A PRELIMINARY ANALYSIS FOR THE TRANSITION OF THE U.S. VIRGIN ISLANDS FROM PETROLEUM-BASED POWER GENERATION

By

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May 2013

Masters Project submitted in partial fulfillment of the requirements for the Master of Environmental Management degree in the Nicholas School of the Environment of

Duke University
Abstract

Small island economies are almost entirely dependent on petroleum-based products as the fuel stock for power generation. This dependency places a significant burden on economic growth with up to 30% of GDP attributable to importing oil along with accompanying environmental concerns. This paper focuses on the U.S. Virgin Islands (USVI) and considers different generation technologies that can help the USVI meet its goal of 60% reduction in petroleum usage for power generation by 2025. The paper assesses the cost effectiveness of different utility-scale generation technologies evaluated against the current baseline system in the context of cost and carbon emissions.

The approach for the analysis assesses secondary research and publications on transitioning island economies from petroleum-based power generation. Research specific to the U.S. Virgin islands is utilized along with technology data to develop a cost effectiveness optimization model for serving the load demand in the U.S. Virgin islands under different scenarios. Two key scenarios are considered, one where energy efficiency measures are successful and electricity load is reduced 36% per NREL research conducted and the second where energy efficiency measures are not successful and load continues to grow at 1.2% annually through 2025. With these scenarios, different generation technologies are evaluated utilizing their respective levelized cost of electricity (LCOE) to determine the most cost effective and carbon considerate technologies to serve the residual load of the USVI.

Findings illustrate that natural gas-fed advanced combustion turbines provide the most cost effective means to meet the USVI demand load, regardless of the success of energy efficiency programs in reducing load. Energy efficiency deployment provides cost savings and value in reducing exposure to fuel price volatility by reducing the load served by oil/natural gas generators. Per these findings, further research is warranted for determining a secure and viable natural gas supply chain, advanced combustion turbine integration studies, cost/benefit analysis and roadmap evaluation of energy efficiency programs for the USVI.
# Table of Contents

1 Introduction – p. 4  

1.1 Statement of the problem – p.4  
1.2 Context/baseline of problem – p.5  
1.3 Review of other island economy efforts to transition off of petroleum – p.8  
1.4 Framework for considering the problem – p.9  

2. Project Overview – p. 10  

2.1 Approach taken for master’s project – p.10  
2.2 Scope and limitations of master’s project – p.12  
2.3 Significance of the master’s project – p.13  

3. Materials and Methods – p. 14  

3.1 Cost Optimization model – 14  

4. Results and Observations – p. 16  

4.1 Baseline/business as usual case (BAU) – p.16  
4.2 Cost optimization analysis for 2025 – p.19  

5. Discussion – p. 23  

5.1 Key findings – p.23  
5.2 Potential limitations of the scenarios – p.25  
5.3 Limitations of the project – p.25  
5.4 Significance of results – p.26  
5.5 Suggestions for further research – p.26  

6. Conclusion – p. 27  

7. References – p. 28  

8. Appendix – p. 30
1 Introduction

1.1 Statement of the problem

The U.S. Virgin Islands (USVI) is entirely dependent on fossil fuels for power generation leaving the economy directly exposed to oil market volatility and high electricity rates. Until recently, USVI had an agreement with HOVENSA (a large local oil refinery) to supply diesel fuel for power generation at a discounted price relative to the market. However, this context recently changed with the closing of the HOVENSA refinery and the cancellation of the contract. Due to the cost and volatility of oil, the price of electricity is significantly higher in the USVI as compared to the continental U.S. (under the HOVENSA fuel agreement, retail rates have reached $0.40/kWh compared to an average of $0.12/kWh in the continental U.S.)\(^1\). As of March 2013, rates for USVI residents are $0.51/kWh and $0.55/kWh for commercial customers.\(^2\) The USVI Water and Power Authority (WAPA) utilizes the Levelized Energy Adjustment Clause (LEAC), a fuel pass through surcharge applied to customer’s electricity bills. Exposure to fuel costs has a direct impact on electricity rates and an economic impact on residents and business in the USVI, as exhibited in Figure 1.

![Historical LEAC and WAPA Oil Price](chart.png)

**Figure 1:** NREL: Historical fuel surcharge and utility fuel costs


With this context, there is significant need for diversification of the power sector in the USVI. To address this, the USVI has publicly announced a goal of reducing petroleum usage 60% from the projected baseline of petroleum usage by 2025. Research was conducted to assess different possible approaches for accomplishing this goal. The objective of this paper is to contribute to the body of work by looking at different generation mix sources under two different “states of the world scenarios” to provide insight into different technology approaches the USVI could pursue to achieve its petroleum reduction goal. The work can serve to support the body of research that is developing to help island states with similar energy infrastructure challenges and constraints throughout the world in transitioning off of petroleum based generation.

1.2 Context/baseline of problem

The U.S. Virgin Islands is heavily dependent on fossil fuels for power generation using diesel as the main fuel. St. Croix, St. Thomas and St. John, until recently have sourced this fuel from the large oil refinery (HOVENSA) that is based on St. Croix at a discount compared to the market price. All of this changed with the previously unannounced closing of the HOVENSA refinery in January 2012. HOVENSA was not only the fuel source for USVI power generation, but also the largest private employer, exacerbating the issue. With the closing of the refinery, 2,000 jobs were lost and the unemployment rate doubled from 9.6% to 18.7%.³

In the USVI, as in other small island economies, petroleum based power generation has been the standard due to a combination of factors including: historic lack of non-renewable energy resources, high energy content of petroleum, transportability and the established supply chain of global oil markets. The infrastructure dedicated to power generation reflects this dependency on petroleum fuels and presents one of the challenges in transitioning off of petroleum. Due to this dependency, in 2011, WAPA incurred fuel expenses of nearly $200 million dollars representing 91% of its production expenses, see 2011 WAPA Income Statement in the appendix. Up until the HOVENSA closing, sourcing diesel was not considered a challenge due to the

agreement and proximity of the refinery in St. Croix. However, the closing of HOVENSA has only added to the urgency in transitioning off of petroleum.

