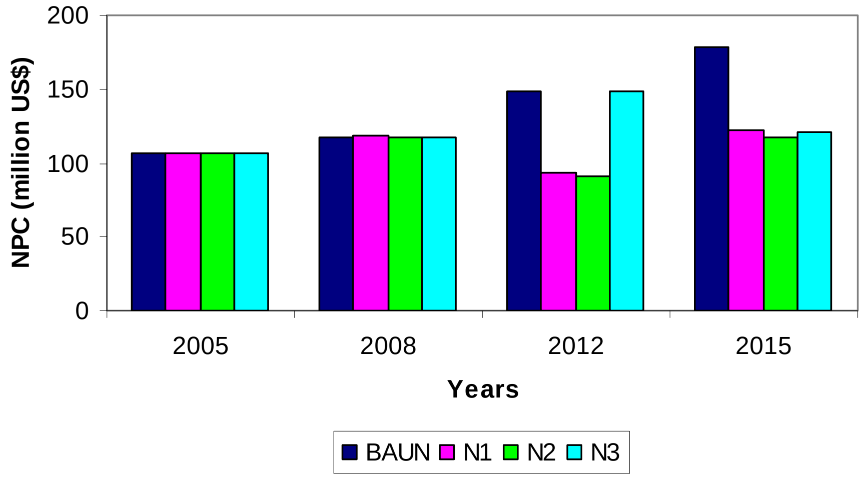


Figure 7.13 Net present costs per scenario for Nevis

When we look at the CO_2 emissions related to the scenarios for Nevis, one can see the same trends as in the previous figure. The CO_2 emissions drop considerably when the geothermal development is introduced, see figure 7.14. This figure also shows the electricity production at the end of each time frame for all the scenarios related to Nevis.

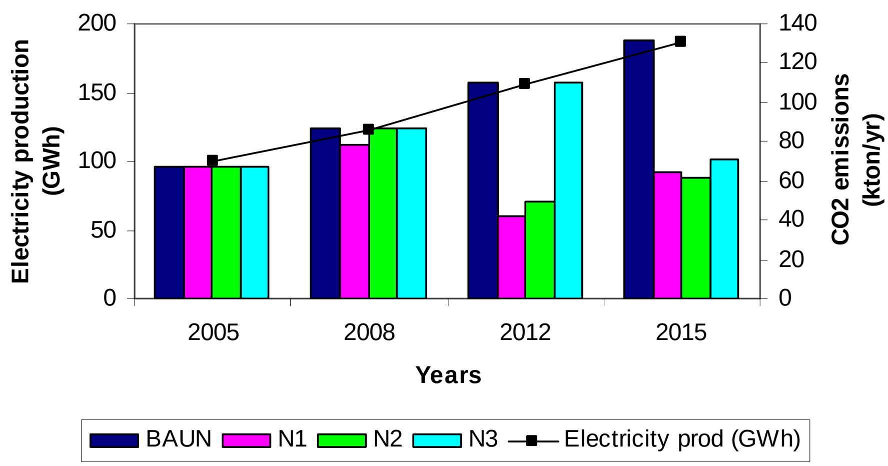


Figure 7.14 CO_2 emissions per scenario for Nevis

From the previous section we see that the faster RETs are introduced, for Nevis especially the geothermal option, the less diesel capacity is required the less fuel is used, this leads to a decrease in the costs for electricity production and also more CO_2 emissions can be avoided.

In the case of scenarios N2 the CO_2 emission is decreased from 86.8 kton per annum in period 2005-2008 to 49.7 kton per annum in 2012.

As done for St. Kitts scenarios the carbon credit is calculated for the situation on Nevis. See table 7.2 for the results. As discussed for table 7.1 (St. Kitts) the results are just given as illustration to show the relative differences between the scenarios and one should take in mind that the (net) NPC showed in the table are not calculated in the correct way and should not be used, unless re-calculated in manner as described in the text describing table 7.1.

Table 7.2 Overview of carbon credit calculations for scenarios of St. Kitts

Scenario	Parameter	2005	2008	2012	2015	Unit
BAUN	CO2 emissions	67	86.8	110.2	131.9	kton/yr
	NPC	**106.4**	**117.9**	**148**	**178.6**	US$ (million)
N1	CO2 emissions	67	78.5	42.3	64.3	kton/yr
	Avoided CO2	0	8.3	67.9	67.6	kton/yr
	CO2 credit value	0	222	1813	1805	x10^3 US$/yr
	NPC	106.4	118.8	93	122.1	US$ (Million)
	(net) NPC	**106.4**	**118.6**	**91.2**	**120.3**	US$ (Million)
N2	CO2 emissions	67	86.8	49.7	62	kton/yr
	Avoided CO2	0	0	60.5	69.9	kton/yr
	CO2 credit value	0	0	1615	1866	x10^3 US$/yr
	NPC	106.4	117.9	90.8	117.4	US$ (Million)
	(net) NPC	**106.4**	**117.9**	**89.2**	**115.5**	US$ (Million)
N3	CO2 emissions	67	86.8	110.2	71.2	kton/yr
	Avoided CO2	0	0	0	60.7	kton/yr
	CO2 credit value	0	0	0	1621	x10^3 US$/yr
	NPC	106.4	117.9	148	120.8	US$ (Million)
	(net) NPC	**106.4**	**117.9**	**148.0**	**119.2**	US$ (Million)
CO2 price		26.7				US$/ton CO2

7.5 Multi Criteria Analysis

In this section we will analyze the possible economic, social and environmental impacts of introducing renewable energy technologies. As discussed before, due to limited availability of data a qualitative analysis is done to select the scenario that scores best related to the economical and socio-environmental effects.

From the previous sections we have gathered information on the renewable fraction, cost of electricity production (COE), the net present costs (NPC) and the CO2 emissions related to each scenario for St. Kitts and Nevis. These data are used in the Multi Criteria Analysis (MCA).

The weighing of values to these parameters is subjective. But in order to limit the subjectivity in the results, it is chosen to take two perspectives in account, the economical and the socio-environmental perspective. In the case of the economical perspective a higher weighing value is set on the cost reduction or cost effectiveness of the electricity production system, where for instance the lower the COE, the better. In case of the socio-environmental perspective attention is set on the decrease of environmental impact, as the CO_2 emission reduction. As social impact, the renewable fraction is highly valued, this is because the larger the contribution of renewable energy the less dependant the economy will be to external diesel fuel price developments, also the continuation of the renewable energy projects can create diversified employment.

The available version of the BOSDA model has not the capacity to perform the multi criteria analysis for continuous time frames. Thus the choice is made to take the scenario data related to 2008, 2012 and 2015 in account and run BOSDA separately for each scenario.

The available data for each evaluation parameter is standardized to a range between 0-1. Two perspectives, the economical and the socio-environmental perspective, are used. The weighing factors are distributed as described in table 7.3.

Table 7.3 Distribution of weighing factors for the MCA

	Weighing factor	
	Economical	Socio-environmental
COE	0.4	0.1
NPC	0.4	0.1
CO2 emissions	0.1	0.4
Renewable fraction	0.1	0.4

St. Kitts MCA results

Table 7.4 gives an overview of the calculated evaluation indicators of each scenario for St. Kitts in the years 2008, 2012 and 2015 that are used in the multi criteria analysis.

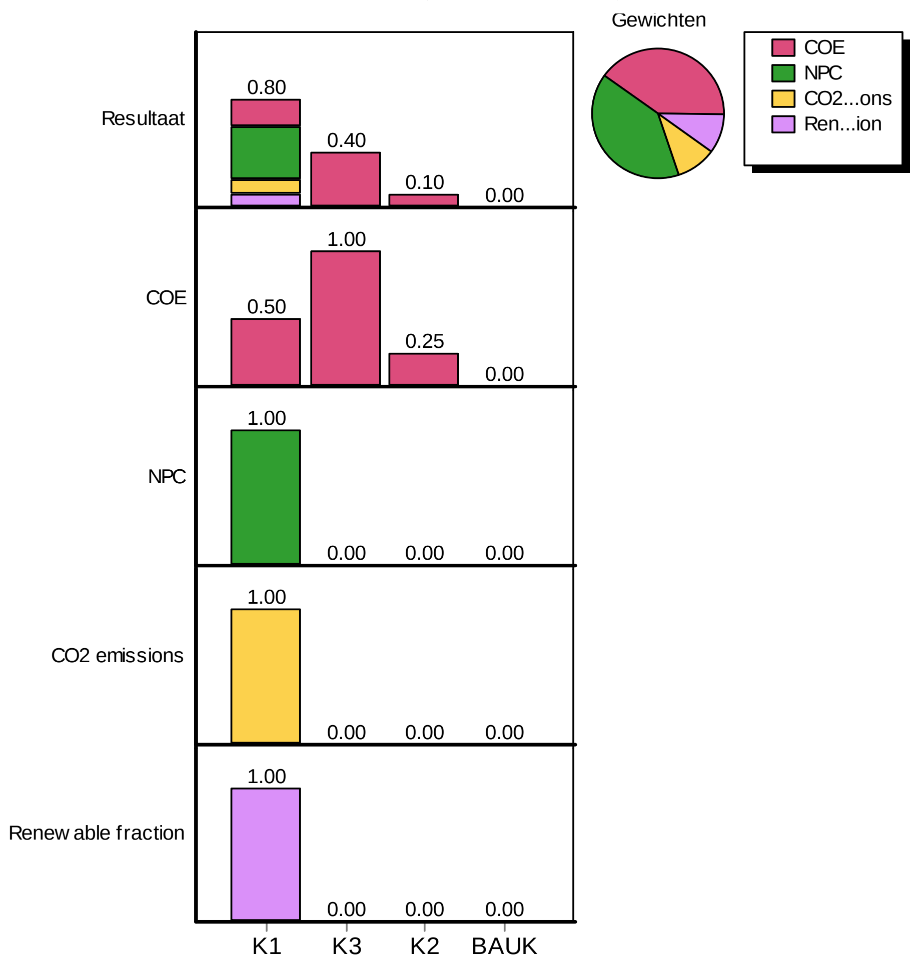
Table 7.4 Overview of the evaluation parameters related to scenarios for St. Kitts

		BAUK	K1	K2	K3	Unit
2008	COE	0.091	0.089	0.091	0.091	US$/kWh
	NPC	308.1	301.3	308.1	308.1	million US$
	CO2 emissions	252.3	234.3	252.3	252.3	kton CO2 / yr
	Renewable fraction	0	7.2	0	0	%
2012	COE	0.087	0.087	0.09	0.087	US$/kWh
	NPC	339.9	339.4	351	339.9	million US$
	CO2 emissions	289.4	266.4	268.8	289.4	kton CO2 / yr
	Renewable fraction	0	8.6	7.3	0	%
2015	COE	0.087	0.09	0.089	0.087	US$/kWh
	NPC	370.5	383	380.5	368.6	million US$
	CO2 emissions	315.5	287.3	293.2	299.4	kton CO2 / yr
	Renewable fraction	0	9.5	7.4	5.1	%

The data provided in table 7.4 is inserted in the BOSDA model. The model gives the option to standardize the input values to be able to do a comparative analysis. The choice was made to standardize the input data as a relative percentage of the minimal and maximal input value. Thus in case of the renewable fraction (in 2015, table 7.4) the maximal input value is 9.5% and this is set on 100% or value 1. The minimal is 0, thus the standardized values variate between 0-1. This same method is applied to all the input data for the scenarios of St. Kitts and Nevis.

