GRENADA

TECHNOLOGY NEEDS ASSESSMENT

MITIGATION REPORT

FEBRUARY 2018

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Executive Summary

The Technology Needs Assessment is a global project geared towards assisting parties to the UN Kyoto Protocol to determine their technology priorities for greenhouse gas emission reduction and climate change adaptation. This report focuses on the TNA- mitigation, which was conducted to determine and prioritize technologies for reducing greenhouse gases in Grenada.

The project commenced with a comprehensive analysis of policies that drive development and climate change mitigation decisions. In this regard, the Growth and Poverty Reduction Strategy for Grenada served as one of the main documents for determining the sustainable development of Grenada. From this perspective, some social, environmental and economic strategic objectives were gleaned from the policy document.

However, the climate change vision and the goal of greenhouse gas reductions enshrined in the Nationally Determined Contributions (NDCs) formed was key t formulating the context for selecting the sector/sub-sector and overall aim for this analysis. The climate change policy states:

"An empowered Grenadian population capable of managing the risks from climate change with emphasis on pursuing a low carbon development pathway and building resilience at the individual, community and national levels".

While the emissions reduction goal is:

"Grenada commits to reducing Greenhous gas emission by 30% of 2010 by 2025, with an indicative reduction of 40% of 2010 by 2030"

The NDCs further identified four (4) sectors in which GHG emissions reduction can occur: electricity, waste, forestry and transportation. A comprehensive analysis of the current GHG reductions in each of these sectors revealed the energy, including domestic transportation, accounted for about 70% of all emissions. These findings were tabled at a number of stakeholder meetings, including with the TNA Coordinator and the cabinet appointed Sustainable Development Council (SDC) and it was agreed that the Energy, with transportation and waste as sub-sectors will be the focus of this analysis. This is shown in the table below.

Sector	Sub-sectors
Energy supply and consumption	Transport
	Waste

A comprehensive analysis of the energy sector was selected for prioritization. In this regard, the National Energy Policy for Grenada included goals on renewable energy and energy efficiency. Coupled with the targets established by the NDCs, the main aim/goal of the TNA analysis is to address the use of renewable energy technologies for energy (electricity) production, while analyzing potential technologies for energy efficiency. From this perspective a long list of technologies were also tabled at the stakeholder meetings, including with TNA Coordinator for further prioritization.

At a 2-day workshop held on the 31 January and 1 February, 2018, decision context and prioritization of the technology options were conducted. Using the multi-criteria analysis approach, seven technology options were suggested to the TNA Committee for consideration.

At the meeting of the TNA Committee held on the 28-02-2018, the committee agreed that the technologies for energy production and consumption to be analyzed for barriers and suggested enabling framework will be: solar PV (both grid-ties and stand-alone); LEDs; biogas; and high efficiency HVAC systems. It was further agreed that electric plug-in vehicles will also be included under the transportation sub-sector for further a similar further analysis.

(Sub) sector	**Technology options**
Electricity production and consumption	Solar PV- grid tied and stand-alone
	LEDs
	Biogas
	High efficient HVAC Technologies
Transportation	Electric plug-in vehicle

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List of Acronyms

BAU	Business-as-usual
CFCs	Chloroflourocarbons
DTU	Technical University of Denmark
GHGs	Greenhouse gases
GOG	Government of Grenada
GRENLEC	Grenada Electricity Services
GPRS	Growth and Poverty Reduction Strategy
GSWMA	Grenada Solid Waste Management Authority
HFCs	Hydroflourocarbons
LPG	Liquid Petroleum Gas
MCA	Multi- criteria Analysis
NDC	Nationally Determined Contributions
NGO	Non-Governmental Organization
NADMA	National Disaster Management Agency

NAWASA	National Water and Sewage Authority
NEP	National Energy Policy
SDC	Sustainable Development Council
SDGs	Sustainable Development Goals
SNC	Grenada Second National Communication to the UNFCCC
TNA	Technology Needs Assessment
UNFCCC	United Nations Framework on the Convention for Climate Change
UNDP	United Nations Development Program
WAM	With Additional Measures
WEM	With Existing Measures
WPM	With Potential Measures

Chapter 1: Introduction

This report describes the Technology Needs Assessment- Mitigation process and reports on the results of the prioritization of the technology options for climate change mitigation. After the sector/sub-sectors and the context for the TNA were agreed, the multi-criteria analysis method was used to prioritize a long list of technologies options.

The report therefore contains three chapters. In chapter one, a comprehensive overview of the policies that drive sustainable development and climate change decisions in Grenada were outlined. The chapter also described the four main sectors in which the analysis could occur and the explained how a priority sector/sub-sectors was selected.

I chapter 2, the institutional arrangements and stakeholder engagement process for the TNA was explained. In chapter 3, the technology prioritization for the selected sector: energy (transportation and waste), was fully explained. In this regard, the objective for the TNA-mitigation was outlined; the decision context was further expanded upon for the selected sector; the prioritization process was explained and the results were reported.

A summary of the report and next steps concludes the report.

1.1 About the TNA process

The Technology Needs Assessment (TNA) is a global project, implemented by the UNEP/DTU partnership. The project is into its second phase. Grenada is one of twenty-six (26) countries participating in the second phase of the project, which started in 20114.

The main aim of the TNA project is to assist countries, which are Parties to the United Nations Framework Convention in Climate Change (UNFCCC), to determine their technology priorities for greenhouse gas emissions reduction and adaptation to climate change pressures.

