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Optimizing Integrated Energy Resources on a Small Island Power System with Predominantly Geothermal Power

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ABSTRACT

In an effort to reduce dependency on fossil fuels for power generation, several Caribbean islands have recently sought to exploit their indigenous geothermal resources. Traditionally geothermal plants are used for base load generation. However small island states load demand profiles characteristically have significant intra-hourly variations which would require rapid changes to geothermal plant power output that may be more economically handled by other power sources and balancing mechanisms.

The paper examines various scenarios of future energy resource integration together with grid and energy management, technological development on the Caribbean island of Nevis. The main objective is the displacing of diesel generation with baseload geothermal energy.

Using simple power system models and simulations, the paper proposes designs and stepwise development toward improving the efficiency, sustainability, flexibility and stability of the Nevis island grid. The paper shows that geothermal energy integrated with other renewable resources, along with modern grid and energy management technologies, allows for the realization of reduced energy costs, improved energy security and environmental conditions for the island of Nevis. The findings are also applicable to other islanded power systems or grids with weak connection to a main grid.

1. INTRODUCTION

Small island developing states (SIDS) such as St Kitts and Nevis have historically developed their electric utilities powered by fossil fueled generators. For such islands, there are significant cost associated with the transporting and bunkering of fuel. Imported fossil fuels can be much higher than mainland prices causing island economies to be vulnerable to oil price fluctuations. 90% of the Caribbean's energy demand is met by imported fossil fuels accounting for up to 30% of GDP spending which is common to these islands and other SIDS (Kuang et al. 2016).

High CO_2 emissions from combusting fossil fuels along with world oil price volatility has resulted in island nations diversifying their electrical energy generation to utilize renewable energy resources. Additionally, during the Conference of Parties 21 (COP21) held in 2015, over 190 countries including several Caribbean and Pacific SIDS, signed on to a legally binding climate change agreement which aims to avert the increase of global atmospheric temperatures by 2^0C.

Table 1: Electricity production from renewable energy in selected islands (Kuang et al. 2016)

Island	Total percentage of electricity production from renewable energy (%)	Main type of renewable energy	Renewable energy plan/target (percentage of total power)	Electricity consumption per capita (kWh)	Region
Samsoe	100	Wind	100% (present)	\	The Atlantic Ocean
Pellworm	64.95	Wind, Solar	100% (present)	20,457	The North Atlantic
Fiji	59.3	Wind, Hydropower	90% (2015)	946.8	The South Pacific
Reunion	31.2	Hydropower, Biomass, Ocean	100% (2030)	3382	The Indian Ocean
Crete	26	Wind, Solar, Biomass	50% (2020)	3806	The Mediterranean
Cape Verde	21	Wind, Biomass	50% (2020)	595	The Indian Ocean
Cyprus	2.8	Wind, Solar	16% (2020)	4081	The Mediterranean
Tuvalu	2	Wind, Solar	100% (2020)	489	The South Pacific
Barbados	0.0	Solar	29% (2019)	3491	The Caribbean

As shown in table 1., wind and solar are the predominant renewable energy resources being used for electricity production in island nations. It must be noted however that the deployment of variable renewable energy (VRE) systems on island grids has to be carefully designed to mitigate negative impacts on power quality due to the stochastic nature of the energy resources. Voltage and frequency perturbations exceeding regulations can occur in time scales ranging from milliseconds to minutes. Additionally, island power systems are unstable and prone to disruptions from severe weather events (Kuang et al. 2016). Geothermal energy in contrast can be exploited to obtain a stable, base load energy source that is available to many islands in proximity of the ring of fire and tectonic plate boundaries.

However due to significant developmental risks and large capital investment requirements as illustrated in figure 1, VRE technologies such as wind and solar PV have proliferated over geothermal. Increased uptake of VRE technologies is projected to continue as the global weighted-average cost of electricity generated by onshore wind and solar PV fell by 13% in 2018 in contrast to 1% for geothermal. With this trend it is estimated that greenfield utility scale solar PV and onshore wind commissioned in 2020 could provide cheaper electricity than the cheapest new coal-fired, oil or natural gas option (IRENA 2019).

Nonetheless integrated energy resource planning necessitates the techno-economic examination of all available indigenous and exogenous energy resources, to determine the optimal energy mix for meeting existing and future energy demands in the most sustainable means possible.