In figure 7.13 one can see a detailed overview of the MCA results for the St. Kitts scenarios in the year 2008. On the left side the economical view is presented and on the right the socio-environmental perspective. The pie diagram shows the relative importance of each evaluation parameter depending on the perspective chosen. In 2008, the K1 scenario scores the best on both perspectives.

St. Kitts scenarios in 2008 (economical view)



St. Kitts scenarios in 2008 (socio-envirmt. view)

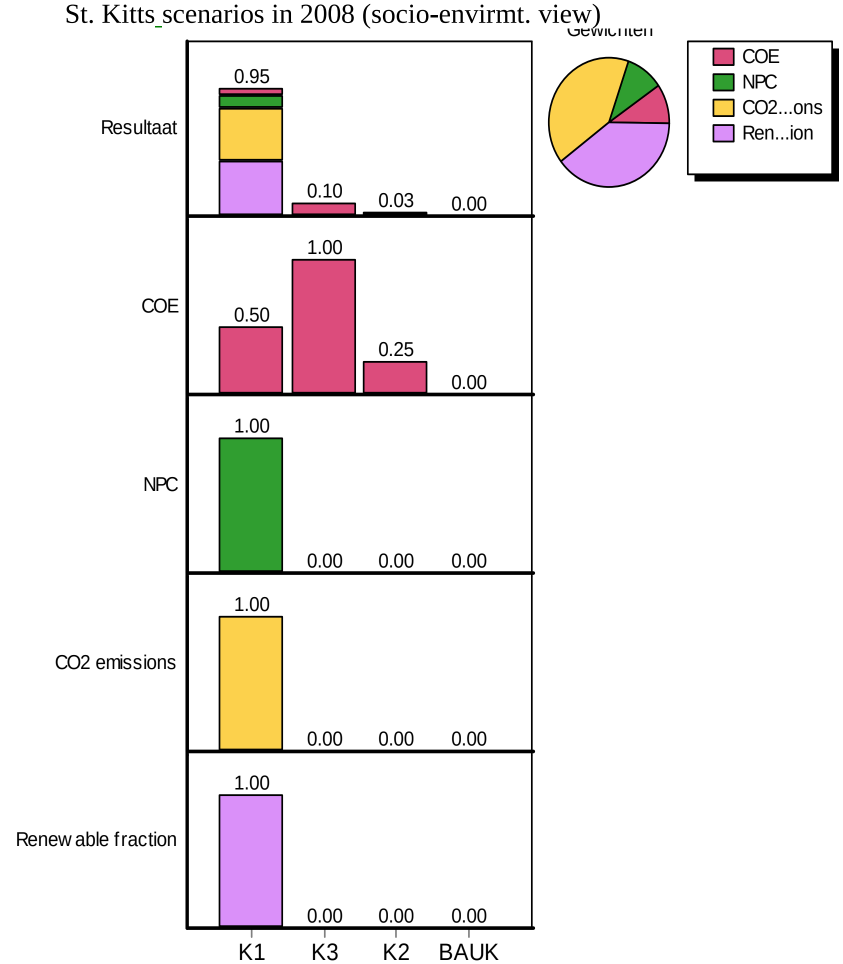


Figure 7.13 Overview of MCA results related to St. Kitts scenarios in year 2008

When we perform the MCA for the years 2008, 2012 and 2015 we can get a better view of the best performing scenario in the situation of St. Kitts based on the perspective.

In figures 7.13 till 7.15 one can see that scenario K1 scores the best in 2008, 2012 and 2015 from a socio-environmental perspective. In the year 2015 the K3 scenario scores best from the economical perspective. This is because as can be seen in figure 7.5 and 7.6, the COE and the NPC are the lowest and comparable to the BAUK scenario, the difference between the K3 scenario and the BAUK scenario is that in 2015 there is a renewable technology added to the electricity production system that makes this scenario to score better than the BAUK scenario.

In general one can conclude that the K1 scenario is the scenario that scores best on both economical and socio-environmental perspective. And is thus recommended to be a starting point for further scrutinized techno-economic analysis and form the baseline for the development of a possible sustainable energy plan for island of St. Kitts.

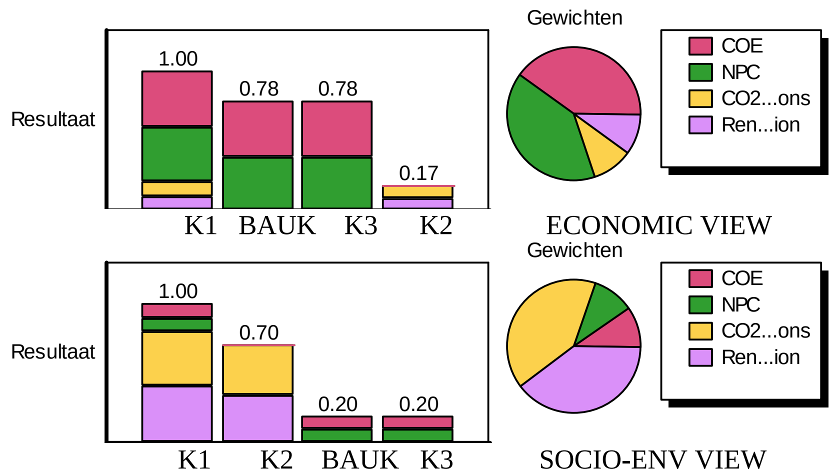


Figure 7.14 MCA results for St. Kitts scenarios in year 2012

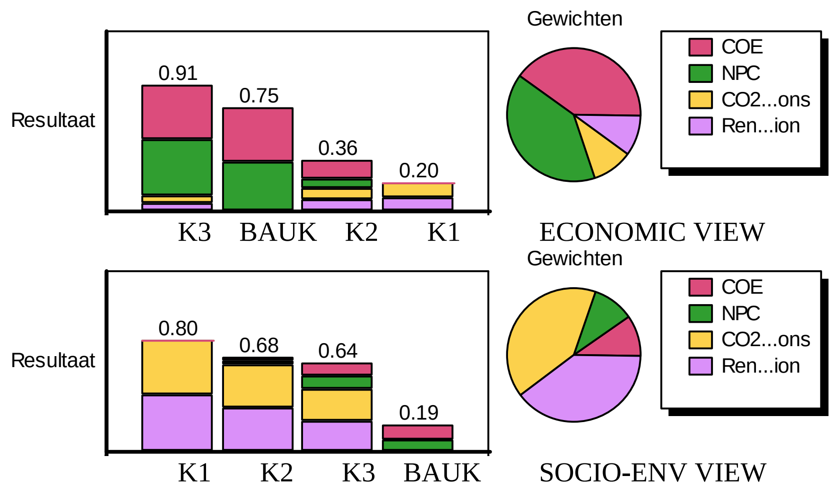


Figure 7.15 MCA results for St. Kitts scenarios in year 2015

Nevis MCA results

The same method used for the MCA for St. Kitts is repeated for the scenarios related to Nevis. See table 7.5 for an overview of the evaluation parameters used for the multi criteria analysis for Nevis.

Table 7.5 Overview of the evaluation parameters related to scenarios for Nevis

		BAUN	N1	N2	N3	Unit
2008	COE	0.112	0.113	0.11	0.112	US$/kWh
	NPC	117.9	118.8	117.9	117.9	million US$
	CO2 emissions	86.8	78.5	86.8	86.8	kton CO2 / yr
	Renewable fraction	0	12.1	0	0	%
2012	COE	0.111	0.07	0.068	0.111	US$/kWh
	NPC	148	93	90.8	148	million US$
	CO2 emissions	110.2	42.3	49.7	110.2	kton CO2 / yr
	Renewable fraction	0	63.9	56	0	%
2015	COE	0.112	0.077	0.074	0.076	US$/kWh
	NPC	178.6	122.1	117.4	120.8	million US$
	CO2 emissions	131.9	64.3	62	71.2	kton CO2 / yr
	Renewable fraction	0	52.4	53	47	%

In figures 7.16 to 7.18 one can see the MCA results for the scenarios related to Nevis for the years 2008, 2012 and 2015.

In figure 7.16 one can see clearly that the view point chosen has an influence on the optimal scenario. The N2 scenario scores best from the economical view point, because it has the lowest cost of electricity production, while the N1 scenario scores best from the socio-environmental view point, because it has a high renewable contribution and CO2 emission reduction potential.

From the results seen in figures 7.16 to 7.18 one can say that scenario N2 scores best from the economical point of view for all years. While the N1, with exception of year 2015, scores best from the socio-environmental perspective.

It is recommended to have a more detailed research in both scenarios to have a better view of the real socio-environmental impacts and economical benefits in order to make the issue of evaluation view point discussable. As said before, this type of analysis tends to be subjective. As example, if a policy maker puts priority to economic benefit above the environmental impacts, than scenario N2, is the optimal scenario. At this stage, nothing can be said about the possible job opportunities that can be created, the real health benefits or other aspects that are not included in this study, this all may cause scenario N1 to be undiputably the optimal scenario. Thus one has to be aware of the subjectivity inherent to these results. Nevertheless they form a good basis for further discussion towards the development of a possible sustainable energy plan for island of Nevis.