1.2 Existing policies on climate change mitigation and development priorities

Grenada's overarching policy direction is generally guided by the Grenada Growth and Poverty Reduction Strategy (GPRS), 2014-2018. The strategy is premised on the idea of "pro-poor growth as, growth which reduces the level of poverty' (GPRS, 2015: 40). In this regard, the GPRS notes that the transition to a 'New Economy' "driven primarily by endogenous knowledge, technology, innovation and entrepreneurship" is imperative. To achieve this shift the following thematic areas are in focus:

- Building resilience
- Developing competiveness with equity
- Reducing vulnerability
- Strengthening governance and security

For each of these themes, priority areas and key strategic objectives are identified. These objectives can be categorized into social, environmental and economic pillars, thus encompassing an integrated process of sustainable development. In the context of the Technology Needs Assessment, a sample of relevant strategic objectives are summarized in table 1-1. As shown in the table, it is suggested that some objectives will not fit exactly into one pillar, therefore more than one objective will appear under more than one pillar. This is an indication of the cross-cutting nature of sustainable development.

Table 1-1: Some relevant strategic objectives to guide the TNA-Mitigation

Sustainable development pillar	Strategic objectives
Economic pillar	Boosting growth and job creation
	Up-scaling investment in the development of clean and renewable energy resources
	Energy development and energy security
Social pillar	Development of health and wellness
	Energy development and energy security
	Promoting of accessible and relevant education and vocational training
	Policy intervention to support gender equality
Environmental pillar	Up-scaling investment in the development of clean and renewable energy resources
	Climate and disaster proofing development initiatives

Adapted from the GPRS, 2014

Grenada's further commitment to sustainable development was reinforced in 2015, with the address delivered at the United Nations Conference to adopt the sustainable development goals (SDGs). In this regard, it was noted that partnerships could point the way forward to better education, more innovation and more jobs in efforts to reduce poverty and inequality. It was indicated that this approach demonstrates the integrated nature of the SDGs, including SDG 1 on poverty, SDG 5 on gender, SDG 8 on employment and SDG 9 on industry and innovation.

More specifically and in line with the fact that Grenada is a Small Island Developing State, the address focused attention on the greening of Grenada's economy with the creation of a new Electricity Supply Act with a view to going 100% renewables. This initiative is congruent with SDGs 7 and 13, which focus on affordable energy and climate change, respectively. To date (Jan 2018) a more comprehensive Sustainable Development Plan is under preparation.

Moreover, for the TNA- Adaptation, three (3) fundamental objectives that capture the key pillars of the sustainable development of Grenada are adapted for the TNA-Mitigation. These are to contribute to:

1. sustainable economic development
2. poverty reduction through increased employment or income
3. climate change mitigation and protection of the environment

Transitioning to the new economy-focused on blue-green economy and moving on to a path of sustainable development, require a concerted effort to mitigate and adapt to climate change. In the context of this analysis, mitigation is in focus. In this regard, the National Climate Change Policy for Grenada, Carriacou and Petite Martinique, 2017-2021, was adopted in 2017. The policy provides the most comprehensive direction for climate change through its vision and objectives. The objectives that appear to be most relevant to mitigation are reported along with the vision statement. Firstly, the vison for dealing with climate change is:

“An empowered Grenadian population capable of managing the risks from climate change with emphasis on pursuing a low carbon development pathway and building resilience at the individual, community and national levels”.

According to the policy, all levels of Grenadian society, including Government; citizens, communities and consumers; companies; research institutes and civil society groups and NGOs will be empowered to respond to climate change in a manner that is consistent with realizing their opportunities. To achieve this vision by 2021, the policy outlines eight (8) objectives. The ones that appear to be most relevant to climate change mitigation are to:

- Strengthen institutional structure to support coordination, mainstreaming and implementation of climate change adaptation and mitigation action and the systematic integration of climate change adaptation into development policies, plans, programs, projects, budgets and processes
- Facilitate climate smart (low carbon, climate resilient) infrastructure location, planning, design and maintenance, and sustainable land management and reduce greenhouse gas (GHGs) the electricity, transport, waste and forestry sectors.
- Strengthen institutional arrangements for the collection, storage, analysis, sharing and use of climate, GHG emission and pollution/chemical data and information to inform Evidence-Based Decision Making
- Access climate technologies for mitigation and adaptation along with capacity building and increase external climate fiancé support to Grenada’s adaptation and mitigation

To make this vision and objective operational, and as a commitment to climate change mitigation, the Government of Grenada (GOG), announced its mitigation or GHG emissions targets in the country’s Nationally Determined Contributions (NDC) In this regard:

“Grenada commits to reducing Greenhous gas emission by 30% of 2010 by 2025, with an indicative reduction of 40% of 2010 by 2030”

Four sectors were selected by the GOG for mitigation action: electricity; transport; waste and forestry.

Driven by the overarching strategy for growth and poverty reduction and more specifically by the vision for climate change and the sustainable development of Grenada, the sectors suggested by the NDCs are considered. These are discussed and analyzed for proposing and selecting appropriate sector(s)/sub-sector(s) for the TNA-mitigation.

1.3 Sector selection

This section describes the four sectors that are articulated in the NDC as the official sectors identified by the GOG and the eventual sector/sub-sectors agreed for analysis. A synopsis of the process for selecting the sector/sub-sectors is also done. The information for this section is adapted from the Grenada Second National Communication to the United Nations Framework Convention on Climate Change, 2017 (SNC). The sectors are first analyzed in this context, with transportation subsumed under the electricity sector and industrial processes, which represents a substantive increase in GHGs due to the refrigeration and air conditioning sector and closely relates to the electricity sector.