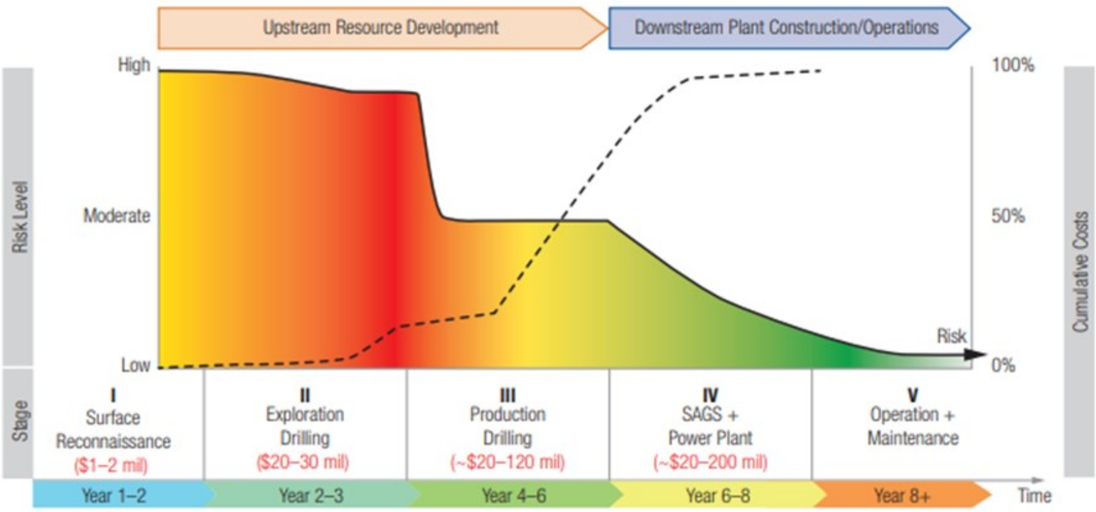


Figure 1: Overview of the Typical Geothermal Development Process (Berman et al. 2018)

2. CASE STUDY OF THE ISLAND OF NEVIS

Nevis is a 93 KM^2 Caribbean island which forms part of the federation of St Kitts and Nevis (SKN). Both islands are of volcanic origins located along the Atlantic and Caribbean plate boundary.

2.1 Plans for Renewable Energy Development on Nevis

In 2015 SKN signed onto the COP21 accords with Intended Nationally Determined Contributions (INDC) of achieving 22 % and 35% reduction in greenhouse gas (GHG) emissions by 2025 and 2030 respectively, as per the United Nations Framework Convention on Climate Change (UNFCCC) objective as detailed in Article 2 of the Convention, and in accordance with decisions 1/CP.19 and 1/CP.20 (Saint Kitts and Nevis 2015).

As shown in Figure 2, the proposed energy measures and policies to be implemented within the federation of St Kitts and Nevis towards achieving the INDC include electricity generation from renewable resources. From figure 2 it can be seen that SKN intends for geothermal to be the largest renewable energy generator with at least 35MW developed in the mid to long term future followed by 7.6MW of wind and 1.9 MW of solar PV.

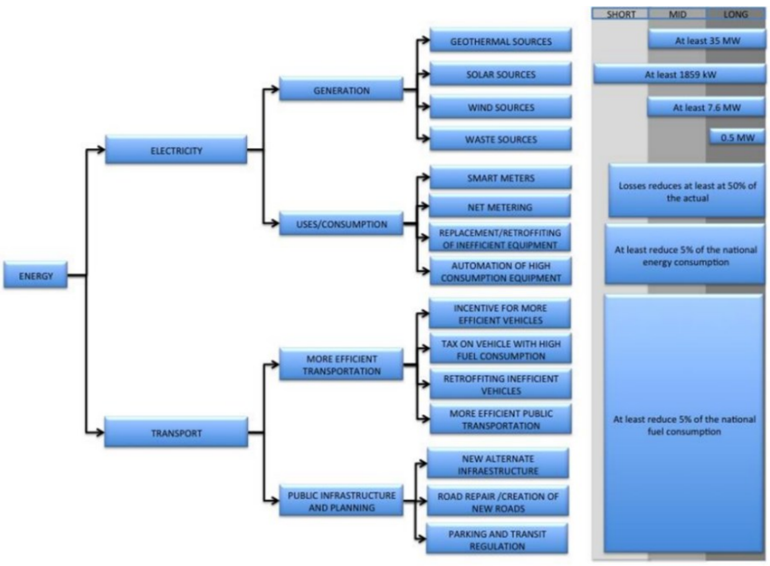


Figure 2: St Kitts and Nevis INDC Energy Polices and Measures Towards Achieving the UNFCCC Article 2 Objectives (Saint Kitts and Nevis 2015)

3. NEVIS RENEWABLE ENERGY RESOURCES

Indigenously the island has three main viable renewable energy resources; wind, solar and geothermal.