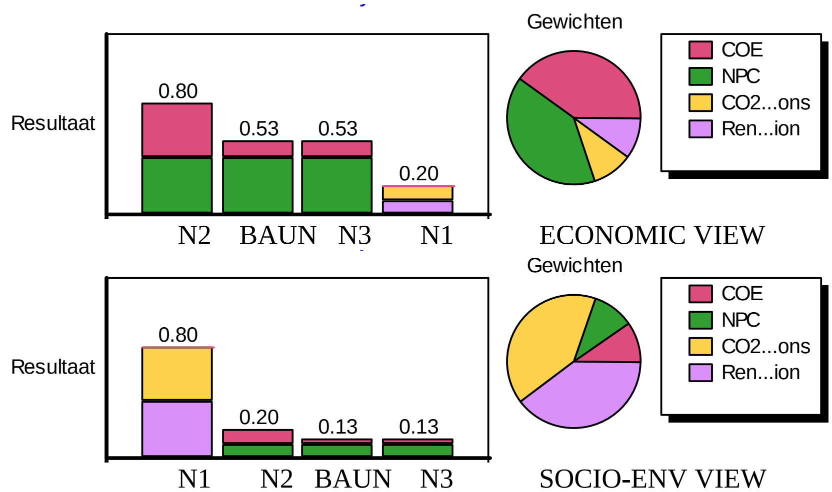


Figure 7.16 MCA results for Nevis scenarios in year 2008

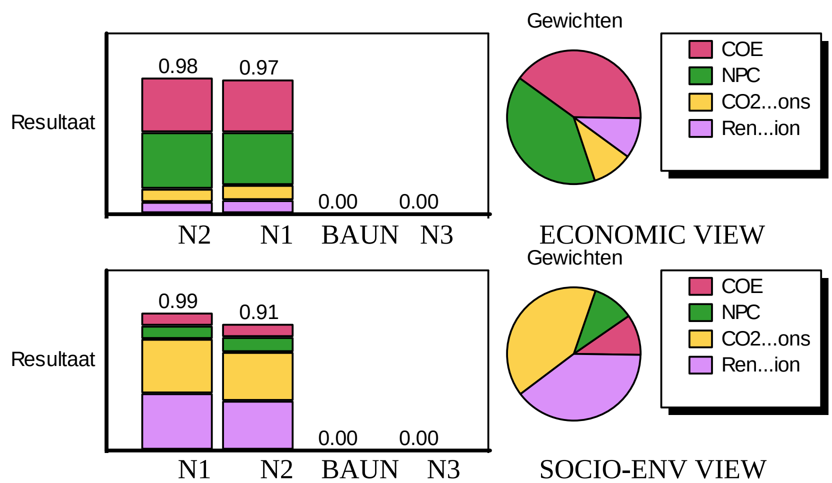


Figure 7.17 MCA results for Nevis scenarios in year 2012

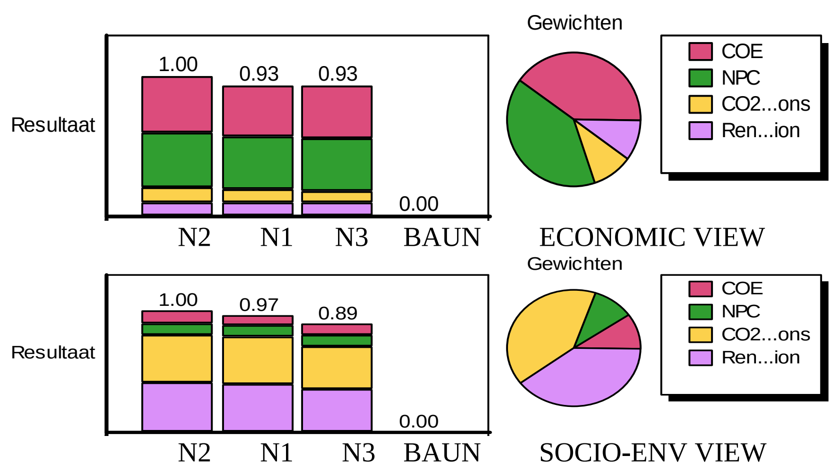


Figure 7.18 MCA results for Nevis scenarios in year 2015

8. Sensitivity Analysis

There are several parameters used in the analysis of the scenarios related to St. Kitts and Nevis that are uncertain or have an error margin. Therefore we perform a sensitivity analysis to investigate the influence of a variation of these parameters on the change in the main indicator, the levelized cost of electricity.

For the sensitivity analysis the following parameters are analyzed:
- interest rate
- fuel costs
- diesel investment costs (Nevis scenarios)
- RET turn key investment costs
- converter capacity investment costs
- biomass feedstock price

The interest rate is set at 10% for all the scenarios, and since this is used as an assumption we will have to to know what the COE sensitiveness is to this parameter. The fuel costs are chosen because of the expected repercussions of the recent developments related to the creation of Petrocaribe, where the fuel prices may change considerably and it is interesting to know what the impact of these changes is on the COE (see for more info section 6.4.3). In the case of the scenario for Nevis, a sensitivity analysis is performed on the influence of the NPV for the installed diesel units at NEVLEC, since the data used for the analysis is from St. Kitts Electricity Department. The uncertainty range in the RET turnkey investment used in the economical analysis needs to be analyzed to know the effect on the final COE of each scenario. The converter investment costs is estimated and used in all scenarios and therefore it is important to know if this has a large influence on the COE in order to evaluate if it is necessary to do extra research on this. The biomass feedstock price is also estimated on 10 US$/ton, this is because no data is provided on this and by giving an uncertainty range to this value we can indicate that the COE should be within this range.

The difficulty is that because we have four moments of measurement, years 2005, 2008, 2012 and 2015 in each scenario, we need to make sure that all the parameters are changed in the same relative order. A choice is made to consider only the hybrid systems in the time frame with the highest renewable fraction of the scenarios that scored best in the multi criteria anlysis, for the sensitivity analysis. These are thus scenario K1, N1 or N2. This is because these scenarios have the greatest potentials of decreasing the cost of electricity production, while increasing the renewable fraction to the total electricity production.

Scenario K1 (2008)
First we will look at the biomass feedstock price, the interest rate, converter investment costs and the fuel costs for scenario K1. The biomass feedstock price is set at 10 US$/ton and when we deviate 25% and 50% from this value we see that the levelized cost of electricity maximally increases or decreases by 2.9%, thus the COE ranges between 0.089±0.002 US$/kWh.

When we look at the interest rate, we know that in general the interest rate ranges between 8-12%. When we apply this range, the COE results will range between 0.089±0.002 US$/kWh. In the case of the converter investment costs, we have set turnkey investment on 649 US$/kW during the analysis. When we deviate 25% and 50% from this value the COE will range between 0.089±0.0005 US$/kWh.

For the fuel cost we considered the information given in figure 6.20, where the possible fuel price is given for different scenarios, including possible price development due to the new energy supply agreement “PetroCaribe” for the Caribbean, that St. Kitts and Nevis has signed with Venezuela. The fuel price can range between 0.28-0.41 US$/L. The lowest fuel price of 0.28 US$/L represents the possible future Petrocaribe price, the high fuel price of 0.41 US$/L is the case of the high diesel fuel price development as projected by the US energy information administration (EIA) and will cause a change in the COE of 0.089±0.014 US$/kWh. This means that the fuel price has a very large influence on the COE. Thus we will have to analyze the best hybrid system when we take in account that the price of fuel oil #2 may decrease from 0.35 US$/L (reference price in 2008) to a PetroCaribe price of 0.27 US$/L (in 2008). See figure 8.1 for a graphic view of the sensivity results.

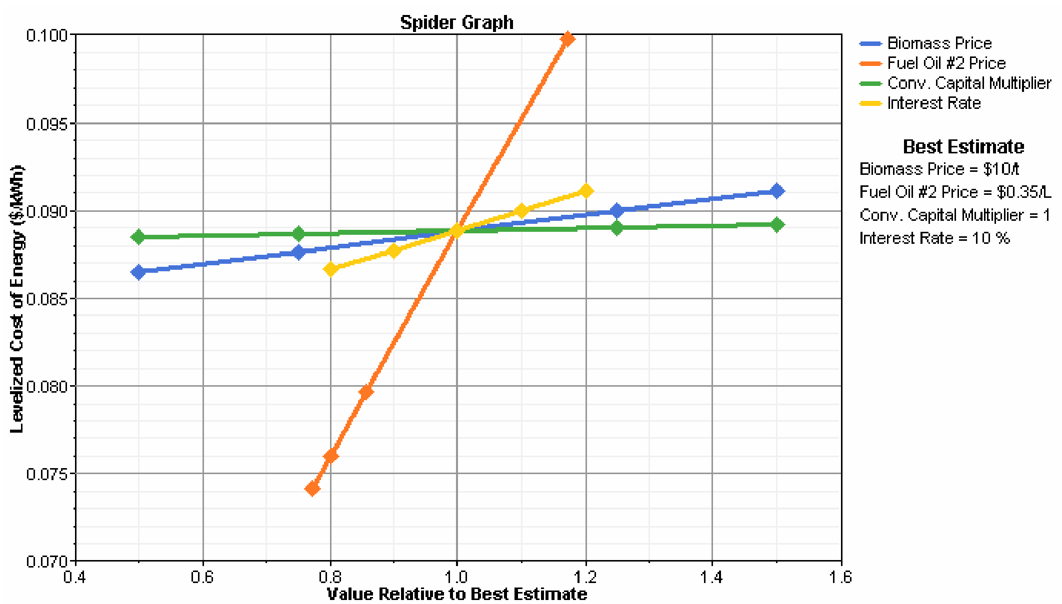


Figure 8.1 Sensitivity of COE for variations in biomass price, fuel oil price, conversion investment costs, and interest rate for the K1 scenario

From figure 8.1 one can see that it is the fuel price that has the highest influence on the levelized cost of electricity production. This is explained by a small relative change in the fuel price (depicted on the x-axis) creating a large range of results in the COE (see y-axis).

Since the COE is most sensitive to the fuel price development, and an extended research is done to identify the possible diesel fuel price development (see section 6.4.3.), a general conclusion can be made that the COE ranges maximal between 0.089±0.014 US$/kWh.

Scenario N1

For scenario N1 it is most important to know if the change in NPV of the installed diesel capacity has high influence on the COE. Also the fuel price development is analyzed. We randomly choose to analyze scenario N1 in the year 2012.