1.3.1 An overview of sectors, projected climate change, GHG emissions status and trends of the different sectors

Energy (including domestic transportation)

The energy and domestic transport sub(sector) is based on imported refined hydrocarbon products. In this regard, diesel, kerosene, gasoline, liquid petroleum gas (LPG) are the key products used for the generation of electricity, domestic transportation, and other commercial and domestic activities, including household and commercial cooking. According to the SNC (2017):

Based on this significant reliance on fossil fuels the increase in GHG emissions were significant in the period 2000 to 2014. For the Energy (including domestic transport) sub-sector GHG emissions in 2000 was 212.8 Gg CO_2e and rose to 285.5 Gg CO_2e in 2014, an increase of 34.2%. This increase was mainly attributed to Energy industries (power plants)”.

Industrial processes

Two key sources of GHG emissions are identified in the SNC (2017): food and beverage manufacture and -gases (HFCs and SF6). However, only the emission trends for the F-gases source was estimated. In this regard, “For the Industrial Processes, sub-sector GHG emissions in 2000 was 1.4 Gg CO_2e and rose to 58.3 Gg CO_2e in 2014, 41 times the 2000 figure. This increase was mainly attributed to the dramatic increase since 1995 as chlorofluorocarbons (CFCs) banned by the Montreal Protocol were substituted by other agents”. There is significant potential for GHG reduction in this sector through the transition to more energy efficient technologies, including the use of alternative to F-gases in the Refrigeration and air conditioning sector.

Agriculture, forestry and other land use (AFOLU)

The main component of this sub-sector considered in the SNC (2017) is forestry as indicated in the NDC. In this regard, the SNC (2017) notes:

In spite of ravages to the main commercial crops, namely nutmeg and cocoa, emissions from the sub-sector in 2000 was 16.6 Gg CO_2e and rose modestly to 18.3 Gg CO_2e in 2014, a meagre increase of 9.3 %. This small increase was mainly attributed to drought conditions even in the rainy season and to the destruction of crops caused by tropical storms and hurricanes. But enteric fermentation from animals and manure management showed slight increases in CH_4 emissions.

For the Forestry and Other Land Use sub-sector GHG emissions/removals in 2000 was 0.2 Gg CO_2e and 0.0 Gg CO_2e in 2014. This trend in this sub-sector was mainly because in 2004 and 2005 the sub-sector became a source of GHG emissions (887.1 Gg CO_2e instead of a sink following ravages of the forests and other ecosystems by Hurricane Ivan (2004) and Tropical Storm Emily (2005): the fermentation of the destroyed forests and other ecosystems led to GHG emissions. But starting in 2006 and leading up to 2010, the regrowth of the forests and other ecosystems led the sub- sector to become once again a sequestration sink (-177.4 Gg CO_2e).

It is noted therefore that the significance of this sector to GHG emission is low.

Waste

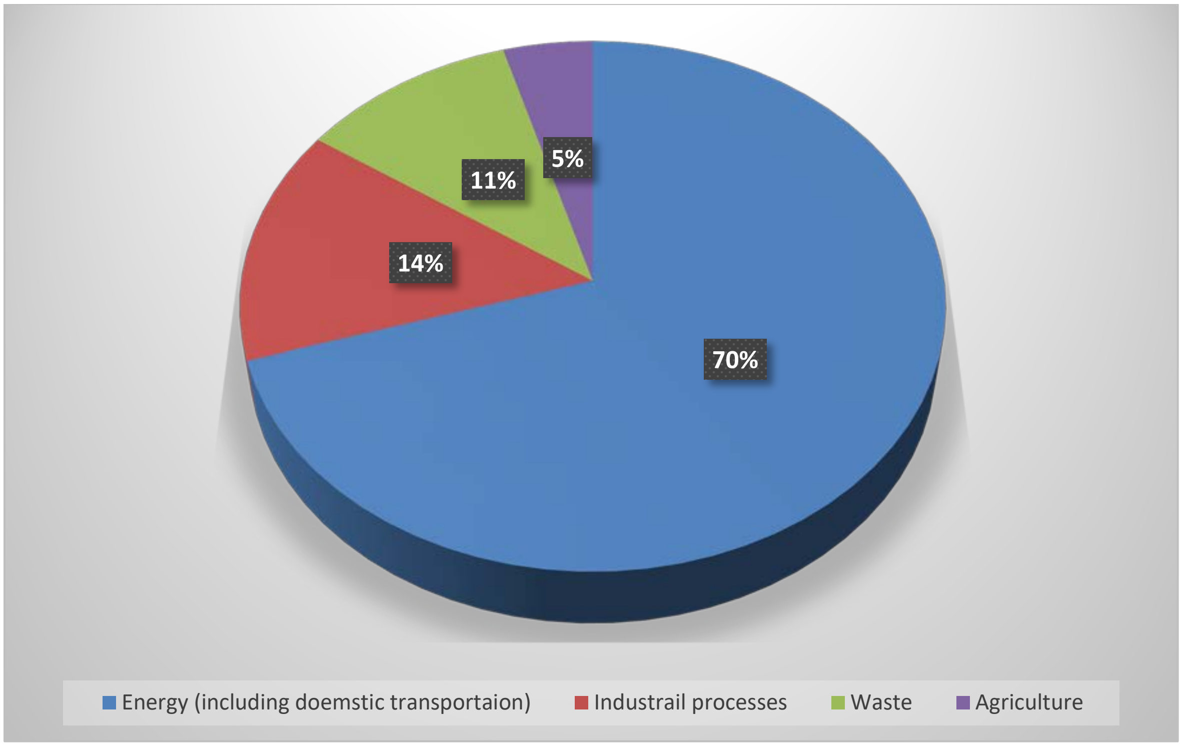
The waste sector includes the collection and disposal of solid waste and the handling of waste water. As it relates the former, the majority of solid waste generated is landfilled at two main sites: one on the main island of Grenada and the other on the smaller island of Carriacou. There is only one main sewage handling system in Grenada, which is located in the town of St. George's and in the south of the island.