3.1 Wind

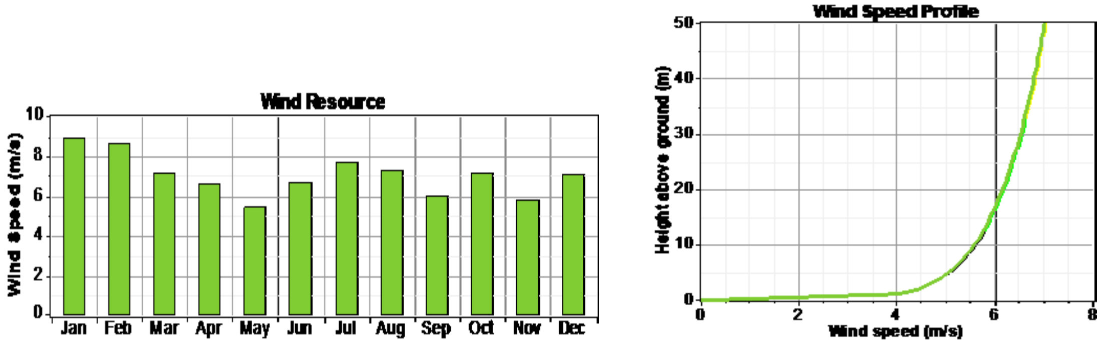


Figure 3 Nevis monthly average wind speeds (left) and Nevis wind speed profile (right)

Figures 3 illustrates the average speed profile of the Nevis island wind resource which has the following key characteristics:

- Annual average wind speed: 7.024 m/s
- Hour of peak wind speed: 03:00
- Weibull: k = 3.43, c = 7.80 m/s

It must be noted that the peak wind resource availability coincides with period of lowest power demand. The island presently has a 2.2 MW IPP owned and operated grid tied windfarm without energy storage. At most the amount of onshore wind that can be installed approximates 5 MW, due to the small size of the island there is a limitation on the amount of space available for utility scale windfarms.

The most economical wind power generation is in large wind farms i.e. tens or hundreds of MW. Wind generation in Nevis will be less than that so that the cost of power generation can be expected to be somewhat more expensive than in the large windfarms. If the electricity systems for Nevis and St Kitts were interconnected, then there might be a marked for a larger more economical windfarm.

3.2 Solar

Figure 4 shows the solar map of St Kitts and Nevis. Both islands have good solar resources with a global horizontal irradiation (GHI) value averaging in the excess of 5.7 kWh/m2/day, thus the low-lying areas of the islands are suitable for solar PV and solar hot water systems (LCCC 2011).

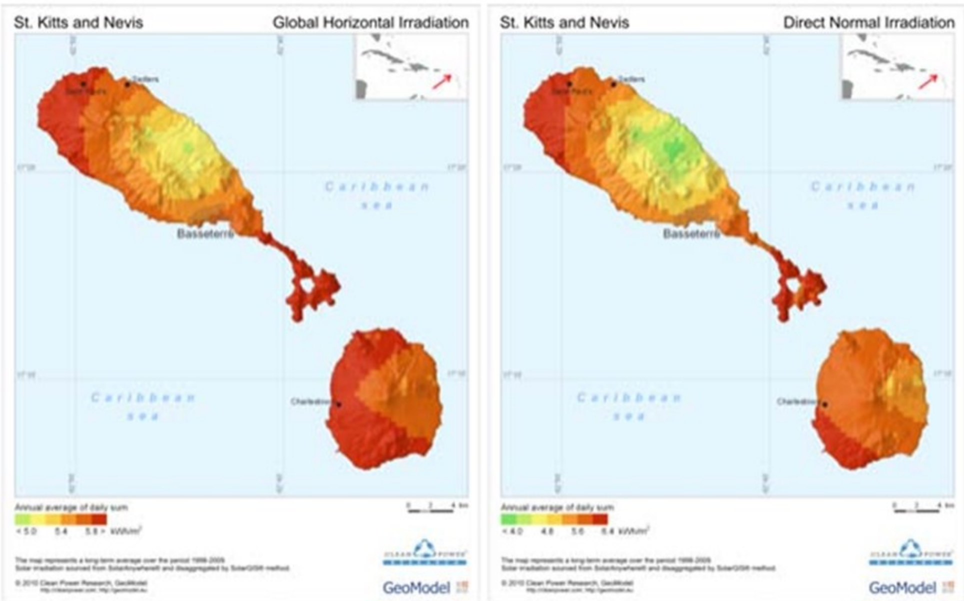


Figure 4: Solar Resource Maps of St Kitts and Nevis (LCCC 2011)

Daily solar insolation availability coincides with peak cooling energy demands. Therefore, solar PV can contribute to the reduction of diesel generation to meet day time loads. From an optimal integrated energy resource management perspective, grid integration of this resource must be assessed from a stability and cost effectiveness standpoint given that it either must have online spinning reserves or energy storage. The price of solar panels has been coming down fast, so the feasibility of using solar panels for power generation is expected to increase.

3.3 Geothermal

Nevis has numerous geothermal surface manifestations including hot springs. Over the past 11 years successive exploration rights and power purchase agreements (PPAs) were signed between the Nevis Island Administration (NIA) and two independent power providers (IPPs).