As in scenario K1, the fuel price change has a considerable effect on the COE, 0.064±0.01 US$/kWh with a small deviation in fuel price of 0.41±0.19 US$/L. The NPV of the installed capacity is deviated by 25%, 50% and 75%. This has caused the COE to change by 0.064±0.002 US$/kWh. The NPV is set on 412 US$/kW for the installed diesel capacity, when we deviate 75% from this value, it means that the NPV can range between 103-721 US$/kW and only causing a change of about 3% in the COE. Thus it can be said that the maximal change in the COE depends on the fuel price, thus 0.41±0.19 US$/L for scenario N1 in year 2012.

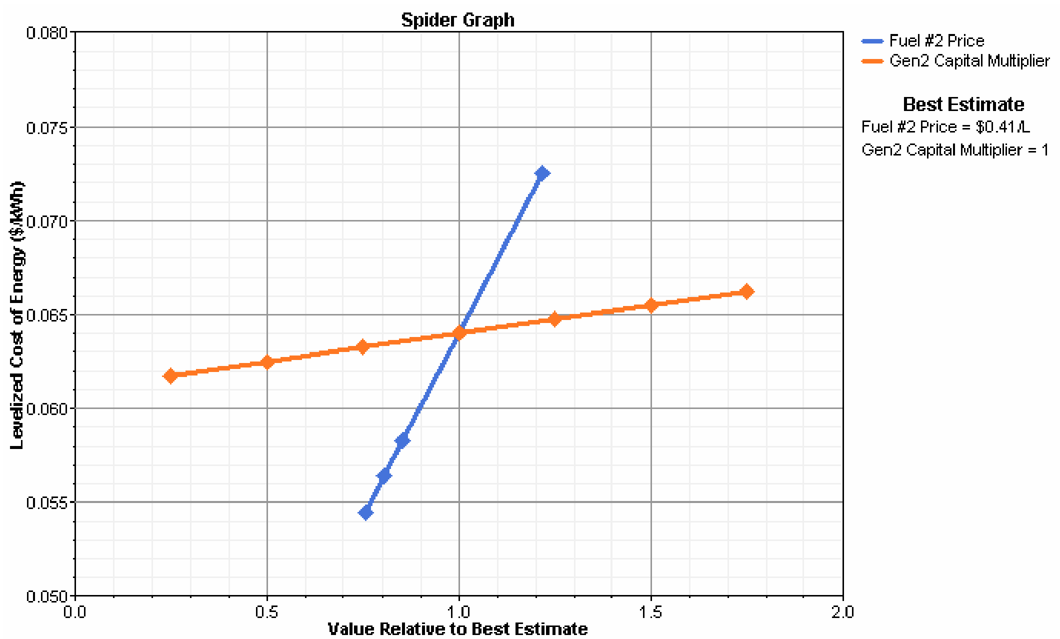


Figure 8.2 Sensitivity of COE for variations in fuel oil price and NPV of installed diesel capacity for the N1 scenario

For the K1 scenario, as for N1 scenario, the fuel price has a large impact on the COE. Thus we will have to run the analysis with variating fuel prices and see what the maximal range in COE will be over the period 2005 to 2015. See figures 8.3 and 8.4 for the results for the scenarios K1 and N1.

As a general conclusion one can say that the maximal range of the COE for scenario K1 over the period 2005 to 2015 is 0.069-0.103 US$/kWh. And for scenario N1 it is between 0.060-0.128 US$/kWh. Note that in the case of year 2012 in the N1 scenario the COE deviation range is much smaller than other years. This is caused by the large renewable capacity (10 MW geothermal energy) that is installed and in operation, that causes for less need of diesel units, thus less fuel imports. After this due to the continuous increase of demand, new diesel units will have to be installed and the electricity production system will become more dependant on fuel price again.

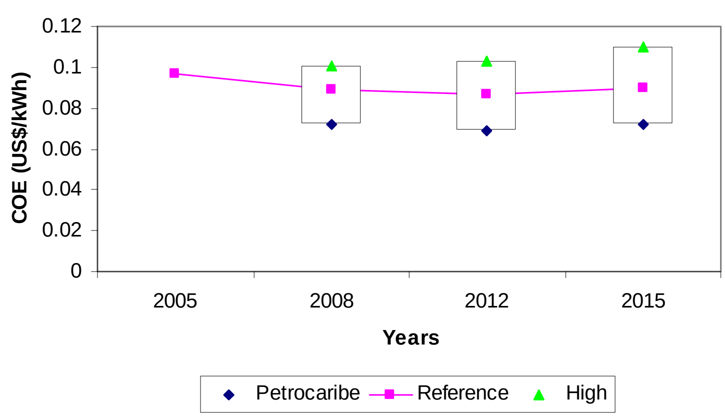


Figure 8.3 Maximum cost of electricity production deviation for scenario K1 over the period 2005-2015

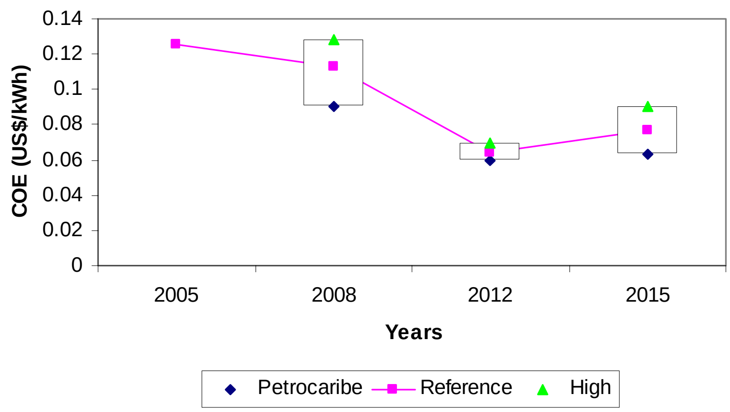


Figure 8.4 Maximum cost of electricity production deviation for scenario N1 over the period 2005-2015

Discussion of results

From the sensitivity analysis we can conclude that the fuel price has the greatest impact on the cost of electricity production. The interest rate has less influence on the COE but should eventhough be scrutinized by looking at literature of multinational banks or financing agencies as GEF or World Bank when designing optimal systems. The change in COE by the change in converter investment costs is limited, we therefore will accept the current value, and as long as this value is applied uniformly to all the scenarios, the outcomes of the analysis can be considered acceptable. For the biomass feedstock price, although the change in value does not have much influence on the COE, still there is a large uncertainty in the value used of 10 US$/ton. To be able to come to real biomass feedstock prices, an extended research on the land, cultivation, collection, treatment and transportation costs should be done, or more literature research will have to done to find feedstock prices for similar conditions as on St. Kitts.

And as general conclusion, the maximal range of COE over the period 2005-2015 for the best case scenarios (K1 and N1/N2) for the federation of St. Kitts and Nevis is between 0.060-0.128 US$/kWh.

9. Discussion

In this chapter we will discuss all the bottlenecks and unexpected events that came along during this study. There are many assumptions made, and many data required and requested for the natural resource assessment and the energy and economic analysis are not provided or not available. In this chapter we will highlight the most important issues that may have had an influence on the final results of this study.

Energy/Economical analysis

- First of all, the scenarios are set up in a static way, in reality the introduction of the RETs does occur gradually and not on an ad-hoc basis as described in the scenarios. The reason for setting up the scenarios in this way, is to limit the amount of scenario analysis runs and prevent extra input consideration for the use of the HOMER model.
- The HOMER model has the limitation that it cannot make future load curve projections for continuous analysis. It can only analyze the NPC over a project lifetime from one starting point (where all the input data should be related to this starting point). This is the reason why four time moments are considered in all the scenarios, thus year 2005, 2008, 2012 and 2015. This meant that all the input data to run the model needed to be modified to be able to come to results for the period 2005 to 2015.
- Although the economical inputs have a large uncertainty range, at least with the sensitivity analysis we can indicate the parameter with the highest influence on the COE. By considering an acceptable range for this parameter we can estimate the COE range that should indicate a realistic situation.
- Due to limited information on the current electricity production costs, the HOMER model could not be calibrated. Thus no information was available on the break down of the electricity price (as taxes, payback of loans/investments, labour, profit margin, etc) at St. Kitts Electricity Department and Nevis Electricity Company. Nevertheless, the COE values that are calculated in the BAUK and BAUN scenarios (0.091 and 0.112 US$/kWh in 2005) are used in the analysis. Compared to the present sold electricity price in St. Kitts and Nevis of 0.169 and 0.19 US$/kWh, this would mean that for St. Kitts and for Nevis there is a margin of 0.078 US$/kWh, that generally includes fuel surcharge and the profit margin of the utilities.
- For most grid-connected systems, the concept of operating reserve has virtually no effect on the operation of the system because the grid capacity is typically more than enough to cover the required operating reserve. But because there is no information requested about the grid and there is no clear view on the future investments/plans in the grid on St. Kitts and Nevis, the choice was made to exclude the grid in this analysis. This may mean that the results, as the net present cost, in this study are higher than in the case the grid is included (because of higher diesel capacity need, thus higher investments, O&M and fuel costs compared to investments in new grid).

Bio-energy

- We assume that the available land was 7,000 acres during this time frame, which results in an average sugar cane yield of 29.3 ton/acre in 306 days per year, thus with an average sugarcane production of 205,333 ton/year. The amount of available land may be currently decreased considerable since there are new urban developments and other competing land use options in streamline.
- The biomass feedstock price (sugarcane production costs) is chosen to be within the range of 10-20 US$/ton dry matter on long term, thus 2008-2015. To be able to calculate the costs related to the production, handling and transportation of the sugarcane more detailed information is required.

- The biomass technology has a limitation that two months in the year it has no biomass feedstock to produce energy. This makes it necessary to set-up storage capacity for biomass feedstock which then can be used strategically, or to have extra diesel capacity for these two months. If there is an alternative bio-fuel for these two months, then a considerable diesel capacity can be avoided, thus less fuel usage, lower COE and CO_2 emissions.