The SNC (2017) summarizes the GHG emissions, which are only methane and nitrous oxide as follows:

"For the waste sub-sector, the main GHG emitted is Methane (CH_4) from landfills and wastewater handling. For the Waste, sub-sector GHG emissions in 2000 was 41.2 Gg CO_2e and rose to 44.5 Gg CO_2e in 2014, an increase of 8%. This increase was mainly attributed to the slight increase in population and residential, commercial and industries, especially tourism related activities, generating more solid waste and waste water".

Figure 1-1 summarizes the GHGs emissions for all the sectors/sub-sectors identified in the NDC and SNC.

Figure 1-1: Shares of GHG emission estimates for 2014



Adapted from the SNC, 2017

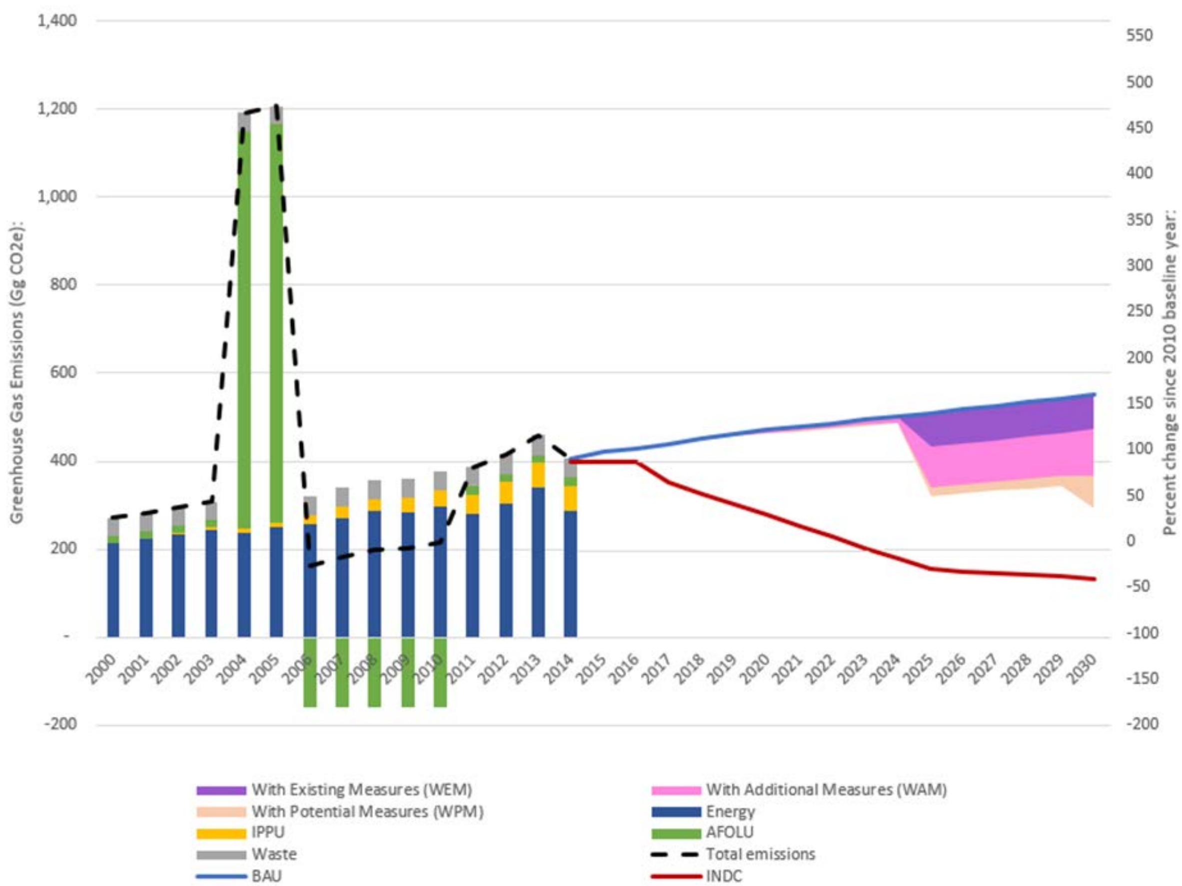
According to the SNC (2017) report, an analysis of the future projections of climate change mitigation or GHG reduction was conducted under the following scenarios:

- The NDC scenario (dark red line) shows the planned path to the target of a 30% reduction by 2025, and the indicate target of a 40% reduction by 2030 compared to a 2010 baseline.
- The BAU baseline (blue line) suggests that, due to projected GDP growth (forecasted to grow approximately 4 % per year between 2014 and 2030) (IMF, 2014), energy demand (and associated emissions) are likely to steadily increase to 2030. This represents a challenge for Grenada. However, it also offers opportunities to achieve economies of scale and reasonable returns on investment in renewable energy generation and energy efficiency implementation.
- The 'With Existing Measures' (WEM) scenario (purple area) includes implemented actions or actions in an advanced planning stage. These actions are most likely to be implemented. They assume no further action beyond those specified in the action plan. Any additional carbon reductions planned would be included under WAM and or WPM.

- The 'With Additional Measures' (WAM) scenario (pink area) includes additional actions deemed possible in the medium to long-term that are reasonably certain to be undertaken, including implementation beyond 2020 or 2025.
- The 'With Possible Measures' (WPM) scenario (orange area) includes any additional actions deemed possible in the medium to long-term, utilizing the near-full potential for identified renewable energy sources in Grenada and would mainly be implemented beyond 2025.