The USVI has a relatively small load demand, as exhibited in Figure 2. Due to the distance between the islands, there are two main power facilities that serve the electricity load of the USVI. The Randolph E. Harley Generating Station, with a rated capacity of 191 MW, serves St. Thomas/St. John and the Estate Richmond Generating Station, with a rated capacity of 117 MW serves St. Croix. Both of these stations are fully dependent on petroleum and have generators that date as far back as the late 1960s.

USVI Load Information (note: St. Thomas generation serves St. John)

<table>
<thead>
<tr>
<th>Island</th>
<th>Average Daily Peak</th>
<th>Annual System Peak</th>
<th>Average Loads</th>
<th>Minimum Loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>St. Thomas</td>
<td>78 MW</td>
<td>88 MW</td>
<td>65 MW</td>
<td>50 MW</td>
</tr>
<tr>
<td>St. Croix</td>
<td>50 MW</td>
<td>55 MW</td>
<td>40 MW</td>
<td>35 MW</td>
</tr>
</tbody>
</table>

Source: WAPA

Figure 2: USVI Load Demand

In 2010, the USVI electricity demand was approximately 900,000 Mwh. With projected growth of demand at 1.2% annually, electricity demand will grow to approximately 1,069,000 Mwh by 2025 per the business as usual (BAU) case. If we assume load grows at the same straight line rate, holding everything else constant, this would place average loads for St. Thomas at approximately 74 MW and St. Croix at approximately 46 MW for a total USVI load of 120 MW (current average load is 105 MW).

In order to meet the objective of reducing petroleum consumption 60% by 2025 from the business as usual case, NREL estimates that up to 36% of the load demand can be reduced through energy efficiency measures. Therefore, average generation load could be as low as 77 MW for the USVI if energy efficiency deployment mechanisms are successful. This paper considers two scenarios for assessing different generation technologies to help the USVI transition off of petroleum: Scenario A, successful deployment of energy efficiency programs
that reduce electricity demand 36% by 2025 and Scenario B, unsuccessful deployment of energy efficiency programs resulting in energy demand growing at 1.2% annually.

1.3 Review of other island economy efforts to transition off of petroleum

Hawaii\textsuperscript{4}

The state of Hawaii, albeit much larger than the USVI, shares similar challenges regarding their dependency on oil-fired power generation and shares similar aspirations for transitioning off of petroleum for power generation. Hawaii generates 90% of its electricity from petroleum-based power generation. In light of this, Hawaii’s electricity rates are more than double that of the continental U.S. In October 2008, the Hawaii Clean Energy Initiative was signed by the State of Hawaii, Hawaii electric companies and the state consumer advocate. The initiative’s goal is to reach 70% clean energy in power generation and transport by 2030.

To support this goal, Act 155 was passed in 2009 and established as state law that 40% of electricity sales must be from renewables along with 30% energy efficiency savings from baseline by 2030. In a report conducted by NREL in 2009, Hawaii is estimated to have 2,133 MW of renewable energy resources. Hawaii’s current total installed electricity capacity is 2,450 MW; therefore, renewable energy holds tremendous potential in helping Hawaii meet its goal and transition from oil-fired power generation.

Hawaii looks to source a significant portion of its renewable resource mandate from wind. Hawaiian Electric has pledged to increase its renewable portfolio by at least 1100 MW by 2030. The most notable project to date is the proposed 400 MW Big Wind project that is proposed for Molokai and/or Lanai. As Hawaii takes measures to meet its goal of 70% clean energy by 2030, the USVI and other islands economies will be able to gain best practices and insights from this effort.

ABB was awarded a project in 2011 to help El Hierro transition completely off of diesel based generation and become the world’s first island that is entirely powered by renewable energy. Although the island has about 10% of the population of the USVI, the project and efforts can serve to offer insight for the USVI as it works to transition off of petroleum based power generation.

The design of the project consists of 11.5 MW of wind and 11.3 MW hydroelectric pumped storage facility. These installations will provide approximately 80% of the energy needs of the island. The remaining 20% will be generated with Solar Thermal and Solar PV installations. The project is projected to cost $87 million dollars and ABB is helping lead the design and development of the system.

1.4 Framework for considering the problem

The need to transition from petroleum based power generation in the USVI and other island economies has received growing attention in recent years. Researchers are considering different means to help island economies diversify and develop more resilient energy systems. Most notably for the USVI, the National Renewable Energy Laboratory (NREL) was commissioned to conduct a study on how the USVI could reduce its petroleum consumption for power generation 60% by 2025. The Integrating Renewable Energy into the Transmission and Distribution System of the U.S. Virgin Islands was presented in September 2011 and focused on different ways the USVI could meet its goal by focusing on energy efficiency and renewable energy technologies.