Wind

- We have to keep in mind that the wind speeds used in the calculations for this study are only indicative, since the measurements were only done at the airports of both islands. For better wind assessment wind maps of the area on and around the islands is needed.
- As each turbine has its own power curve with different cut in/out speeds and different turbine sizes it forms a challenge to find the correct turbine for a certain spot, i.e., wind regime. One has to be aware that the wind turbine used in the analysis is only chosen to illustrate possible wind energy production and is not per definition the best applicable turbine type for the St. Kitts and Nevis conditions. There are low speed (longer blades) and high speed (shorter blades) wind turbines available with different capacities ranging between 300-2500 kW. The reason that the following calculations are just indicative is that no extensive wind resource assessment is performed and no objective comparative analysis is done between all the available wind turbines on the global market[174]. Since the objective of this study is to assess the theoretical potential of all RETs, this detailed research falls out of the scope of this study.
- The initial wind energy potential was simulated in the Wind Power Calculator of the Wind Turbine Industry Association, later in the study the analysis was performed in the HOMER model. There may be differences between the two models, first of all HOMER can integrate the electricity potential of the wind turbines into the electricity production mix for each island. Thus integrating wind energy potential next to bio-energy, solar and other RETs and find out what is the best combination for the islands of St. Kitts and Nevis. And as input data it requires the Weibull factor, the autocorrelation factor, diurnal pattern and the hour of peak wind speed[175]. This while the Wind Power Calculator requires less input data, being the Weibull factor and the roughness index.

Diesel

- Since the HOMER model only analyzes from one static starting point, the NPV of the turnkey investments of the installed and new diesel units need to be modified to the years included in the scenarios, thus 2005, 2008, 2012 and 2015. The diesel investment costs are estimated by the representatives of St. Kitts Electricity Department. Since NEVLEC did not provide financial data related to the installed diesel units, the choice was made to use the initial NPV of the diesel units at St. Kitts modified to unit sizes installed at NEVLEC. This entails a high uncertainty, thus the results related to Nevis should be treated with care. Nevertheless for this study the results are still valid since the focus is on the relative differences between the scenarios.. And the motivation is to show that introducing renewable energy has positive impact on the costs of electricity production as well as socio-environmental issues.

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[174] See: EWEA, Wind energy, the facts, volume 1, Technology, 2004, page 19, source: http://www.ewea.org/06projects_events/proj_WEfacts.htm for an updated overview of wind turbines.

[175] The diurnal pattern strength and the hour of peak wind speed indicate the magnitude and the phase, respectively, of the average daily pattern in the wind speed. HOMER provided default values for each of these parameters.

Geothermal

- In the natural resource assessment, the theoretical geothermal energy production is not described in such detail as the other renewable options. This is because the 10 MW energy production potential is based on pre-feasibility studies performed by the OAS. In the case of geothermal energy potential estimation it is only in the latest stages of the project that one can calculate the real energy production potential. But since the geo-caraibes project is in streamline and results are soon to be expected the choice was made to include this energy production technology in the scenarios for Nevis.

Multi criteria analysis

- The multi criteria analysis tends to be subjective. In order to increase the objectivity of the results, an extended questionnaire is necessary to collect information and opinions of all the relevant stakeholders. In this manner the weighing factors can be created for each performance indicator to more reliably select the best scenario.

10. Conclusions and Recommendations

In this chapter an overview is given of conclusions that could be drawn from the several sections of this report. Also recommendations are made for further study in the HOMER model design that has the potential to greatly contribute to this field of energy analysis and to aid small island developing states in the evaluation and introduction of renewable energy technologies.

Conclusions

- As a general conclusion, the electricity requirement will increase from 230.4 GWh to 499.3 GWh in the period 2005-2015. And the scenarios that scored best on the four performance indiactors, COE (US$/kWh), NPC (US$), CO_2 emissions (kton CO_2 / yr) and the renewable fraction (%), were the scenarios having a high contribution and fast introduction of renewable energy, thus scenario K1 for St. Kitts and scenarios N1 and N2 for Nevis.
- For St. Kitts (K1 scenario), the HOMER model found the optimal system architecture for period 2008-2015 to be 4 x 800kW Nordex wind turbines, 2.9 MW Bio energy, an inverter/rectifier capacity of 3.5 MW and an increasing diesel capacity over the years from 50.6 to 63.4 MW in period 2005-2015. This causes a decrease in the COE from 0.097 US$/kWh to 0.090 US$/kWh in the period 2005-2015. The COE decreases by 8.2% per annum (2005-2008), 2.2% per annum (2008-2012) and 2.3% per annum (2012-2015). This means less diesel is required compared to the business as usual scenario, and thus less fuel usage, a lower COE and lower CO_2 emissions.
- For the bio-energy option for St. Kitts has higher energy production potential when other bio-energy conversion routes and technologies are considered, the choice was made to analyze the bio-energy production potential via anaerobic digestion, which has lower overall energetic efficiency than other available technologies. Thus it makes sense to perform a detailed techno-economic analysis of the bio-energy.
- For Nevis the best option was N1 (from socio-environmental perspective) and N2 (from economical perspective). In the case of N1 scenario the optimal system architecture was based on a varying diesel capacity, 6 x 800 kW Nordex wind turbines and 10 MW geothermal energy. The renewable fraction increases drastically in 2012 because the geothermal energy technology will start operating. In period 2012 to 2015 this geothermal influence will decrease steadily since the load demand will continue to grow and more diesel capacity is required, with higher operational costs that causes the COE to increase. This development makes the COE drop from 0.124 to 0.077 US$/kWh over the period 2005-2015. The COE decreases by 3% per annum (2005-2008), 9.5% per annum (2008-2012) and steadily increases by 3.3% per annum (2012-2015).
- For scenario N2 (best case scenario from economical perspective), the optimal system architecture consists of 6 x 800 kW Nordex wind turbines and 10 MW geothermal energy. The difference with scenario N1 is that the wind turbines are installed in a later stage (2012-2015). This causes the COE to drop from 0.124 to 0.074 US$/kWh over the period 2005 to 2015. The COE decreases by 3.8% per annum (2005-2008), 9.5% per annum (2008-2012) and steadily increases by 2.9% per annum (2012-2015).
- It makes sense, in case the assumption of 10 MW geothermal potential is correct, to invest and introduce the geothermal energy technology as fast as possible, because although the assumptions and results of the HOMER model may be disputable, the potential for reduction of the COE is considerable.

Recommendations

- As said in the conclusions, the biomass energy production capacity does not have to be limited to the 2.9 MW as used in the scenarios, when the biomass feedstock cultivation, collection/handling and transportation is optimized. When considering other (higher energetic value) biomass conversion routes the bio-energy production potential may increase. One can also look at options as import of biomass or incorporating MSW (Municipal Solid Waste) or RDF (Refused Derived Fuel) as fuel to increase the total capacity. One could argue that because of the urgency to find a solution for the closing down of the sugar manufacturing company, and because the landfills on both islands are near or passed their treatment and filling capacity, it would be interesting to look at the burning of biomass by using the bagasse in combination with organic waste from MSW, next to other options as ethanol production or direct fuel cane incineration. The reason for this is that both islands St. Kitts and Nevis are dealing with large problems with the waste management, the landfills are reaching their maximum capacity and there is not much land available to again lay down new landfill cells. So in the nearby future one will have to come with other alternatives next to landfilling. Thus as one option the government can focus on the use of organic waste next to sugar bagasse to incinerate in for instance a fluidized bed reactor, which has the capacity to burn mixed fuels. See table 10.1. for an overview of the mass quantity of the different components of the MSW.

Table 10.1 Waste quantity information by waste type on St. Kitts

Conaree Sanitary Landfill (St. Kitts Waste Management Corporation)				
	Data: 1/1/2004-12/31/2004		Data:1/1/2005-6/30/2005	
	Weight (tons)	Weight (%)	Weight (tons)	Weight (%)
Batteries	20.0	0.08	0.6	0.00
Commercial	4074.3	15.84	2202.5	15.39
Construction / demolition	2585.1	10.05	1028.8	7.19
Derelict vehicles	34.9	0.14	13.9	0.10
E-waste	23.8	0.09	4.4	0.03
Green waste	**1455.0**	**5.66**	**581.3**	**4.06**
Household	**10390.0**	**40.39**	**5029.1**	**35.14**
Hazardous waste	21.0	0.08	8.4	0.06
Industrial	888.0	3.45	572.2	4.00
Land clearing	3514.1	13.66	3165.2	22.12
Rental of metal bins	263.8	1.03	1.6	0.01
Institutional	149.8	0.58	262.4	1.83
Used oil	136.1	0.53	111.4	0.78
Purchase plastic bins	3.0	0.01	1.8	0.01
Steel cable	2.1	0.01	0.4	0.00
Septic tank waste	1875.7	7.29	1176.1	8.22
scrap metals	10.0	0.04	14.1	0.10
disposal of special waste	5.1	0.02	23.7	0.17
ship generated waste	6.2	0.02	9.0	0.06
tires 16inch or smaller	212.2	0.82	91.0	0.64
tires 16inch with rims	7.6	0.03	3.2	0.02
tires GT16inch	18.2	0.07	5.8	0.04
Tires GT16inch with rim	2.0	0.01	2.3	0.02
white goods	26.0	0.10	3.1	0.02
	25723.9	**100**	**14312.1**	**100**

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Appendices

Appendix 1. HOMER

What is HOMER?[176]

HOMER, the micropower optimization model, simplifies the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications. When you design a power system, you must make many decisions about the configuration of the system: What components does it make sense to include in the system design? How many and what size of each component should you use? The large number of technology options and the variation in technology costs and availability of energy resources make these decisions difficult. HOMER's optimization and sensitivity analysis algorithms make it easier to evaluate the many possible system configurations.

How do I use HOMER?

To use HOMER, you provide the model with inputs, which describe technology options, component costs, and resource availability. HOMER uses these inputs to simulate different system configurations, or combinations of components, and generates results that you can view as a list of feasible configurations sorted by net present cost. HOMER also displays simulation results in a wide variety of tables and graphs that help you compare configurations and evaluate them on their economic and technical merits. You can export the tables and graphs for use in reports and presentations.

When you want to explore the effect that changes in factors such as resource availability and economic conditions might have on the cost-effectiveness of different system configurations, you can use the model to perform sensitivity analyses. To perform a sensitivity analysis, you provide HOMER with sensitivity values that describe a range of resource availability and component costs. HOMER simulates each system configuration over the range of values. You can use the results of a sensitivity analysis to identify the factors that have the greatest impact on the design and operation of a power system. You can also use HOMER sensitivity analysis results to answer general questions about technology options to inform planning and policy decisions.

How does HOMER work?

Simulation

HOMER simulates the operation of a system by making energy balance calculations for each of the 8,760 hours in a year. For each hour, HOMER compares the electric and thermal demand in the hour to the energy that the system can supply in that hour, and calculates the flows of energy to and from each component of the system. For systems that include batteries or fuel-powered generators, HOMER also decides for each hour how to operate the generators and whether to charge or discharge the batteries.