The results of these analyzes are shown in figure 1-2.

Figure 1-2: Future GHG emissions reduction under various scenarios



Adapted from the SNC, 2017: 272

The observations and suggestions emanating from this analysis were adequately summarized in the SNC (2017: 272):

The analysis confirmed that the implementation of intermittent (wind and solar) and non-intermittent (cogeneration and Waste-to-Energy) energy sources would contribute to reduce GHG emissions. However, the analysis further revealed that due to economic growth, the Government should make sure its focus includes ensuring that efforts are sustained beyond 2020. Furthermore, the analysis suggests that adequate emphasis should be put on developing a low-carbon economy, This focus will then reduce electricity generation costs as well as GHG (particularly CO_2) emissions and Grenada's long-term dependency on fossil fuels.

This point of departure was used to present the argument for the eventual selection of the sector and sub-sectors to be analysed.

1.3.2 Process and results of sector selection

The sector selection process was initiated by the consultant, through a comprehensive document analysis outline previously. The key sectors suggested were those in the NDC: electricity, transport, waste and forestry. Using guidance from the SNC and other key policy directions, the following merging of sector and subsectors were suggested.

The energy supply and consumption sector was suggested as the key sector for analysis; waste incorporated as a sub-sector. The rationale for this suggestion is based on the fact that in the waste sector technologies for GHG reduction are predominantly focused on waste-to-energy technologies. As a consequence, these technologies will be long-listed for further analysis.

With this suggestion, three separate meetings were convened to discuss the proposal. The first meeting was the Ministry of Energy Finance- Economic and Technical Cooperation Division, which is represented at on the TNA Committee. The second meeting was held with the PS for the Environment, who is the TNA Coordinator and Ambassador for Multi-lateral Agreements. The third meeting was convened with the Energy Division of the Ministry of Finance and Energy. At these meetings, the suggestion for using the Energy sector, with waste considered as sub-sector was agreed.

From the meeting with the PS and Ambassador, it was suggested that he proposal be tabled at a wider stakeholder forum- the Sustainable Development Council (SDC). The SDC is a Cabinet appointed body of various stakeholders, including the private sector, government, academia, and other civil society organizations. The proposal as suggested before was agreed.

The final decision on the sector and subsector, was tabled at the final 2-day stakeholder consultation. At this consultation key stakeholders representing organizations such as: the Energy Division, Ministry of Finance and Energy; Grenada Solid Waste Management Authority (GSWMA); Grenada Electricity Services (GRENLEC); National Water and Sewerage Authority (NAWASA); the National Disaster Management Agency (NADMA) and other renewable energy companies and Non-Governmental Organizations. The stakeholders at the workshop were in agreement with the suggested sector and sub-sectors.

The transport sector was also further incorporated into the energy sector following the trend in the SNC. In this regard, and at the two wider stakeholder consultations, it was agreed that the transportation sector is again subsumed under the energy sector. In this regard, the use of electric vehicles as a proposed technology for mitigating climate change was agreed. With one proposed technology a presentation was done by the Grenada Electricity Services on the project the company is undertaking with electric vehicles. It was agreed therefore that once the energy sector is transitioned to a sustainable energy system, then EVs can become the technology of choice.

The forestry sub-sector was not further considered as this sector was identified as a sequestration sink of GHGs.

In summary therefore, the sector and sub-sectors for which a long list of technologies were selected is shown in table 1-2.

Table 1-2: Results of sector selection

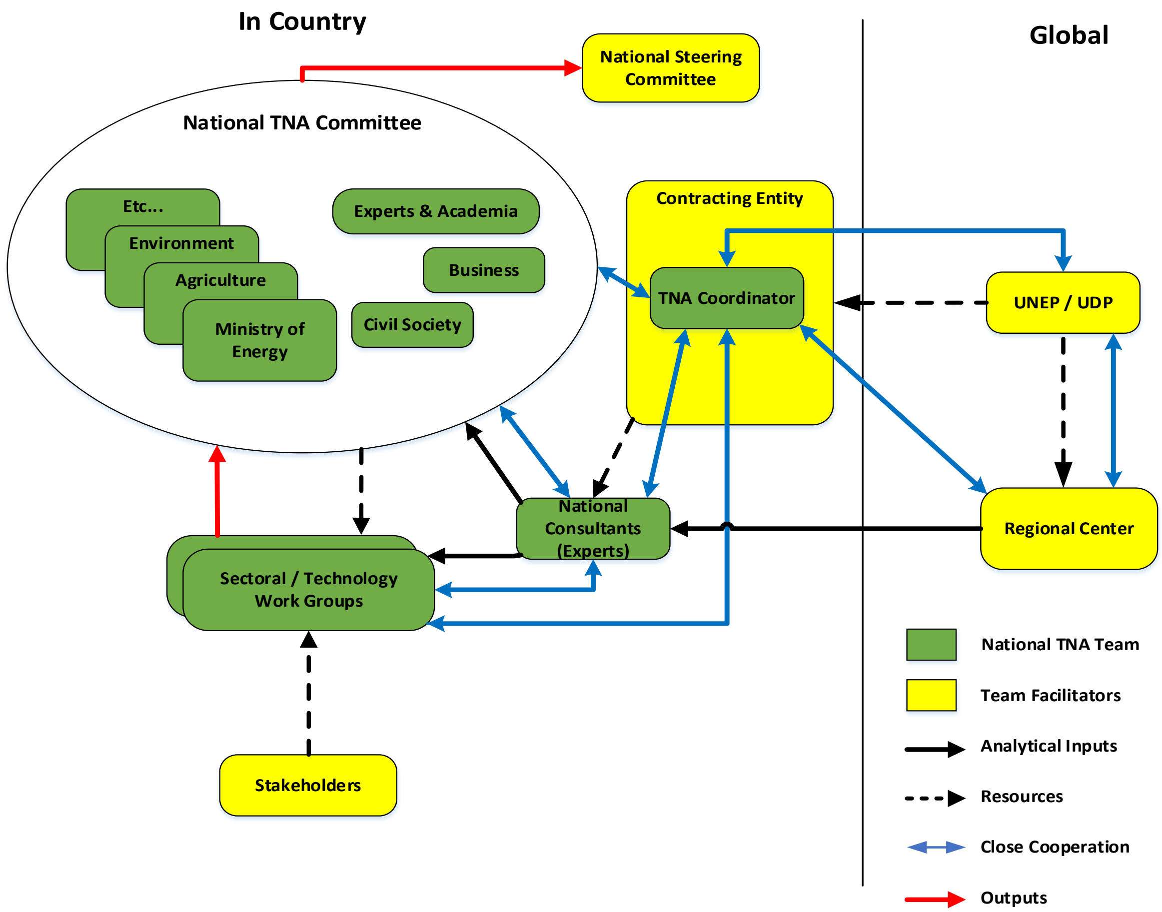
Sector	Sub-sectors
Energy supply and consumption	Transport
	Waste