The NREL report focused on different scenarios utilizing wind, solar and waste-to-energy (WTE) to help meet energy demand and reduce petroleum consumption to meet the USVI 60% reduction goal. NREL collected data

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from WAPA and USVI authorities to assess and model the current baseline energy demand, the current diesel power generation system, its fuel consumption, efficiencies and cost to produce electricity. NREL utilized the HOMER modeling software to compare the current baseline system in consideration of adding wind, solar and waste to energy with sensitivity to oil prices.

NREL found that 15 MW of wind at a capital cost of $2,500/kw is cost competitive at wind speed rates as low as 3.5 meters/second and fuel oil price as low as $0.50/liter (or approximately $80/barrel) making it a viable option at the time of the study.\(^6\) Therefore, the limit to wind is not considered cost, but the amount of wind resource available and the amount the current grid could feasibly manage without sacrificing reliability due to the variable nature of renewables. Solar was not cost competitive at current oil prices due to current capital costs. Solar would not become competitive until installed PV costs are below $5.50/W at oil prices of $0.50/liter.\(^7\) A 16 MW Waste-to-Energy (WTE) facility was also considered and found to be cost competitive in reducing the amount of oil consumed for base load generation while providing a means of managing the municipal waste produced annually in the USVI. However, public acceptance of WTE applications has yet to materialize as of the time of this report.

2. Project Overview

2.1 Approach taken for master’s project

Helping the USVI and other island economies transition off of petroleum based power generation has been addressed by organizations and research in recent history (as noted by the NREL report). In approaching this master’s project (MP), the objective is to add to the body of work assessing different means/options for island economies to reduce their dependence on petroleum-based power generation. The approach taken was to first assess the current body of work and findings regarding transitioning the USVI from petroleum power generation


\(^7\) NREL, 2011
and second, to develop a cost optimization model that evaluates the cost of meeting the USVI power demand by utilizing the levelized cost of electricity (LCOE) of generating technologies. The paper focuses upon two different scenarios: successful deployment of energy efficiency programs reducing electricity demand 36% by 2025 and unsuccessful deployment of energy efficiency programs resulting in 1.2% annual growth of electricity demand through 2025.

The USVI was selected due to a number of converging factors that make the territory an interesting case for the MP. Similar to other island economies, the USVI is entirely dependent on oil, is an isolated economy that is independent of other power infrastructure and has very high electricity prices in comparison to larger economies/power systems (50 to 55 cents/kWh).

Like other small island economies, it has a relatively small load demand/profile that facilitates different potential technology applications (85 MW average peak capacity for St. Thomas/St. John and 55 MW average peak capacity for St. Croix) in contrast to other regions that require larger applications due to energy demand. However, the USVI has several factors that have the potential to more readily facilitate a transition from petroleum dependency that include: a public goal of 60% reduction in petroleum consumption by 2025; the closing of the HOVENSA refinery and subsequent loss of a local oil hedge contract and resource support from the United States as a U.S. territory.

The work conducted by NREL to assess renewable energy integration into the current infrastructure served as a baseline to build upon with the MP research. The NREL “on the ground” analysis of USVI’s current power infrastructure was vital to developing the baseline/business as usual case that captures the current power generation system for the USVI and its subsequent cost and emissions performance.

The basis for framing the MP is to assess the two different scenarios along with the different generation sources/mixes that are cost competitive against the current generation system (baseline/BAU) and can help the
USVI meet its goal of reducing petroleum consumption for power generation 60% by 2025. The approach taken was to assess the research already conducted for the USVI and then conduct an analysis looking at different viable generation options. The two means of input for the analysis was a review of secondary research and to develop a cost optimization analysis using LCOEs for different generation technologies to determine the most cost competitive alternatives to the current baseline power generation system.

- Hypothesis
  - The USVI can effectively reduce its dependence on petroleum generation by 60% for power generation through current practices that are cost competitive compared with the current system in place.

2.2 Scope and limitations of master’s project

The scope of the MP focuses on the USVI, its resources and constraints. The research builds off of the body of work that NREL initiated in considering different renewable energy technologies for the USVI. The MP takes the analysis of the current power generation system to provide the baseline BAU scenario and utilizes current fuel cost estimates, post the HOVENSA refinery shutting down to update the baseline cost of operation. With the baseline for the current generation system, different generation technologies are considered to determine cost competitiveness and CO2 emissions.

The MP is focused primarily on two outputs: cost and carbon emissions. Dynamic considerations, such as variability in demand, constructability, integration efforts, transmission and distribution upgrades required from the different generation sources fall outside the scope of the work conducted for the MP and require further research.

Certain assumptions for renewable energy integration follow those made by NREL in their analysis. Renewable energy integration was limited to between 10 and 20% of expected demand to safeguard against grid reliability issues. The NREL data and assessment of the current WAPA power generation is utilized to provide insight to the system structure and baseline costs of operation. No significant, permanent changes were found to be made
to the USVI Water and Power Authority (WAPA) power generation system since 2011 and subsequent changes made to the system after this will not be factored into the BAU case.

2.3 Significance of the master’s project

NREL’s report took place pre-HOVENZA closing and assessed strictly wind, solar and waste to energy. This paper focuses on utility scale generation sources that will cost-effectively help the USVI transition off of petroleum and reduce carbon emissions. Technologies that would facilitate electricity import (e.g., underwater cables) were not considered in this report. The focus of the project is on “stand alone” power generation technologies that can help the USVI transition from petroleum generation without dependence on an external grid or generation system.