HOMER performs these energy balance calculations for each system configuration that you want to consider. It then determines whether a configuration is feasible, i.e., whether it can meet the electric demand under the conditions that you specify, and estimates the cost of installing and operating the system over the lifetime of the project. The system cost calculations account for costs such as capital, replacement, operation and maintenance, fuel, and interest.

[176] This appendix is taken from the HOMER help file.

Optimization
After simulating all of the possible system configurations, HOMER displays a list of configurations, sorted by net present cost (sometimes called lifecycle cost), that you can use to compare system design options.

Sensitivity Analysis
When you define sensitivity variables as inputs, HOMER repeats the optimization process for each sensitivity variable that you specify. For example, if you define wind speed as a sensitivity variable, HOMER will simulate system configurations for the range of wind speeds that you specify.

HOMER on the Internet
The HOMER website, www.nrel.gov/homer, contains the latest information on the model, as well as sample files, resource data, and contact information.

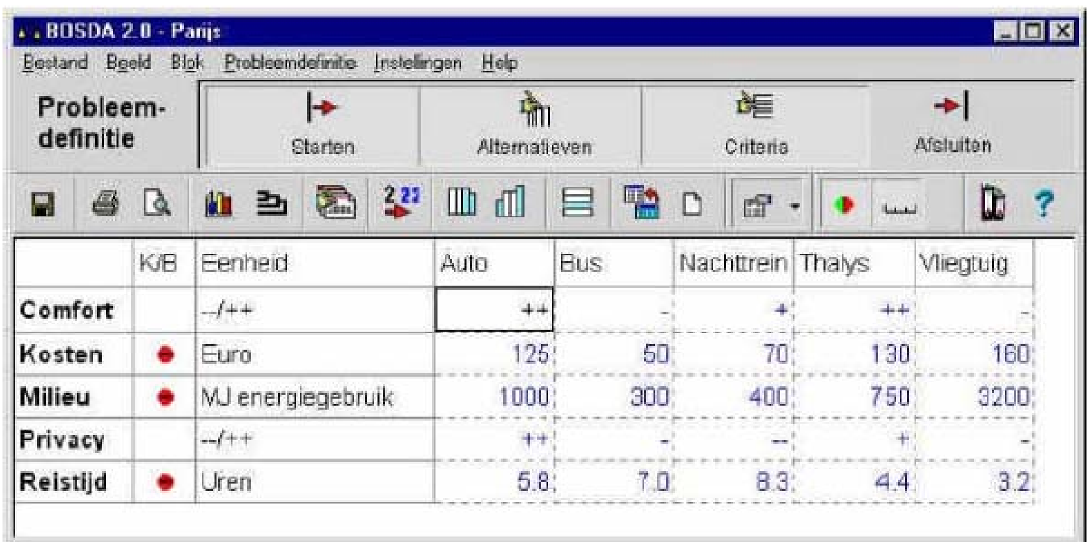
Written by: Paul Gilman (paul_gilman@nrel.gov)
Last modified: May 6, 2004.

Appendix 2. Multi Criteria Analysis (BOSDA model)

"Beslissings Ondersteunend Systeem voor Discrete Alternatieven" (BOSDA) is a software tool that is developed to create, compare and evaluate alternatives to support policy decisions. BOSDA contains several Multi Criteria methods along with graphic presentations, validation methods and a broad scale of sensitivity analysis. BOSDA is a joint product of the Institute for Environment of the "Vrije Universiteit Amsterdam" and the department of Policy evaluation and instrumentation of the Dutch Ministry of Finance.

The Multi Criteria Analysis (MCA) is a method that gives the opportunity to evaluate alternative technologies based on risks and impact parameters. In other words environmental or social impacts are compared on spatial (local to global level) and temporal scale (hours to decades). The selection of the best RET depends on the perspective used, there can be an economical or an environmental perspective.

Before one starts with the MCA a problem definition has to be described. The objective of this step is to create an impact table, where criteria are defined and all the required data for each criterion is collected. Once this is done the MCA can be applied.



	K/B	Eenheid	Auto	Bus	Nachttrein	Thalys	Vliegtuig
Comfort		--/++	++	-	+	++	-
Kosten	●	Euro	125	50	70	130	160
Milieu	●	MJ energiegebruik	1000	300	400	750	3200
Privacy		--/++	++	-	--	+	-
Reistijd	●	Uren	5.8	7.0	8.3	4.4	3.2

Figure A2-1. Example of impact table (Paris trip case)[177]

On figure A2-1 an example of an impact table is showed. Here you can see that the criteria are comfort, costs, environment, privacy and travel time. Each criterion has its own unit and basic data is collected based on these units.

The general MCA approach in the model is based on the following 3 steps.

- Standardization
- Weighing
- Order

[177] Jansen and Herwijnen, BOSDA voor Windows, Beleidsanalyse, 2000

Standardization

Since in general we try to compare parameters with each a different unit, here the objective is to equalize the units and make the comparison of the scores for the various criteria possible. Hereby the scores lose their dimension and thus their unit. There is a broad choice of standardization methods within BOSDA, see the following list:

- Maximum Standardization
- Interval Standardization
- Goal-Standardization
- Convexe Standardization
- Concave Standardization
- S-Curve Standardization
- Free style Standardization

The objective is to create a standardized impact table where the values can be compared.

Weighing

This procedure helps you to attach quantitative or qualitative weights to criteria. Before BOSDA can perform a MCA it is required that the criteria are given a weighing factor. To decide upon these weighing factors is in general not an easy task. It is a difficult task to give objective quantitative weighing factors.

There are several ways to attach weighing factors. The BOSDA model has next to the option of direct quantitative or qualitative weighing, four methods available for attaching weighing factors to the criteria based on the collected qualitative information. The methods are:

- Pairwise comparison
- Expectation value method
- Random weighing
- Extreme weighing

Arrangement

This procedure shows the results of the performed MCA. In general a stock diagram is used to show the results graphically. On the x-axis all the alternative choices are shown and on the y-axis the value of the arrangement. The height of the stock indicates the priority or best alternative.

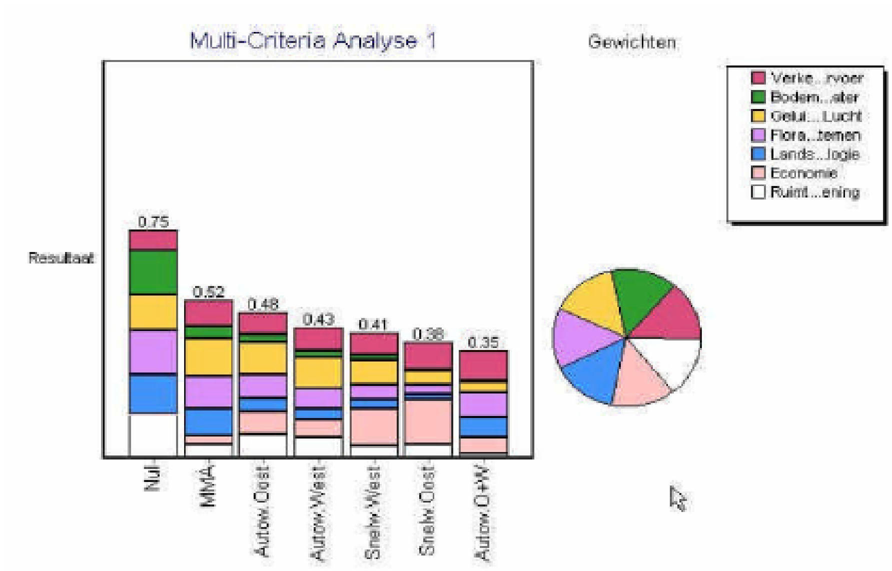


Figure A2-2. Example of MCA results (Rijksweg 73 case)[178]

In figure A2-2 you can see that the first alternative "NuI- route" (x-axis) scores best on a combination of factors as traffic flow, limit of impact on soil, noise, flora, land use, economical impact, etc. A discussion point when performing a MCA is always the weight factors brought to each criterion that makes the comparison of technologies possible. To limit its subjectivity it has to be tried to involve all the relevant stakeholders to make a preliminary assessment of the criteria and weighing factors, an alternative is to choose opposite perspective, fos instance an economical on one side, and a socio-environmental perspective on the other side.

General key weighing points are:

- Cost-effectiveness
- Environmental friendliness
- Social acceptability

Possible topics for evaluation of feasibility of the RET´s on socio-environmental level are:

- competing land uses (agriculture and tourism)
- energy production and environmental preservation (hydro power projects)
- siting of RET projects and cultural/environmental important sites (archaeological sites)
- public opinion or acceptance

[178] Jansen and Herwijnen, BOSDA voor Windows, Beleidsanalyse, 2000

Appendix 3. Figures and Tables

Table A3-1 St. Kitts and Nevis Population growth (1991-2001), source: Statistics Division Planning Unit St. Kitts & Nevis (Ministry of Finance, Technology & Sustainable Development), 2005.

ST KITTS & NEVIS	
Year	Population
1991	41.000
1992	42.670
1993	43.520
1994	43.050
1995	43.530
1996	42.280
1997	40.740
1998	40.130
1999	42.460
2000	40.410
2001	46.111

Table A3-2 Gross Domestic Product in US$ per capita on St. Kitts and Nevis for the period 1993-2003, source: Statistics Division Planning Unit St. Kitts & Nevis (Ministry of Finance, Technology & Sustainable Development), 2005.

ST KITTS & NEVIS	
Year	**GDP/capita (US$)**
1993	3837,9
1994	4349,9
1995	4465,4
1996	4869,0
1997	5682,6
1998	6017,8
1999	6056,0
2000	7013,7
2001	6367,9
2002	6360,0
2003	5427,0

Table A3-3 Installed capacity at St. Kitts Electricity Department for the period 1998-2005, source: St. Kitts Electricity Department, 2005.

St. Kitts Electricity Dep.								
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Installed Capacity	20500	33500	33500	33500	33500	33500	33500	33500
Base Capacity	12100	14000	14000	14000	14000	18400	18400	18400
Peak Demand	14900	16700	17300	18100	18500	19000	19100	20000

Table A3-4 Projection of the Annual peak demand for St. Kitts for the period 2005-2015, source: Generation expansion plan 2005-2015, St. Kitts Electricity Department, 2005.