Chapter 2: Institutional arrangements for the TNA and the stakeholder arrangements

2.1 National TNA committee

The arrangement for the TNA-mitigation is similar for the TNA-adaptation. The TNA committee is established under the auspices of the Environment Division, within the Ministry of Agriculture, Lands, Forestry and the Environment. The Head of the National TNA committee and the TNA Coordinator is the PS for the Environment (see figure 2-1). The PS may designate logistical and other planning issue to the Head of the Environment Division.

Figure 2-1: Representative TNA institutional set-up for Grenada



The National TNA committee comprises of representatives from:

- Ministry of Agriculture, Lands, Forestry and Environment
- Ministry of Tourism
- National Water and Sewage Authority

On the request of the PS Environment, who is also the TNA Coordinator, one of the most august bodies on sustainable development- the cabinet appointed Sustainable Development Council, served as one of the main sounding boards for the development of the TNA-mitigation. However, the TNA Committee and Coordinator are the main decision makers for the TNA mitigation project.

According to figure 2-1, other consultants and experts were also involved in the TNA set-up, in this regard, two (2) energy experts were engaged to provide guidance on the technology option selection and to produce and present technology factsheets. There were no sectoral/technology specific working groups, however, these will be convened if the need arises.

2.2 Stakeholder engagement process followed in the TNA- Overall assessment

The overall TNA process required the engagement of key stakeholders at all stages of the process. The initial stakeholder selection was conducted through research of previous similar projects, such as the Renewables Readiness Assessment. These list were consulted and a number of primary stakeholders were determined. The primary stakeholders in this regard are:

1. Energy Division, Ministry of Finance and Energy
2. Grenada Electricity Services (GRENLCE)
3. National Water and Sewage Authority (NAWASA)
4. Ministry of Communication and Works
5. National Disaster Management Authority (NADMA)
6. Grenada Solid Waste Management Authority (GSWMA)

These key stakeholders are critical to the success of the TNA.

The TNA- mitigation project commenced with a desk top study of key policy and other documents that focused on climate change and energy. The results of this review provided the context for the analysis of the eventually selected long list of technology options. These results were reported in chapters 1 and 3.

With this critical information, three (3) small group stakeholder meetings were convened. The most important of these meetings was with the TNA Coordinator, PS in the Ministry of Environment. The other two (2) small group stakeholder meetings were with the Ministry of Finance and Energy's: Energy Division and Division of Economic and Technical Cooperation. At all these meetings the TNA-mitigation project was introduced, the initial context was shared and the long list of technologies was discussed.

The other major stakeholder engagement was suggested by the TNA-coordinator. This was a presentation and discussion at the Sustainable Development Council, a cabinet appointed advisory body on sustainable development. At this meeting, stakeholders representing, academia, NGO's, secondary schools, Government departments, statutory bodies, private entities, were in attendance. Indeed this engagement of stakeholders was the largest and deepest. At this meeting, the context was agreed and suggestions for technology options were accepted. The sector for analysis- energy (including transportation and waste subsector) was agreed.

The final stakeholder engagement was at a two (2) day workshop held on the 31 January and 1 February, 2018. Most of the primary stakeholders identified above were represented:

- Energy Division, Ministry of Finance and Energy
- Environment Division, Ministry of Agriculture, Lands, Forestry, Fisheries and the Environment
- Grenada Electricity Services (GRENLEC)
- National Water and Sewage Authority (NAWASA)
- Grenada Solid Waste Management Authority (GSWMA)
- Two (2) solar PV design/install companies
- National Disaster Management Agency (NADMA)
- On Non-governmental organization (NGO)

At this final meeting the context was further agreed, the long list of technologies was comprehensively discussed and the prioritization of these technologies were finalized.