The generation technologies are evaluated against two electricity load demand scenarios: Scenario A where energy efficiency programs are successful in reducing electricity load demand 36% against BAU by 2025 and Scenario B where energy efficiency programs are not successful and electricity demand continues to grow at 1.2% annually through 2025. Generation technologies considered include: natural gas advanced combustion turbine, nuclear small modular reactors, solar PV, wind and Waste-to-Energy (WTE). These generation sources were evaluated against solution criteria that included:

- potential cost effectiveness in comparison to the current USVI power generation system baseline;
- technical feasibility
- ability to reliably meet demand;
- reduce petroleum consumption;
- and reduce carbon emissions.

Dependence on petroleum for power generation is not limited to the USVI, but is a challenge faced by island economies around the world.
“Small island developing states (SIDS) need to free themselves from dependence on fossil fuel imports and transform their energy sectors to encompass modern, efficient, clean and renewable sources of energy.” United Nations Secretary-General Ban Ki-moon at the Barbados Conference, May 7, 2012.8

Island economies currently spend upwards of 30% of their GDP9 on oil imports to power their grids and transportation systems. Therefore, this is an issue that has economic and ecological ramifications going forward for the development of these island economies. The MP research will serve to support the growing body of work to address the challenge of helping island states transition off of petroleum.

3. Materials and Methods

3.1 Cost optimization model

The purpose behind the cost optimization model is to assess different generation technology sources and their respective costs (utilizing LCOE’s) against the current USVI petroleum-based power generation system to determine the cost effectiveness of technologies that can support the transition from petroleum consumption. Two different scenarios are utilized to evaluate generation technologies: Scenario A where energy efficiency programs deployed reach full potential and energy demand is reduced 36% by 2025 and Scenario B where energy efficiency programs are not effective and energy demand continues to grow annually at 1.2% through 2025.

The USVI power generation system is modeled as one “representative generator” in the cost optimization model. Electricity demand for both St. Croix and St. Thomas/St. John are combined into one USVI demand. Total USVI demand for each hour of the day is balanced with power generation supply aggregated from the different generation sources evaluated and optimized based off of their respective LCOEs.

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9 UNDP, 2012
Model Design:

Objective function:

\[
\text{Min total cost} = \frac{\sum_i (\sum_{\text{Generation}_i} \text{LCOE}_i)}{\text{Total Generation}}
\]

where \(i\) is the type of generation source

\[\cdot\]

Subject to:

\[\cdot\] Supply \(\geq\) Demand

\[\cdot\] Generation, LCOE \(\geq\) 0

\[\cdot\] Generation sourced \(\leq\) generation availability

\[\cdot\] Context constraints: modeled as one representative generation system, 40% load served by BAU, Solar and Wind included, held hourly demand constant and utilized load profile of a representative day

Where \(\text{LCOE} = \frac{(\text{Capacity (kW)} \cdot \text{Capital Costs ($/kW)}) \cdot (\text{WACC} / (1 - (1 + \text{WACC})^{-\text{Equipment Life}}))}{\text{(Annual Electricity Production (kWH))}} + \text{Variable costs ($/kWh)}\)

Hourly energy demand (kWh) for the USVI is utilized from the data collected by NREL from WAPA. As NREL noted, “The variation in the load profile is minimal throughout the year due to the lack of seasonal variation of the tropical climate” and therefore random variability for demand was not built into the model due to minimal variation and subsequently the demand trend observed throughout the day was held constant (i.e., the demand trend modeled for one day is considered an average/representative day).
Inputs for LCOEs (e.g., heat rate, fuel costs, capacity factors, equipment life, fixed O&M costs and variable O&M costs) are sourced from published data to reflect current costs and LCOEs, see Figure 3.

<table>
<thead>
<tr>
<th>Generation Technology</th>
<th>LCOE ($/kWh)</th>
<th>LCOE ($/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAU (Diesel Gen)</td>
<td>$ 0.322</td>
<td>$ 322.316</td>
</tr>
<tr>
<td>Energy Efficiency</td>
<td>$ 0.050</td>
<td>$ 50.000</td>
</tr>
<tr>
<td>Waste to Energy</td>
<td>$ 0.122</td>
<td>$ 121.635</td>
</tr>
<tr>
<td>Advanced Combustion Turb</td>
<td>$ 0.103</td>
<td>$ 103.343</td>
</tr>
<tr>
<td>Wind</td>
<td>$ 0.102</td>
<td>$ 101.539</td>
</tr>
<tr>
<td>Nuclear SMR</td>
<td>$ 0.110</td>
<td>$ 109.587</td>
</tr>
<tr>
<td>Solar PV (Utility)</td>
<td>$ 0.170</td>
<td>$ 169.533</td>
</tr>
</tbody>
</table>

Figure 3: LCOE costs for generation technologies considered

The cost optimization model meets load demands by serving load with the lowest LCOE generation technologies first and utilizes the next lowest cost generator. This is similar to a supply, bid stack mechanism for power generation. Provided the scope of this MP, the output we are most interested in is the cost and carbon emissions of the technologies.

Technology integration and upgrading of new base load technologies will require more detailed analysis as to the influence on the existing power system design and required upgrades. These design considerations and requisite costs fall outside of the scope of the MP. The scenarios are provided through the context of “overnight” deployment considerations to provide context to potential cost and carbon savings. Further detailed analysis regarding integration and implementation measures will be required to deploy these technology considerations in the USVI.

4. Results and Observations

4.1 Baseline/business as usual case

The baseline/business as usual scenario considers the cost of the current system in place at today’s fuel prices under the assumption that nothing changes, no efficiency upgrades are made and the USVI stays entirely
dependent on diesel power generation. The baseline scenario follows closely to the data and information NREL collected regarding the hourly load demand, capacity and efficiencies of the equipment.