St. Kitts Electricity Department						
Year	**Base (kW)**	**Min (kW)**	**Max (kW)**	**Base (MW)**	**Min (MW)**	**Max (MW)**
2005	22109	21602	22232	22,1	21,6	22,2
2006	25458	23960	25717	25,5	24,0	25,7
2007	27929	25756	28374	27,9	25,8	28,4
2008	29549	27050	33424	29,5	27,1	33,4
2009	31188	28346	35616	31,2	28,3	35,6
2010	32078	29180	37198	32,1	29,2	37,2
2011	32966	30054	38649	33,0	30,1	38,6
2012	33895	30969	40120	33,9	31,0	40,1
2013	34869	31929	41115	34,9	31,9	41,1
2014	35876	32936	42136	35,9	32,9	42,1
2015	36931	33991	43191	36,9	34,0	43,2

Table A3-5. AIP Scenario results

	2001	2010	2020	2030	2040
Total Consumption in TWh (IEA)	15578	19973	25818	30855	36346
Biomass	180	390	1010	2180	4290
Large Hydro	2590	3095	3590	3965	4165
Small Hydro	110	220	570	1230	2200
Wind	54,5	512	3093	6307	8000
PV	2,2	20	276	2570	9113
Solar Thermal	1	5	40	195	790
Geothermal	50	134	318	625	1020
Marine	0,5	1	4	37	230
Total RES	**2988,2**	**4377**	**8901**	**17109**	**29808**
RES Contribution	**19,2%**	**21,9%**	**34,5%**	**55,4%**	**82,0%**

Source: http://www.erec-renewables.org/documents/targets_2040/EREC_Scenario%202040.pdf page 11.

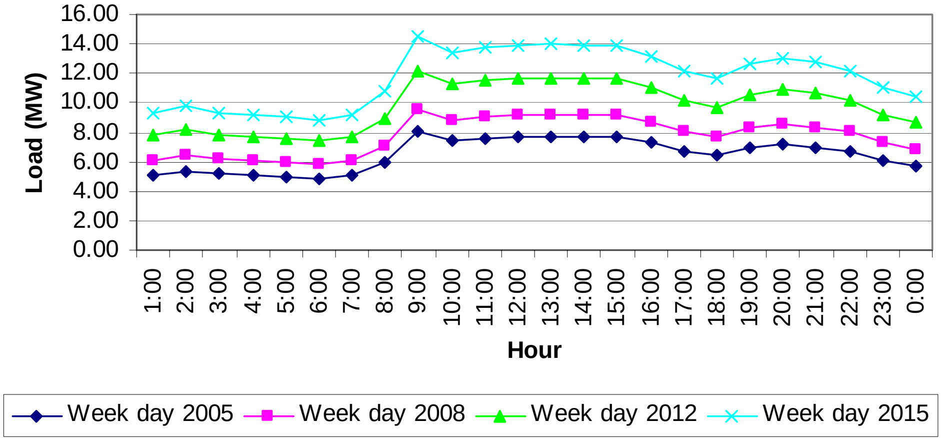


Figure A3-1 Daily load factors for weekdays in 2005, 2008, 2012 and 2015 (NEVLEC)

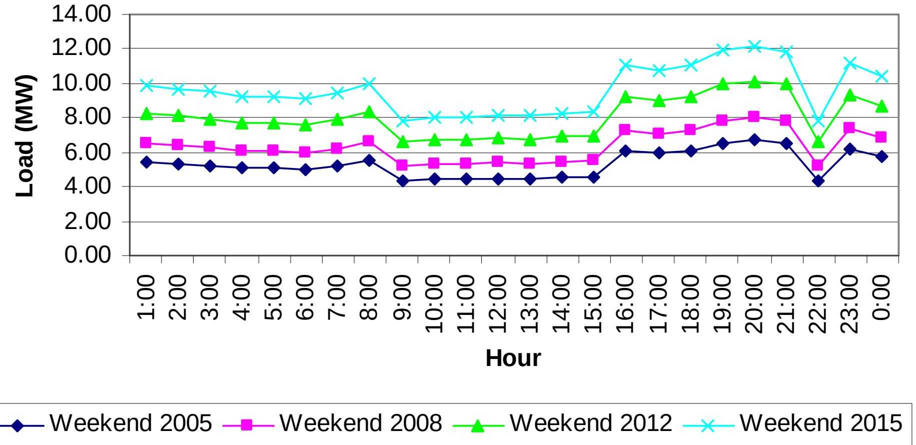


Figure A3-2 Daily load factors for weekends in 2005, 2008, 2012 and 2015 (NEVLEC)

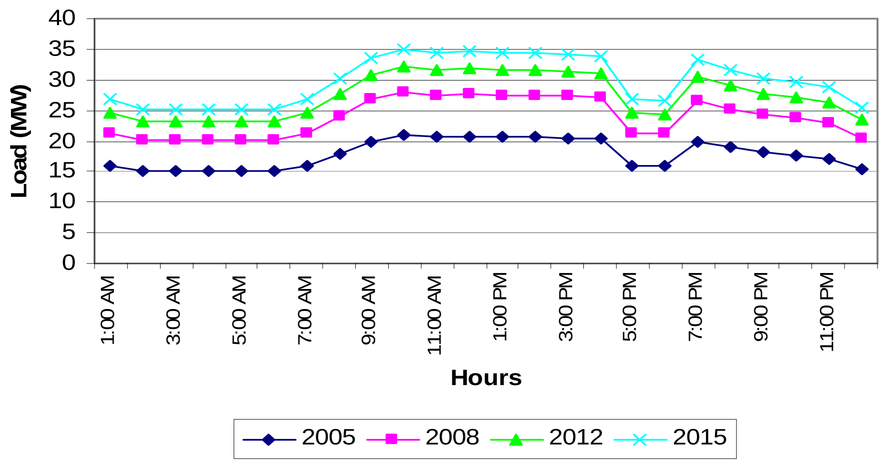


Figure A3-3 Daily load factors for weekdays in 2005, 2008, 2012 and 2015 (St. Kitts)

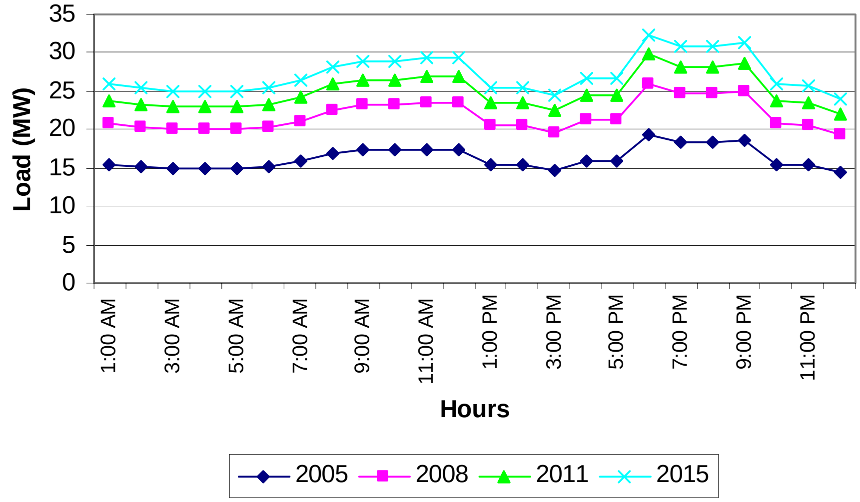


Figure A3-4 Daily load factors for weekends in 2005, 2008, 2012 and 2015 (St. Kitts)

Table A3-6 Overview of energy output per turbines capacity for St. Kitts

St. Kitts (v_{av} = 6.56 m/s (hub height))		
Turbine type	capacity (kW)	energy output (kWh/year)
NEG Micon 600/48	600	1491083
Nordex N43/600	600	1273000
Vestas V39 600/39	600	994819
NEG Micon 900/52	900	1917499
Nordex N50/800	800	1703988
Vestas V52 850/52	850	1954732
NEG Micon 1500/64	1500	3158416
Nordex S70/1500	1500	3812114
Vestas V66 1650/66	1650	3328911

Table A3-7 Overview of energy output per turbines capacity for Nevis

Nevis (v_{av} =7.89 m/s (hub height))		
Turbine type	Capacity (kW)	Energy output (kWh/year)
NEG Micon 600/48	600	2077998
Nordex N43/600	600	1833119
Vestas V39 600/39	600	1507936
NEG Micon 900/52	900	2736625
Nordex N50/800	800	2461316
Vestas V52 850/52	850	2755242
NEG Micon 1500/64	1500	4540223
Nordex S70/1500	1500	5296477
Vestas V66 1650/66	1650	4828421

Table A3-8 Turn key investment of diesel units for St. Kitts & Nevis

	Turn key investment cost (US$/kW)			
	2005	2008	2012	2015
Installed diesel	338	284	233	175
New diesel (0.2 MW)	942	708	484	363
New diesel (2.5 MW)	1069	803	549	412
New diesel (4.0 MW)	1035	778	531	399

Table A3-9 Estimation of NPV of total installed + required diesel capacity of scenario BAUK and K1 at St. Kitts

BAUK	2005	2008	2012	2015
Installed diesel	5	4	3	3
new 2.5	0	1	1	2
new 4	0	7	10	12
Installed diesel	1689	1136	700	526
new 2.5	0	803	549	824
new 4	0	5443	5311	4788
NPV	**338**	**615**	**469**	**361**
New diesel		31.1	12.5	9.9
K1				
Installed diesel	5	4	3	3
new 2.5	0	0	0	1
new 4	0	6	9	11
Installed diesel	1689	1136	700	526
new 2.5	0	0	0	412
new 4	0	4666	4780	4389
NPV	**338**	**580**	**457**	**355**
New diesel	0.0	25.5	11.7	9.9

Table A3-10 Estimation of NPV of total installed + required diesel capacity of scenario K2 and K3 at St. Kitts

K2	2005	2008	2012	2015
Installed diesel	5	4	3	3
new 2.5	0	1	2	3
new 4	0	7	8	10
Installed diesel	1689	1136	700	526
new 0.2	0	0	0	0
new 2.5	0	803	1097	1236
new 4	0	5443	4249	3990
NPV	**338**	**615**	**465**	**360**
New diesel	0.0	31.1	6.1	9.9
K3				
Installed diesel	5	4	3	3
new 2.5	0	1	1	2
new 4	0	7	10	11
Installed diesel	1689	1136	700	526
new 2.5	0	803	549	824
new 4	0	5443	5311	4389
NPV	**338**	**615**	**469**	**359**
New diesel	0.0	31.1	12.5	7.6