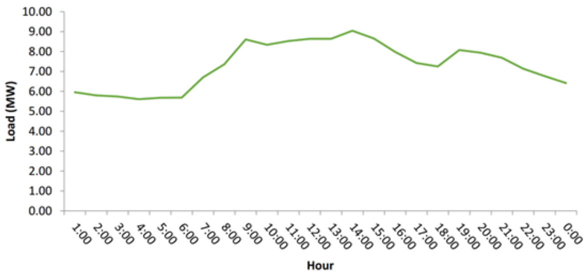
Table 2: Nevis test well results 2008

Well	Depth (m)	Pressure (bar)	Temperature (^{0}C)
Nevis 1	1065	6.8	250
Nevis 2	732	14.5	260
Nevis 3	899	17.9	232

Test well results as summarized in table 2 indicate the abundant geothermal energy potential of Nevis and also show the resource is accessible at considerably shallow depths. Preliminary geothermal power potential estimates for the island approximate 900 MW, however, to date geothermal development in Nevis has not progressed beyond exploration drilling. Apart from the INDC, there also has been significant interest in developing the geothermal resource on Nevis to the magnitude of 200 - 600MW with intent to export to other neighboring islands (NREL 2015).

3.4 Nevis Present Electricity Sector Characteristics

The Nevis island diurnal load profile typically follows the pattern as illustrated in figure 5 with little seasonal variation. As the island is located within the tropics, peak power demands are observed during the summer months when there is increased usage of air conditioning systems. Annually 96% electrical energy demand is met by diesel generators and 4% by wind turbines.



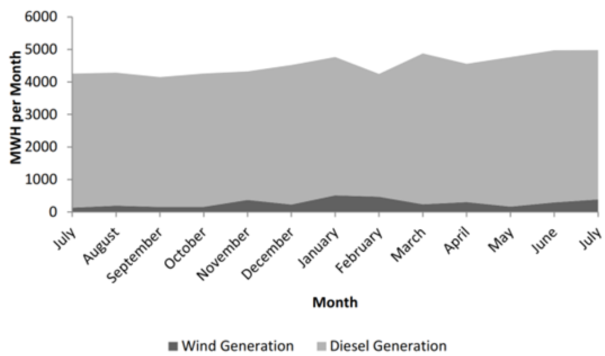


Figure 5: Nevis Island daily load profile (left) and Nevis Island typical annual electrical energy demand profile (right)

3.4.1 Power system technical characteristics

The island power system has the following key characteristics:

- Totally islanded with no import or export of electrical energy
- Average peak daily load demand approximates 9.5MW
- Base load of approximately 6.4 MW.
- Annual energy demand approx. 56 GWh
- 16 MW diesel power station owned by local utility.
- 2.2 MW IPP owned wind farm.
- Approximately 350 kW unregulated rooftop solar PV

See also “Energy Snapshot - The Federation of Saint Christopher and Nevis” (NREL, 2015)

3.4.2 Electricity Consumption by Sector

Sectoral consumption of electricity on Nevis is largely dominated by commercial/industrial activities which account for approximately 65% of the total system demand. Residential and street lighting account for the remaining 35%.

4. NEVIS ENERGY SECTOR FUTURE CONSIDERATIONS

Based on the interest to increase renewable energy on the island, it is expected that Nevis can be largely powered by renewable energy in the future. However, given the small size of the island, integration of various energy resources has to be carefully planned to achieve optimal technical and economic efficacy of implementation and operation.

4.1 Demand growth

It is estimated that island energy demand will increase at approximately 3% per annum for the next 10 years or a total increase of 34% in 10 years or 80% in 20 years. This can probably be considered a careful estimate, based on a largely traditional power consumption. There are however many novel power consumers in sight that could affect this estimate, i.e. electrical vehicles, desalination, increased cooling demand due to global warming and finally lower electricity prices due to utilization of geothermal energy are expected to incentivize increased industrial activity on the island., This has led us to look also at an alternative higher estimate, or 4% per year or a total increase of 48% in 10 years or 119% in 20 years.

4.2 Rooftop solar PV proliferation

Presently rooftop solar PV is unregulated, therefore there is no stipulated limitation to the size of an installation on a private or commercial premise. Motivations for reduction of electricity bills has been the primary driver for uptake of this technology. Notably these systems are grid tied without energy storage, hence backup generation capacity has to be made available in events of overcast conditions and night time loads.

4.3 Impact of energy efficiency measures

In recent years, the Nevis Island Administration (NIA) has spear headed energy efficiency initiatives primarily in the replacement of incandescent and metal halide lighting with compact fluorescent lamps (CFL) and LED fixtures. This trend is expected to continue into the future and be coupled with installation of variable frequency drives (VFD) on pump motors, proliferation of inverter-based AC systems and increased usage of energy efficient house hold appliances such as refrigerators, TVs and washers. To date, historical peak power demand projections have not been realized largely due to the impact of roof top solar PV and energy efficiency measures.

4.4 Transport sector electrification

Globally there is a paradigm shift towards electrification of the transport sector. Transportation and environmental policies have been major drivers for increasing electric vehicle (EV) proliferation. Recent individual cities and collective country environmental mandates including the EU's CO_2 emission standards for 2030 are strong indicators for increasing EV uptake projections (IEA 2018).

Wang et al (Wang et al. 2011) concluded that utilizing scheduled EV charging and demand-side response (DR) to shift load from peak to non-peak hours, enables a system operator to minimize the impact of wind power variation and reduce wind energy curtailment or wastage.