Fuel costs for the system were updated with current fuel prices of $124/barrel for #2 Fuel Oil$^{12}$ and $69/barrel ($610/mt) for #6 Bunker Oil$^{13}$ to determine what the current costs would be for operating the system. With these fuel costs, the LCOE for baseline changes to $0.281/kwh from the $0.265/kwh found by NREL when #2 Fuel oil prices were closer to $101/barrel illustrating the volatility of costs associated with the baseline scenario. At $124/barrel for #2 fuel oil and $69/barrel for #6 Bunker Oil, total cost (fixed and variable) of producing electricity with the current generation system for the USVI is $705,000/day, 5,277 barrels of oil are consumed/day and carbon emissions of 2,727 tons/day are released to serve the current annual demand of roughly 900,000 kWh at an average load of 105 MW for the USVI.

Total USVI fuel-spend for the year at current fuel prices equates to $228 million. To provide context for this number, with fuel prices at $101/barrel for #2 Fuel Oil and $85/barrel for #6 Bunker Oil, the USVI spent $199.5 million in 2011 on total fuel, see appendix. An argument can be made that WAPA has hedged contracts in place for oil that facilitate more cost competitive overall prices than current market rates. However, without knowing what USVI fuel prices are since the HOVENSA closing, for the purpose of this cost effectiveness analysis, the above market fuel rates and associated costs are utilized as baseline rates and considered to be the hurdle that other generation technology sources will be measured against to determine their cost and carbon emissions benefits.

Sensitivity analysis on fuel rates was conducted due to uncertainty of fuel costs in the future and the strong impact they have on the USVI economy. Sensitivity analysis to prices of #2 Fuel oil ranging from $70 to $150 per barrel was conducted to assess the total annual fuel cost of electricity production for the baseline scenario.

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oil

$^{13}$ IndexMundi, 2013
Figure 2 illustrates the total fuel spend for USVI electricity production varies from as low as $143 million/year to as high as $270 million/year depending on the price per barrel of #2 Fuel oil.

![Sensitivity of USVI Fuel Spend to #2 Fuel Price](image)

**Figure 4: USVI total fuel-spend sensitivity to #2 Fuel Oil prices.**

A similar sensitivity was conducted for #6 Bunker Oil prices to assess total USVI fuel spend sensitivity and to a lesser degree, we find a similar result where USVI fuel spend will vary from $214 million to $243 million when Bunker fuel prices range from $40/barrel to $100/barrel, Figure 4. This further reinforces the vulnerability USVI residents and businesses face in consideration of oil price volatility for their electricity costs.
4.2 Cost optimization analysis for 2025

Baseline case for 2025

To provide the business as usual baseline through 2025 for comparison with the two scenarios, electricity demand is projected to grow at 1.2% through 2025 from current levels of 900,000 MWh equating to total demand growth of approximately 20% and load of 1,069,000 MWh. To cover this growth in demand, WAPA would need to add approximately 42 MW of capacity to the current system which would represent an estimated additional cost of $59 million for a medium-speed diesel reciprocating engine to complement the current generation technology\textsuperscript{14}. The LCOE cost of producing electricity with the baseline case generation system with the added generation, holding fuel costs at $124/barrel for #2 Fuel oil and $68/barrel for #6 Bunker fuel, is $0.286/kWh and total fuel spend would be $271 million in 2025 at the current fuel prices. If we apply a fuel

\textsuperscript{14} U.S. Virgin Islands Water and Power Authority (WAPA). Retrieved February 20, 2013, from \url{http://www.viwapa.vi/Home.aspx}
escalator rate of 1.8%/year (above inflation)\textsuperscript{15}, the LCOE would then be 0.322/kWh and total fuel-spend would be about $310 million in 2025. Total straight line cost would be about $345 million to meet demand in 2025. Total oil used in 2025 to meet the demand is 2,386,000 barrels and total carbon emissions would be 1,182,000 tons/yr.

\textit{Scenario A: Energy Efficiency program deployment is successful reducing energy demand 36\% by 2025}

Under the assumption that energy efficiency programs are successful in reducing energy demand per the technical estimate of up to 36\%, energy demand that would have otherwise reached 1,069,000 MWh will be reduced to a total load of 684,000 MWh. Of this load demand, we assume that 40\% will still be serviced by the current petroleum-based generation technologies in place. We also consider current efforts by the USVI to deploy utility scale wind and solar PV and build in 21 MW capacity of wind and 18 MW capacity of solar (WAPA recently executed six Power Purchase agreements for 18 MW of solar). For unmet load, the Advanced Combustion Turbine (Advanced CT) is more cost competitive than the other technologies at a LCOE of $0.103/kWh (this factors in a natural gas cost escalator of 1.8%/year). An Advanced CT at a rated capacity of 165 MW will satisfy 46\% of the demand assuming that 40\% will be managed by the existing diesel system and 9\% is provided by wind and 5\% from solar.

\textsuperscript{15} NREL, 2011. U.S. Federal Energy Management Program’s projected diesel cost escalation rate for the continental U.S. over the next 25 years (1.8%).
The system above, given the constraints of RE and assumption that 40% of load will be served by the existing system, is the most cost competitive of the different generation technologies that can be deployed to meet the load. The total LCOE for the system is $0.174/kWh in comparison to $0.322/kWh for the baseline system for 2025. Petroleum fuel costs are reduced from $310 million to $124 million dollars and oil consumed would be reduced from 2,386,000 to 954,000 barrels annually. Carbon emissions are reduced by more than half from 1,182,000 tons/yr. in the baseline case to 692,000 tons/yr. Total costs for generating electricity are reduced from $345 million to $185 million for 2025.