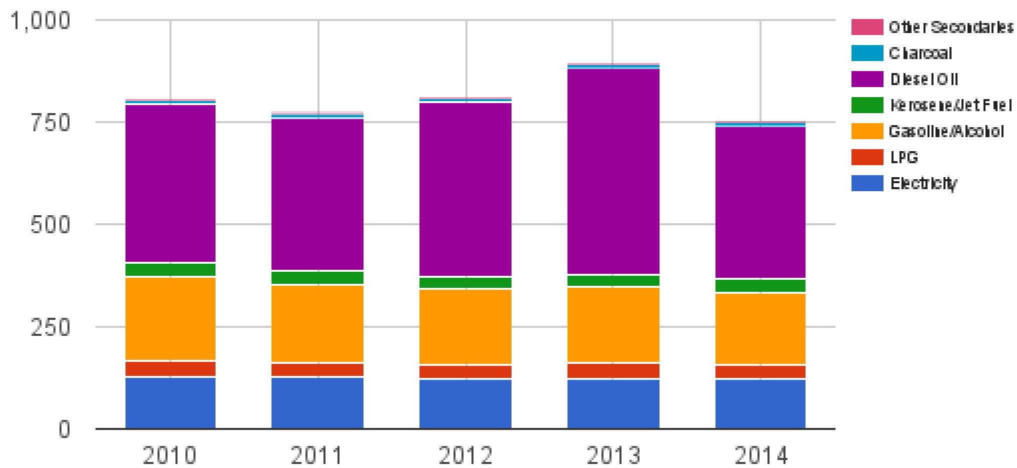
The first draft of the TNA report was presented to the TNA Committee and Coordinator for review and final approvals. This meeting was held on the 28-02-2018 and at that meeting the final technology options were agreed.

Chapter 3: Technology prioritization for the energy (transport and waste)

3.1 GHG emissions and existing technologies

The energy sector is characterized by petroleum based products imported into the country. According to the Energy Policy Guide (GOG, 2017): "Grenada's energy needs are essentially satisfied by its heavy dependence on the use of imported petroleum based derivative: Gasoline, Diesel, Liquefied Petroleum Gas (LPG), Kerosene and the aviation fuels (Avgas and Avjet) to a lesser extent…" As a consequence, Grenada is a net importer of energy with 91% of the energy imported and used for electricity generation and for local use in the market, such as for transport. Figure 3-1 shows the disaggregation of the supply of energy in Grenada for 2014.

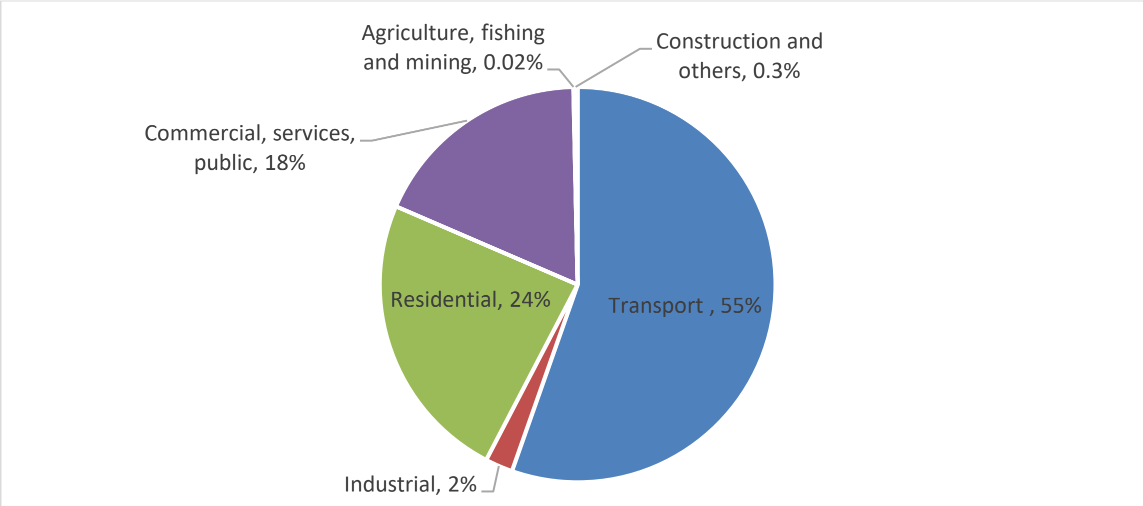
Figure 3-1: Grenada's energy supply, 2010-2014



Adapted from GOG, 2017

Figure 3-2 shows the distribution of energy consumption for the year 2014. The energy consumption in Grenada is dominated by the transport sector, including aviation. According to the GOG (2017), the fuels consumed in the transport sector includes gasoline, diesel and kerosene (including aviation fuel); while in the other sectors, LPG, diesel, and gasoline are mainly consumed. Moreover, electricity which is produced by diesel is consumed in the residential and commercial sectors.

Figure 3-2: Energy consumption by sector



Adapted from GOG, 2017

As was described in chapter 2, the majority of GHG emissions in 2014, came from energy, including domestic transportation. This was followed by waste with only 11% of GHGs in the same year. The SNC (2017) notes that CO2 was the dominant GHG contributing approximately 99% of the emissions in 2014. Two other GHGs were identified in that sector/sub-sector: methane and nitrous oxide. Table 3-1 shows the estimates of GHG emissions for the period 2000 to 2014.