To date there are no EVs on the island of Nevis, however as other Caribbean islands such as Barbados have already begun to make this transition, it is expected that EVs will be utilized on the island. Additionally, considering the small size of the island hence there will be shorted travel distances, if electricity is competitively priced against petrol, financial gains can be realized by switching to electric vehicles

4.5 Need for water desalination

Subterranean wells are the primary source of potable water on the island. In recent years there has been a reduction in rainfall resulting in the depletion of underground reservoirs which has consequently lead to water rationing during the summer months. Presently desalination of sea water is being considered to make up for well water shortages. We assume the desalination will be run during of peak hours using smart grid technology.

4.6 Need for cooling

Due to global warming the need for cooling is increasing, especially during the middle of the day. Solar energy is therefore well suited for providing energy for cooling. Ice production, perhaps from wind energy, for cooling is well suited for energy storage for maybe 3-5 days.

4.7 Energy storage systems

The increased uptake of VRE technologies has largely been assisted by improvements in energy storage technologies. Energy storage systems (ESS) can provide voltage and frequency regulation to mitigate negative impacts of VRE intermittency by storing excess energy during off peak periods and releasing to the grid during periods of peak load (Ren et al. 2017).

Beaudin et al, in their analysis of energy storage systems for mitigating impacts of variable renewable electricity resources, conclude that batteries, flywheels and capacitors due to their rapid response, scalability, modularity, durability and low maintenance requirements, are the most suitable ESS for maintaining grid stability and power quality (Beaudin et al. 2010). However as shown in table 3, these systems have significant capital costs.

However, it is, expected that some variant of energy storage will play a role in Nevis future energy system. This could be pumped storage, battery or maybe even compressed air storage. Production and storage of ice for cooling of hotels etc. is also a form of energy storage that should be investigated.

Table 3: Comparison of various energy storage technologies (Schmidt et al. 2019)

			Pumped hydro	Compressed air	Flywheel	Lithium-ion	Sodium-sulphur	Lead-acid	Vanadium redox-flow	Hydrogen	Super-capacitor
Investment cost - Power	$/kW	C_P	1129 (45%)	871 (35%)	641 (17%)	678 (17%)	657 (27%)	675 (23%)	829 (21%)	5417 (48%)	296 (31%)
Investment cost - Energy	$/kWh	C_E	80 (63%)	39 (58%)	5399 (67%)	802 (24%)	738 (12%)	471 (38%)	760 (17%)	31 (60%)	13560 (19%)
Operation cost - Power	$/kW-yr	$C_{P\text{-}OM}$	8 (26%)	4 (23%)	7 (8%)	10 (35%)	11 (50%)	8 (31%)	12 (52%)	46 (30%)	0 (0%)
Operation cost - Energy	$/MWh	$C_{E\text{-}OM}$	1 (60%)	4 (60%)	2 (60%)	3 (60%)	3 (60%)	1 (60%)	1 (60%)	0 (60%)	0 (60%)
Replacement cost	$/kW	$C_{P\text{-}r}$	116 (5%)	93 (5%)	199 (44%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1637 (48%)	0 (0%)
Replacement interval	cycles	Cyc_r	7300	1460	22500	3250	4098	1225	8272	6388	69320
End-of-life cost	%	F_{EOL}	0%	0%	0%	0%	0%	0%	0%	0%	0%
Discount rate	%	DR	8%	8%	8%	8%	8%	8%	8%	8%	8%

5. DERIVATION OF OPTIMAL FUTURE ENERGY RESOURCE MIX FOR NEVIS

Taking into account the above-mentioned motivations for increased renewable energy proliferation on the island of Nevis, to derive the techno-economic optimal energy resource mix, various scenarios were modelled in EnergyPLAN energy system simulation software(EnergyPLAN 2014) and examined critically against the following expectations

5.1 Economic expectations

The optimal future energy resource mix should produce the lowest levelized cost of energy (LCOE) and a positive net present value.

5.2 Environmental and energy security expectations

The optimal future energy resource mix should be able to meet existing and long-term energy demands while producing the least GHG possible with minimal dependency on imported fossil fuels.

5.3 Power system operation expectations

When operating as an integrated power system, the optimized energy resources should be utilized in a manner that produces minimal negative impact on power system reliability, stability and be without availability constraints.

6. SELECTION OF SIMULATION SOFTWARE

The authors looked at several energy system simulation software packages for this project. A review of a large number of modelling tools for energy systems can be found here (Ringkjøb, Haugan, and Solbrekke 2018). The focus was on free or inexpensive packages suitable for systems with a large content of renewable energy and packages suitable for island systems. The main use of the package would be investment decision support via simulation of various system scenarios.