**Scenario B: Energy Efficiency program deployment is not successful and demand load continues to grow at 1.2% annually through 2025.**

Under the assumption that energy efficiency programs are not successful in reducing energy demand per the potential estimate of up to 36%, electricity load demand would increase to 1,069,000 MWh. Of this load demand, we make a similar assumption that 40% will still be serviced by the current petroleum-based generation technologies in place. We consider the current efforts by the USVI to deploy utility scale wind and solar PV and build in 21 MW capacity of wind and 18 MW capacity of solar. In contrast to Scenario A, there is greater load demand to manage and subsequently greater generation capacity will be required to meet this demand.

The increased load provides the opportunity to utilize Advanced Natural Gas Combustion Turbine technology and has an LCOE of $0.103/kWh (with natural gas cost escalator factored in at 1.8%/year). Advanced Natural Gas Combustion Turbine technology can satisfy up to 51% of the demand assuming that 40% will be managed by the existing diesel system and the balance is serviced by wind and solar installations for a total system LCOE of $0.174/kWh.

Since WAPA appears to be moving forward with solar, per the executed PPAs, this was included into the analysis for the higher load demand rate along with wind at 18 MW and 21 MW, respectively. The total LCOE for the system of $0.174/kWh provides significant cost savings in comparison to $0.322/kWh for current baseline system. Petroleum fuel costs are reduced from $310 million to $124 million dollars and oil consumed
would be reduced from 2,386,000 to 954,000 barrels annually. Carbon emissions are reduced by more than half
from 1,182,000 tons/yr. in the baseline case to 682,000 tons/yr.

The 40% assumption for load served was an artificial constraint implemented to “back into” making sure a 60% petroleum consumption would take place. However, when taking away the 40% minimum load served by existing technology constraint, advanced natural gas combustion turbines serve nearly 91% of the residual load demand that is not served by wind and solar. The LCOE for the entire system falls to $0.106/kWh, total annual system costs to serve load are $113,000,000 and CO2 emissions fall to 555,000 tons/year. Total costs for generating electricity are reduced from $345 million to $206 million in 2025. Figure 6, illustrates the key results for the analysis.

<table>
<thead>
<tr>
<th>Key results for 2025</th>
<th>2025 Baseline</th>
<th>Scenario A: High EE</th>
<th>Scenario B: No EE</th>
<th>No BAU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Load Demand (MWh)</td>
<td>1,069,000</td>
<td>1,069,000</td>
<td>1,069,000</td>
<td>1,069,000</td>
</tr>
<tr>
<td>Avg. Load from Diesel Gen MWh (%)</td>
<td>1,069,000 (100%)</td>
<td>427,465 (40%)</td>
<td>427,600 (40%)</td>
<td>0%</td>
</tr>
<tr>
<td>Avg Load from Wind MWh (%)</td>
<td>0, (0%)</td>
<td>64,154 (6%)</td>
<td>64,140 (6%)</td>
<td>64,140 (6%)</td>
</tr>
<tr>
<td>Avg Load from Solar MWh (%)</td>
<td>0, (0%)</td>
<td>32,077 (3%)</td>
<td>32,070 (3%)</td>
<td>32,070 (3%)</td>
</tr>
<tr>
<td>Avg Load from Advanced CT MWh (%)</td>
<td>0, (0%)</td>
<td>160,383 (15%)</td>
<td>545,190 (51%)</td>
<td>972,790 (91%)</td>
</tr>
<tr>
<td>Energy Efficiency MWh (%)</td>
<td>0%</td>
<td>384,921 (36%)</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Total Load Served (%)</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>System LCOE ($/kWh)</td>
<td>$0.322</td>
<td>$0.174</td>
<td>$0.193</td>
<td>$0.106</td>
</tr>
<tr>
<td>Total Annual Oil Costs ($MM)</td>
<td>$310,000,000</td>
<td>$124,000,000</td>
<td>$124,000,000</td>
<td>0</td>
</tr>
<tr>
<td>Total Annual Cost of Electricity ($MM)</td>
<td>$345,000,000</td>
<td>$185,000,000</td>
<td>$206,000,000</td>
<td>$113,000,000</td>
</tr>
<tr>
<td>Annual Total Oil Consumed (bbls)</td>
<td>2,386,000</td>
<td>954,404</td>
<td>954,000</td>
<td>0</td>
</tr>
<tr>
<td>Annual Total CO2 Emissions (tons)</td>
<td>1,182,000</td>
<td>692,000</td>
<td>682,000</td>
<td>555,000</td>
</tr>
</tbody>
</table>

Figure 6: Key results from cost optimization analysis

From the analysis results, we see a cost savings of approximately 21 million dollars between the Scenarios A & B where energy efficiency measures are deployed effectively up to the point of reducing load 36% from the 2025 baseline. A sensitivity analysis was conducted to determine the impact of energy efficiency deployment (% load reduction), LNG prices and the impact on system operating costs. Findings illustrate that successful implementation of energy efficiency measures that reduce load provide a significant hedge against LNG price volatility resulting in system cost savings as low as $12 million up to $60 million when LNG prices range from
$5/mmbtu up to $20/mmbtu depending on the depth of energy efficiency reduction in load. Therefore, energy efficiency may provide a greater value as a hedge against fuel price volatility, see figure 7.