Table A3-11 Estimation of NPV of total installed + required diesel capacity of scenario BAUN and N1 at Nevis

BAUN	2005	2008	2012	2015
Installed diesel	6	5	4	3
new 0.2	0	3	10	16
new 2.5	0	1	1	1
new 4	0	1	3	5
Installed diesel	2027	1419	933	526
new 0.2	0	2124	4836	5813
new 2.5	0	803	549	412
new 4	0	778	1593	1995
NPV	**338**	**512**	**439**	**350**
New diesel	0.0	7.2	9.4	9.3
N1				
Installed diesel	6	5	4	3
new 0.2	0	6	8	10
new 2.5	0	1	1	1
new 4	0	0	0	2
Installed diesel	2027	1419	933	526
new 0.2	0	4248	3869	3633
new 2.5	0	803	549	412
new 4	0	0	0	798
NPV	**338**	**539**	**412**	**336**
New diesel	0.0	3.8	0.4	8.5

Table A3-12 Estimation of NPV of total installed + required diesel capacity of scenario N2 and N3 at Nevis

N2				
Installed diesel	6	5	4	3
new 0.2	0	3	5	5
new 2.5	0	1	1	2
new 4	0	1	1	3
Installed diesel	2027	1419	933	526
new 0.2	0	2124	2418	1817
new 2.5	0	803	549	824
new 4	0	778	531	1197
NPV	**338**	**512**	**403**	**336**
New diesel	0.0	7.2	0.4	10.5
N3				
Installed diesel	6	5	4	3
new 0.2	0	3	10	11
new 2.5	0	1	1	1
new 4	0	1	3	3
Installed diesel	2027	1419	933	526
new 0.2	0	2124	4836	3996
new 2.5	0	803	549	412
new 4	0	778	1593	1197
NPV	**338**	**512**	**439**	**341**
New diesel	0.0	7.2	9.4	0.3

Table A3-13 Net present value of the total installed diesel capacity in each period in the four scenarios for Nevis

	2005	2008	2012	2015	Unit
BAUN	338	512	439	350	US$/kW
N1	338	539	412	336	US$/kW
N2	338	512	403	336	US$/kW
N3	338	512	439	341	US$/kW

Table A3-14 General results of BAUK scenario (St. Kitts)

BAUK	2005	2008	2012	2015	Unit
Demand	22.1	29.5	33.9	36.9	MW
Load demand	24.6	32.9	37.8	41.2	MW
Installed Diesel	**26.3**	**53.9**	**62**	**67.5**	MW
Capacity shortage	23%	0%	0%	0%	%
NPV	338	615	469	361	US$/kW
Electricity prod	230.4	399.4	458.1	499.3	GWh
NPC	**190.0**	**308.1**	**339.9**	**370.5**	US$ (Million)
COE	**0.097**	**0.091**	**0.087**	**0.087**	US$/kWh
COE	0.262	0.246	0.235	0.235	EC$/kWh
CO2 emissions	145.2	252.3	289.4	315.5	kton/yr
Fuel usage	50.8	88.2	101.2	110.3	x10^6 L/yr

Table A3-15 General results of K1 scenario (St. Kitts)

K1	2005	2008	2012	2015	Unit
Load demand	24.6	32.9	37.8	41.2	MW
Installed Wind		**2 x 800kW Nordex**	**8 x 800kW Nordex**		
Installed Solar PV				**5.4**	MW
Installed Bio		**2.9**	**2.9**	**2.9**	MW
Inverter/rectifier		**3.5**	**3.5**	**3.5**	MW
Installed diesel	**26.3**	**50.6**	**57.9**	**62.2**	MW
NPV	338	580	457	355	US$/kW
Electricity prod	230.4	399.7	461.2	502.4	GWh
NPC	**190.0**	**301.3**	**339.4**	**383.0**	US$ (Million)
COE	**0.097**	**0.089**	**0.087**	**0.090**	US$/kWh
COE	0.262	0.240	0.235	0.243	EC$/kWh
CO2 emissions	145.2	234.3	266.4	287.3	kton/yr
Fuel usage	50.77	81.9	93.2	100.5	x10^6 L/yr
Avoided CO2	0.0	18.0	23.0	28.2	kton/yr
CO2 credit value	0.00	0.48	0.61	0.75	Million US$/yr

Table A3-16 General results of K2 scenario (St. Kitts)

K2	2005	2008	2012	2015	Unit
Load demand (MW)	24.6	32.9	37.8	41.2	MW
Installed Wind	0	0	0	**2 x 800 kW Nordex**	MW
Installed PV	**0**	**0**	**5.4**	**5.4**	MW
Installed Bio	**0**	**0**	**2.9**	**2.9**	MW
Inverter/rectifier	**0**	**0**	**3.5**	**3.5**	MW
Installed diesel (MW)	**26.3**	**53.9**	**57.7**	**63.7**	MW
NPV (US$/kW)	338	615	465	360	US$/kW
Electricity prod (GWh)	230.4	399.4	459	501.1	GWh
NPC	**190.0**	**308.1**	**351.0**	**380.5**	US$ (Million)
COE (US$/kWh)	**0.097**	**0.090**	**0.090**	**0.089**	US$/kWh
COE (EC$/kWh)	0.262	0.243	0.243	0.240	EC$/kWh
CO2 emissions (kt/yr)	145.2	252.3	268.8	293.2	kton/yr
Fuel usage (x10^6 L/yr)	50.77	88.2	94	102.5	x10^6 L/yr
Avoided CO2	0	0	20.6	22.3	kton/yr
CO2 credit value	0.00	0.00	0.55	0.60	Million US$/yr

Table A3-17 General results of K3 scenario (St. Kitts)

K3	2005	2008	2012	2015	Unit
Load demand	24.6	32.9	37.8	41.2	MW
Installed Bio	0	0	0	2.9	MW
Installed diesel	**26.3**	**53.9**	**62**	**64.0**	MW
NPV	338	615	469	359	US$/kW
Electricity prod	230.4	399.4	458.1	499.3	GWh
NPC	**190.0**	**308.1**	**339.9**	**368.6**	US$ (Million)
COE	**0.097**	**0.091**	**0.087**	**0.087**	US$/kWh
COE	0.262	0.246	0.235	0.235	EC$/kWh
CO2 emissions	145.2	252.3	289.4	299.4	kton/yr
Fuel usage	50.77	88.2	101.2	104.7	x10^6 L/yr
Avoided CO2	0	0	0	16.1	kton/yr
CO2 credit value	0.00	0.00	0.00	0.43	Million US$/yr

Table A3-18 Comparative overview of Electricity production in each scenario for St. Kitts

	Component	Production (GWh/yr)			
		2005	2008	2012	2015
K1	Wind turbines	0	7	7	7
	Bio	0	63	63	63
	Diesel	230	330	389	430
	Total	0	400	459	500
K2	PV array	0	0	8	8
	Bio	0	0	63	63
	Diesel	230	339	388	429
	Total	230	339	459	500
K3	Bio	0	0	0	63
	Diesel	230	330	458	436
	Total	230	330	458	499

Table A3-19 Overview of avoided CO2 emission value of scenarios for St. Kitts

		2005	2008	2012	2015	
BAUK	CO2 emissions	145.2	252.3	289.4	315.5	kton/yr
	NPC	**190.0**	**308.1**	**339.9**	**370.5**	US$ (Million)
K1	CO2 emissions	145.2	234.3	266.4	287.3	kton/yr
	Avoided CO2	0.0	18.0	23.0	28.2	kton/yr
	CO2 credit value	0.0	480.6	614.1	752.9	x10^3 US$/yr
	Cum. Credit	0.0	1441.8	2456.4	2258.8	x10^3 US$
	NPC	190.0	301.3	339.4	383.0	US$ (Million)
	NPC (net)	**190.0**	**299.9**	**336.9**	**380.7**	US$ (Million)
K2	CO2 emissions	145.2	252.3	268.8	293.2	kton/yr
	Avoided CO2	0.0	0.0	20.6	22.3	kton/yr
	CO2 credit value	0.0	0.0	550.0	595.4	Million US$/yr
	Cum. Credit	0.0	0.0	2200.1	1786.2	x10^3 US$
	NPC	190.0	308.1	351.0	380.5	US$ (Million)
	NPC (net)	**190.0**	**308.1**	**348.8**	**378.7**	US$ (Million)
K3	CO2 emissions	145.2	252.3	289.4	299.4	kton/yr
	Avoided CO2	0.0	0.0	0.0	16.1	kton/yr
	CO2 credit value	0.0	0.0	0.0	429.9	Million US$/yr
	Cum. Credit	0.0	0.0	0.0	1289.6	x10^3 US$
	NPC	190.0	308.1	339.9	368.6	US$ (Million)
	NPC (net)	**190.0**	**308.1**	**339.9**	**367.3**	US$ (Million)
	CO2 price	26.7				US$/ton CO2

Table A3-20 Overview of Electricity production in each scenario for Nevis

Scenario	Component	Production (GWh/yr)			
		2005	2008	2012	2015
N1	Wind turbines	0.0	15.1	14.2	12.1
	Geo	0.0	0.0	86.9	87.5
	Diesel	99.5	111.0	57.6	89.0
	Total	99.5	126.1	158.7	188.6
N2	Geo	0	0	87.5	87.6
	Diesel	99.5	123.1	68.8	99.5
	Total	99.5	123.1	156.3	187.1
N3	Geo	0	0	0	87.6
	Diesel	99.5	123.1	156.4	99.5
	Total	99.5	123.1	156.4	187.1

Table A3-21 Overview of avoided CO2 emission value of scenarios for Nevis

Scenario	Parameter	2005	2008	2012	2015	Unit
BAUN	CO2 emissions	67	86.8	110.2	131.9	kton/yr
N1	CO2 emissions	67	78.5	42.3	64.3	kton/yr
	Avoided CO2	0	8.3	67.9	67.6	kton/yr
	CO2 credit value	0	222	1813	1805	x10^3 US$/yr
N2	CO2 emissions	67	86.8	49.7	71.2	kton/yr
	Avoided CO2	0	0	60.5	60.7	kton/yr
	CO2 credit value	0	0	1615	1621	x10^3 US$/yr
N3	CO2 emissions	67	86.8	110.2	71.2	kton/yr
	Avoided CO2	0	0	0	60.7	kton/yr
	CO2 credit value	0	0	0	1621	x10^3 US$/yr
CO2 price		26.7				US$/ton CO2