6.1 EnergyPLAN

We selected a widely used package, EnergyPLAN. EnergyPLAN can be used for simulation of energy systems of different sizes, including island systems. Different types of electricity generation are included, not the least renewable energy. The software simulates 1 year at a time in 1-hour time steps. The results are energy, economy and ecology. For the economic evaluation the annualized investment cost is included as well as fixed and variable operation and maintenance costs as well as fuel and emission costs.

7 SIMULATION INPUTS

7.1 Financial data

The with main financial data inputs are as summarized in table 4.

Table 4: Financial inputs for scenario modelling

Type of generation	Total overnight cost $/kW	Fixed O&M cost $/kW/yr
Diesel	1.371	7
Geothermal:		
- Large (50 MW)	3.500	115
- Small incl. binary (5-10MW)	4.500	115
- 5-10 MW greenfield	8.000	115
Wind		
- Large wind parks	1.624	50
Solar		
- Solar utility scale (15 MW St Kitts + Nev	1.210	22
Pumped storage, 10 hours	1.929	40

7.2 Investment cost of geothermal plant.

The investment cost for geothermal plant is of key importance in the simulation of the scenarios. For Nevis we assumed either 5MW or 10 MW geothermal plant. This is a rather small plant and the investment per kW rather high when compared to much larger plants. Also, this will be a greenfield plant, i.e. the first geothermal plant at this site, which still could lead to a l higher price. In the scenarios we used two price categories for the geothermal plants; 4.500 USD/kW as typical cost and 8.000 USD/kWh if the costs of the plant turn out to be high. It can be difficult to accurately estimate the cost of a geothermal plant, especially a greenfield plant, therefor we take this approach with two price scenarios. In the scenarios below we use the cost 8.000 USD/kWh to get cautious cost estimates.

7.3 Scenarios – introduction

Several scenarios were run in EnergyPLAN with the aim of finding the most economical combination of electricity producing units. The investment cost of the diesel generators is included in all scenarios. The diesel generators must always be kept on stand-by as backup power in case a geothermal unit is not running due to scheduled or unscheduled stop.

7.4 Base scenario A – Todays situation, diesel only

This was clearly the most expensive scenario; high fuel cost is mainly to blame. The electricity production cost was 0.249 USD/kWh. The investment cost was based on 12 MW total diesel units. In reality the diesel units are 16 MW in total, but for the purpose of the comparison of scenarios 12 MW is in line with what is needed. Many of the diesel units are old and written off which supports not using the cost of new units.

7.5 Geothermal only scenarios B

<u>7.5.1 Scenario B-1) Geothermal only scenario, Geothermal plant size equal to peak demand.</u>

The peak demand is approx. 9,5 MW so we assume a 10 MW geothermal unit. This results in an electricity production cost of 0,132 USD/kWh. Since the average load is only 6,4 MW the geothermal unit is not well utilized, running on part load most of the time. A geothermal unit of 8 MW would result in a lower electricity production cost of 0,122 USD/kWh, see below. But we assume that within a few years the load will have increased leading to a better utilization of the geothermal unit and lower production cost than from a smaller geothermal unit.

<u>7.5.2 Scenario B-2) Geothermal only scenario. A second plant is constructed as soon as peak demand of first pant is exceeded.</u>

In the beginning there would be no use for the second geothermal plant but the investment cost is high.

This results in a very high electricity production cost of 0,280 USD/kWh, that's even higher than for the diesel only scenario. This is therefore not a feasibly scenario. The investment in the second plant should be postponed until the load has increased substantially

7.6 Mixed scenario C - Geothermal + peak load from diesel

A 8 MW geothermal unit results in a minimum electricity production cost of 0,122 USD/kWh. A smaller, 5 MW unit results in a slightly higher electricity production cost of 0,134 USD/kWh. In this scenario there would also be more CO_2 emission from the diesel plant.

7.7 Mixed scenario D - Geothermal + peak load from Wind and/or solar + energy storage.

A 5 MW geothermal unit and 2 MW wind turbines results in a low electricity production cost of 0,125 USD/kWh. Adding 1 MW pumped hydro storage has marginal effect on the electricity cost. The reason is the high cost of pumped storage. The pumped storage would however lead to slightly less CO_2 emissions.

7.8 Mixed scenario E - Wind and/or solar + diesel (or natural gas)

This scenario includes 8 MW wind and 8 MW solar and 4 MW pumped storage. This results in a electricity production cost of 0,175 USD/kWh, clearly considerably more expensive than the scenarios that include a geothermal unit.

7.9 Mixed scenario F - Wind and/or solar + energy storage.

This scenario results in stability and voltage control problems that will be difficult to handle. We therefore skipped this scenario.