![Figure 7: WAPA cost sensitivity to LNG prices and energy efficiency program implementation](image)

5. Discussion

5.1 Key findings

Each of the scenarios (A, B and No BAU) help in facilitating a reduction in dependency on petroleum based power generation due primarily to their lower LCOEs and subsequent costs to produce power in comparison with the costs to produce power with the current baseline/business as usual case.

Scenario A is contingent on the success of energy efficiency programs by 2025 to reach the 36% reduction in load demand. Should this scenario be successfully implemented, it holds the greatest cost savings and CO2 emissions reduction for the USVI. Scenario A provides an annual total cost of electricity of $185 million, which is $21 million less than Scenario B. There are two ways to look at this cost savings, albeit not mutually exclusive. Energy efficiency programs hold great promise and materialize in the form of 21 million dollars in savings/year for WAPA and its customers in 2025 and/or this is the cost hurdle that energy efficiency, at 36%
load reduction, must beat to be considered cost effective. Although, as the sensitivity analysis illustrated, the benefit of reduced load from energy efficiency programs provides an avoided cost hedge that arguably provides greater value than the first-order, reduced operation costs.

Scenario A utilized Advanced CTs fueled with natural gas due to their low LCOE and smaller demand required. As the USVI and WAPA work to transition from diesel/bunker fuel and replace the combustion turbines that utilize these fuels, Advanced CTs could more able to fit within the current footprint of infrastructure in place helping to mitigate potential siting/green field development and constructability issues. Since the power generation infrastructure is split primarily between two different systems that serve St. Thomas/St. John and St. Croix, the combustion turbines arguably provide a more appropriate means of transitioning considering current infrastructure.

Scenario B considered a more extreme view where energy efficiency programs would not be successful nor have an impact on the growth of electricity demand through 2025. Although this is an extreme consideration and some gains can be expected to be made with energy efficiency programs, to what extent it remains unclear and this provides a “worse case” scenario to determine what generation technologies can help the USVI meet its goal of reducing petroleum consumption 60% by 2025 and be the most cost effective in doing so.

Total annual cost of electricity is $206 million dollars for 2025. This is higher than Scenario A; however, the electricity demand in Scenario B is approximately 56% greater, whereas total electricity costs increase only 11%. Much of this cost savings can be attributed to the Advanced Natural Gas Combustion Turbine technology low LCOE, lower heat rate and respective operational efficiency in comparison to the other generation technologies.

In summary, both scenarios present significant cost and CO2 emission savings in comparison with the business as usual case in 2025. Operation costs can be driven down further if existing diesel generation is utilized less due to its high costs of operations. Therefore, investment decisions will be contingent on many factors that
include measures taken to manage electrical load demand, approach to utilization/upgrading existing facilities and performance of fuel prices going forward.

5.2 Potential limitations of the scenarios

Both scenarios make a few key assumptions: 60% is the maximum reduction in diesel/bunker fuel generation reduction, wind and solar will be deployed (based off of recent WAPA activities) and utilization of natural gas fired technologies that include Advanced CT. Should any of these assumptions change, the end results could provide very different outcomes. The 40% utilization of existing diesel generation assets was assumed to serve as a proxy for the goal of reducing petroleum 60%. These assets could be used less and greater cost savings would be exhibited; however, for this assessment, 40% was used as a constraint to verify a 60% reduction would be in effect.

Solar and wind are considered in the analysis per resource and cost estimates supported by WAPA and NREL. However, to date, small numbers of both solar and wind have been deployed in the USVI. Community issues regarding siting/permitting could delay these generation sources from reaching their potential generation levels.

Advanced CT holds great promise for helping the USVI transition off of diesel based power generation. However, these technologies are contingent on a reliable supply chain of natural gas. For the USVI, this will require receiving LNG to fuel these facilities. The USVI is currently in the process of evaluating the potential of small-scale LNG carriers to receive LNG from the Ecoelectrica LNG terminal in Puerto Rico. These small scale carriers could stage off the coast of the USVI and provide storage as an intermediary step in transitioning to greater natural gas generation. For Advanced CT to be considered viable, a secure and reliable LNG supply chain will need to be established.

5.3 Limitations of the project

A cost optimization model was utilized with respect to LCOE’s for the respective generation technologies considered to provide insight regarding cost effectiveness for the USVI. This work should be considered as a
preliminary step in considering what potential generation could help the USVI meet its goal of reducing petroleum-based power consumption 60% by 2025 in a cost effective and carbon conscious manner.

Dynamic considerations regarding energy demand trends, technology implementation/integration and technical/efficiency impacts of the different generation scenarios on the current generation system are not captured in the analysis and respective costs. Therefore, the findings of this study should be used more so to provide perspective to what generation technologies are worth conducting further analysis on for helping the USVI transition from petroleum.

5.4 Significance of results

The most significant takeaway from the results is that each of the scenarios are cost competitive in comparison to the business as usual case in helping the USVI transition off of petroleum-based power production. This finding should provide positive reinforcement to take action in transitioning off of petroleum-based power generation. NREL research for the USVI did not consider the potential of natural gas generation for the USVI. The findings from the paper provide strong support for looking further into the potential of utilizing natural gas generation to help the USVI transition from diesel and bunker fuels for combustion turbines. The paper also illustrates the value of successfully implementing energy efficiency programs to help manage electricity demand load. The results illustrate that the USVI can capture significant cost savings, reduce carbon emissions and achieve its goal of reducing petroleum consumptions 60% for electricity generation.

5.5 Suggestions for further research

The work conducted in this project helps build the case and support the hypothesis that the USVI can meet their goal of reducing petroleum fuel dependency 60% for power generation by 2025 at measures that are cost competitive with the current baseline. The cost optimization analysis helps provide some context regarding different generation technologies that can be deployed. Further technical analysis needs to be conducted to consider cost of integration with the current system and the technical and economic considerations involved with upgrading the system to handle the new generation sources. Technical feasibility studies regarding the
different generation sources should be commissioned to provide greater certainty that the different technologies are appropriate for the USVI-specific application and its unique system characteristics. Energy efficiency deployment will play a vital role in helping the USVI meet its goal and further cost/benefit analysis and roadmap development to achieve key targets will be beneficial to the success of these efforts. In addition, further analysis is needed to determine the viability of a secure and reliable LNG supply chain for the USVI in consideration of natural gas fired generation technologies.

6. Conclusion

The USVI, like many other island economies, is entirely dependent on petroleum fuels for power generation. Due to the economic and environmental ramifications of this, the USVI has established a goal of reducing petroleum based power generation 60% by 2025. The USVI is not alone in their efforts to transition off of oil and island economies like Hawaii and the Canary Islands are deploying different efforts to facilitate the transition. The objective of this master’s project was to assess different generation technologies that have the potential to help the USVI transition off of petroleum based generation and do so in a manner that is cost competitive while considering CO2 emissions.

Through utilizing previous research conducted by NREL on the baseline generation system in the USVI, different generation technologies considered include: Nuclear small modular reactors, Advanced Combustion Turbines, Solar PV, Wind and Waste-to-Energy. Two scenarios provided different frameworks to evaluate the different technologies. LCOEs and cost optimization methods were used to meet demand requirements. Through the analysis, it was found that each of the different scenarios (and respective technologies considered) are cost competitive with the current baseline system in the USVI and help to reduce carbon emissions in the process. These findings support the hypothesis that the USVI can reach its goal of reducing petroleum based power generation 60% by 2025.
References


Appendix

NREL USVI Roadmap through 2025
Electric System of the Virgin Islands
Water and Power Authority

Statements of Revenues, Expenses, and Changes in Net Assets

<table>
<thead>
<tr>
<th>Year Ended June 30</th>
<th>2011</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating revenues:</td>
<td></td>
<td></td>
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<tr>
<td>Electricity sales to customers</td>
<td>$61,277,675</td>
<td>$62,358,942</td>
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<tr>
<td>Electricity sales to Virgin Islands Government</td>
<td>11,935,201</td>
<td>14,005,366</td>
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<tr>
<td>Fuel escalator revenues</td>
<td>201,665,152</td>
<td>171,605,725</td>
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<tr>
<td>Payment in lieu of taxes</td>
<td>500,827</td>
<td>507,559</td>
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<tr>
<td>Line Loss Surcharge</td>
<td>1,819,407</td>
<td>1,653,702</td>
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<tr>
<td>Other operating revenues</td>
<td>3,271,311</td>
<td>3,058,120</td>
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<tr>
<td>Bad debt expense</td>
<td>(1,014,590)</td>
<td>605,609</td>
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<tr>
<td><strong>Total operating revenues</strong></td>
<td><strong>279,454,983</strong></td>
<td><strong>253,796,023</strong></td>
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<tr>
<td>Operating expenses:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel</td>
<td>199,488,026</td>
<td>174,900,464</td>
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<tr>
<td>Operations and maintenance</td>
<td>19,567,332</td>
<td>17,140,531</td>
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<tr>
<td><strong>Total production expenses</strong></td>
<td><strong>219,055,358</strong></td>
<td><strong>192,040,995</strong></td>
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<tr>
<td>Distribution</td>
<td>10,728,556</td>
<td>10,761,968</td>
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<tr>
<td>Customer service</td>
<td>5,855,295</td>
<td>5,424,412</td>
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<tr>
<td>Administrative and general</td>
<td>28,225,258</td>
<td>25,361,349</td>
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<tr>
<td>Payment in lieu of taxes</td>
<td>500,000</td>
<td>500,000</td>
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<tr>
<td>Depreciation and amortization</td>
<td>19,237,331</td>
<td>19,197,572</td>
</tr>
<tr>
<td><strong>Total operating expenses</strong></td>
<td><strong>283,601,798</strong></td>
<td><strong>253,286,296</strong></td>
</tr>
<tr>
<td>Operating (loss) income</td>
<td><strong>(4,146,815)</strong></td>
<td>509,727</td>
</tr>
<tr>
<td>Nonoperating revenue (expense):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interest expense</td>
<td>(14,386,344)</td>
<td>(13,929,213)</td>
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<tr>
<td>Investment earnings</td>
<td>1,166,274</td>
<td>724,856</td>
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<tr>
<td>Allowance for funds used during construction</td>
<td>917,583</td>
<td>2,013,753</td>
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<tr>
<td><strong>Total nonoperating expenses</strong></td>
<td><strong>(12,302,487)</strong></td>
<td><strong>(11,190,604)</strong></td>
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<tr>
<td>Capital grants and contributions</td>
<td>5,001,622</td>
<td>3,214,364</td>
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<tr>
<td>Decrease in net assets</td>
<td>(11,447,680)</td>
<td>(7,466,513)</td>
</tr>
<tr>
<td>Net assets, beginning of year</td>
<td>93,113,118</td>
<td>100,579,631</td>
</tr>
<tr>
<td>Net assets, end of year</td>
<td><strong>$ 81,665,438</strong></td>
<td><strong>$ 93,113,118</strong></td>
</tr>
</tbody>
</table>

*See accompanying notes.*