7.10 Demand Side Response Scenario

This could be charging of electrical vehicles during off peak hours or production of ice for cooling during off peak hours

7.11 Desalination

See also above about Demand Side Response. This involves production of water through desalination during off peak hours

7.12 Cable connection with St Kitts

We did not calculate the economic aspects of the connection but since this is a key decision for the future of the St Kitts and Nevis, we will here make some general observations about the connection:

- The peak load on St Kitts is about 25 MW and 10 MW on Nevis.
- Due to the short distance between St Kitts and Nevis the connection is low cost compared to many other island interconnections.
- Economy of size. If we assume the geothermal plant is located on Nevis, then approx. two 20 MW or 25 MW would suffice for St Kitts and Nevis initially. This compares with 5MW or 10 MW units for Nevis only. Due to the larger units, generally they should be more economical, i.e. due to economy of size of the investment as well as operation. This would benefit both St Kitts and Nevis through lower energy production cost. The same applies to wind energy,

i.e. due to economy of size larger wind farms, serving both St Kitts and Nevis via the interconnection, are more economical.

- St Kitts pays for the interconnection. Generally speaking, we assume that St Kitts should bear the cost of the interconnection, i.e. the interconnection should not cause increased energy price on Nevis.

- St Kitts energy cost savings. When comparing the current cost of energy from diesel generators with geothermal energy from Nevis, then St Kitts should save several hundred million US$ in energy production cost over the period 2020-2040, assuming the geothermal resource is plentiful enough.

- Flexibility during power system failures. Through the cable connection backup via the cable connection during power system disturbances/failures should improve the power system reliability on both islands.

8. POWER SYSTEM EVOLUTION 2020 – 2040

We studied plans for the evolution of the power system, both for 3% annual load increase and 4% annual load increase, see below:

To arrive at the optimal plans, we tested several scenarios and calculated the Net Present Value of the investments, operation and maintenance and fuel cost for the whole period in million US$. We also calculated the average energy price for the whole period and accumulated the diesel CO_2 emissions in thousand tons in order to compare the environmental effects of the different scenarios..

Table 5: Scenarios 2020-2040, 3% yearly load increase:

Scenarios	Net Present Value Discount rate: 6%	Average price	Diesel CO2 emisssions
	Million $	$/kWh	Thousand Tonnes
a) Diesel only. 12 MW and increased to 18 MW after 5 years	$216	0,248	1.604
b) Diesel only as in a) above + 2 MW wind	$208	0,239	1.512
c) Diesel + 2 MW wind + 4 MW solar	$194	0,224	1.372
d) Diesel + 2 MW wind + 2 MW solar + 5 MW geothermal after 5 years	$147	0,167	836
e) Diesel +2 MW Wi+So+ Geoth. 5MW after 5 years and another 5MW after 10 years	$137	0,151	394
f) Diesel +2 MW Wi+So+ Geoth. 10MW after 5 years	$125	0,137	242

From the above it can be seen that wind and solar energy leads to lower energy price. This can be implemented with short notice, possibly 1-2 years. A substantial price decrease is achieved when a 5MW geothermal plant is introduced. The planning, design and construction of a geothermal plant and the drilling of the wells takes long time, at least 5 years in our plan. This delays the benefits from geothermal power plant. Due to the increase in load, another 5 MW unit is needed 5 years after the first one, see Scenario e). It turns out that an similarly attractive alternative involves installing a 10 MW geothermal plant after 5 years (instead of 5 MW). We choose scenario e) here, instead of f), because it represents a more cautious approach to the geothermal utilization, especially since this is a greenfield project with considerable risks and uncertainties.

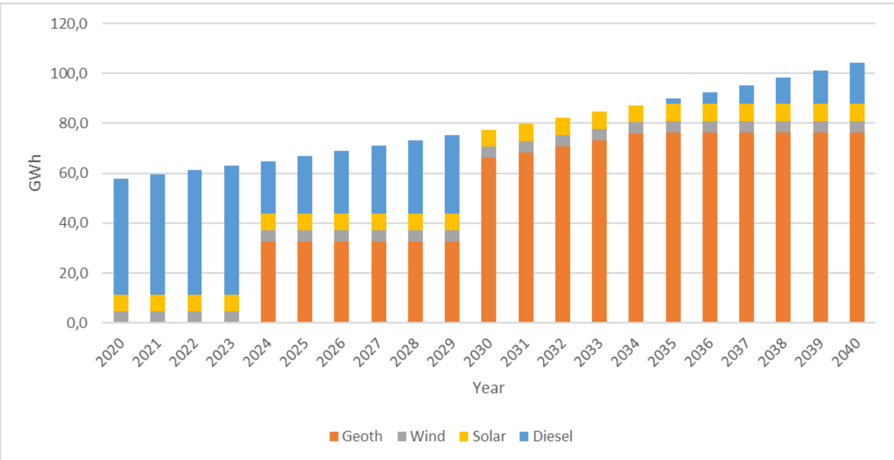


Figure 6: Power generation plan 2020-2040, 3% yearly load growth. Scenario e)

Table 6: Scenarios 2020-2040, 4% yearly load increase:

Scenarios	Net Present Value Discount rate: 6% Million $	Average price $/kWh	Diiesel CO2 emisssions Thousand Tonnes
a) Diesel only. 12 MW and increased to 18 MW after 4 years	$237	0,247	1.806
b) Diesel only as in a) above + 2 MW wind	$229	0,238	1.713
c) Diesel + 2 MW wind + 4 MW solar	$215	0,225	1.573
d) Diesel + 2 MW wind + 2 MW solar + 5 MW geothermal after 5 years	$183	0,191	1.037
e) Diesel +2 MW Wi+So+ Geoth. 5MW after 5 years and another 5MW after 7 years	$147	0,150	466
e2) Diesel +2 MW Wi+So+ Geoth. 5MW after 5 years and another 5MW after 7 years and again after 12years	$143	0,145	276
f) Diesel +2 MW Wi+So+ Geoth. 10MW after 5 years and another 10MW in 18 years	$141	0,144	315

From the above it can be seen that, as before, wind and solar energy leads to lower energy price. This can be implemented with short notice, possibly 1-2 years. A substantial price decrease is achieved when a 5MW geothermal plant is introduced. The planning, design and construction of a geothermal plant and the drilling of the wells takes long time, at least 5 years in our plan. This delays the benefits from geothermal power plant. Due to the increase in load, another 5 MW unit is needed 2 years after the first one, see Scenario e) and in scenario e2) the third 5MW unit is commissioned after 5 more years. It turns out that an similarly attractive alternative involves installing a 10 MW geothermal plant after 5 years and a second 10MW unit after 18 years (2038). Whether to choose 5MW or 10 MW can be decided based on the quality of the geothermal resource and based on how cautious the approach to the geothermal utilization is, especially since this is a greenfield project with considerable risks and uncertainties..

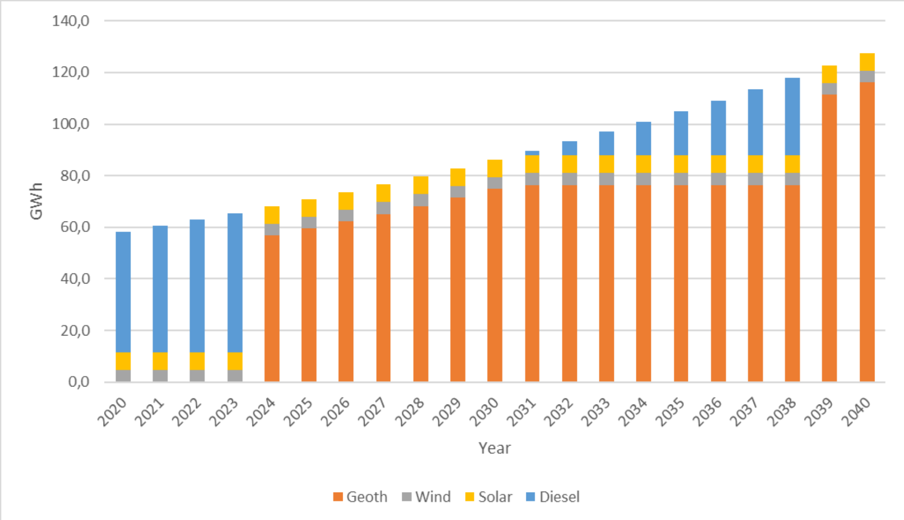


Figure 7: Power generation plan 2020-2040, 4% yearly load growth. Scenario f)

9. SUGGESTED FURTHER RESEARCH

While working on this project several ideas surfaced for future research topics. We leave these ideas for the future:

- Natural gas instead of diesel. The price of gas has been decreasing in recent years. Using natural gas instead of diesel also causes somewhat less CO_2 emissions.
- Hydrogen production for energy storage and for vehicle and ship propulsion
- The feasibility of balneology tied to the geothermal utilization should be investigated. This could attract tourists as has been done in Iceland and in some other countries.

10. CONCLUSIONS

From the 2020 – 2040 scenarios it can be seen that the Net Present Value of converting the electricity production from mainly diesel fuel to renewable energy, mainly geothermal, is close to 100 million US$ over the period 2020-2040. Additionally, CO_2 emission will be reduced by close to 1,5 million tons over the period. Harmful air pollution from the use of diesel will also be reduced.

When the energy production in Nevis is mostly from renewable energy then Nevis can be promoted as an "green energy island". This might attract some additional tourists and thus benefit the economy. Also the geothermal plant could perhaps be opened to tourists as an attraction. This has been done at a couple of geothermal plants in Iceland.

Solar energy fits well with cooling requirements in the middle of the day. Price of solar energy has been coming down fast in recent years. The installation of 2-4MW solar should be investigated with this in mind and in cooperation with large cooling consumers. The feasibility of the solar installations depends much on the planning of the geothermal plant. This must therefore be studied together.

Wind energy is not as regular as solar and may need some form of energy storage to work properly. Energy storage such as pumped storage is expensive so it is doubtful if large scale installation of wind is feasible, especially if it competes with geothermal. One possible energy storage option is ice production for cooling. Producing ice for maybe 3-5 days consumption. This might fit well with the wind energy, but has to be studied further with potential customers such as large hotels. Timed charging of electrical vehicles (smart grid) could also be of interest here.

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