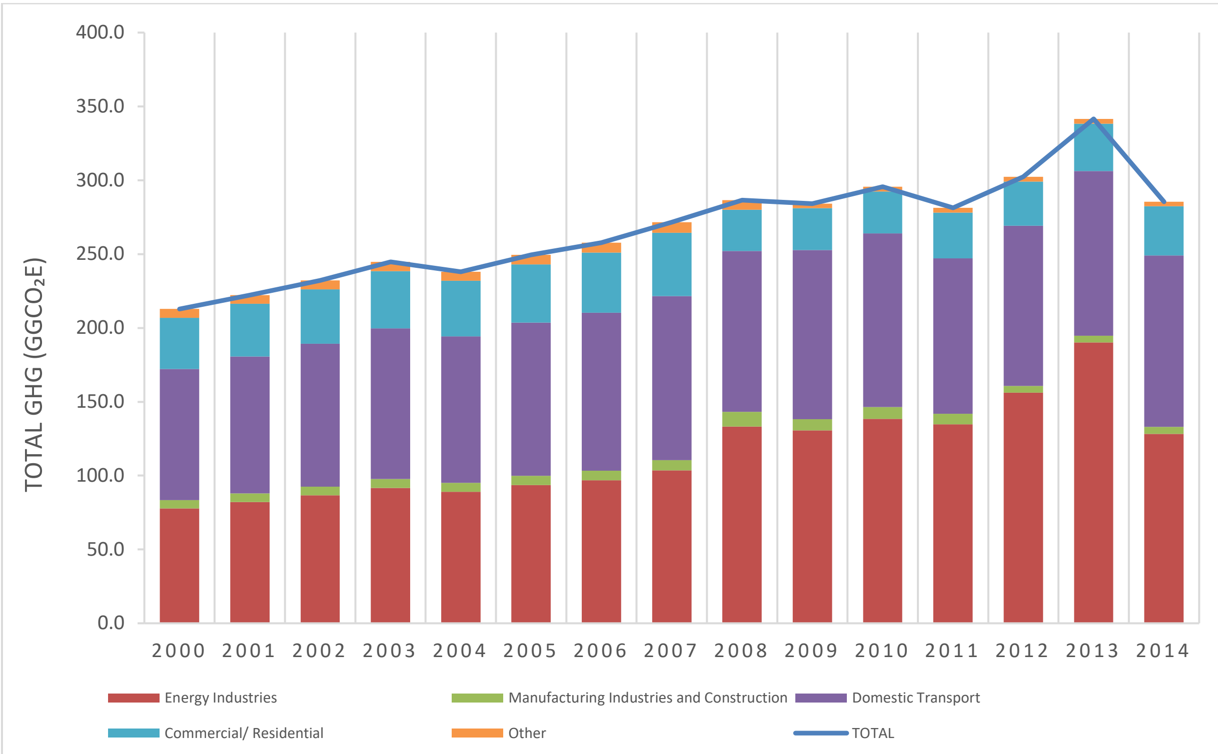
Table 3-1: Greenhouse gas emissions from the energy (transportation) sector, 2000-2104

Year	CO_2	CH_4	N_2O
2000	207.5	2.1	3.2
2001	216.7	2.2	3.3
2002	226.4	2.3	3.5
2003	238.7	2.4	3.7
2004	232.2	2.4	3.6
2005	243.4	2.5	3.7
2006	251.4	2.6	3.9
2007	264.9	2.6	4.0
2008	280.1	2.5	3.8
2009	277.8	2.5	3.9
2010	289.0	2.6	4.1
2011	275.0	2.6	3.7
2012	295.9	2.6	3.8
2013	335.0	2.6	4.0
2014	278.9	2.7	4.0

Adapted from the SNC, 2017

The SNC (2017) further estimated GHG emissions by source category and the time series for the period is shown in Figure 3-3.

Figure 3-3: Greenhouse gas emissions by source, 2010-2014



Adopted from SNC, 2107

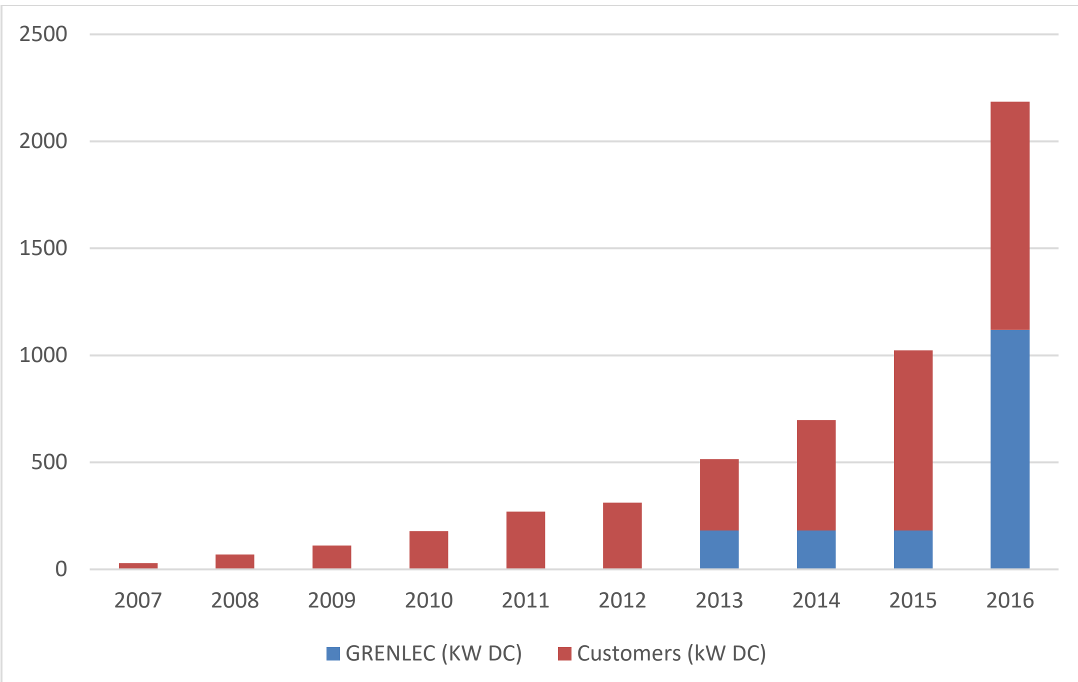
The time series reveal a steady increase in GHG emissions from 2000 to 2014, with a peak in 2013. According to the SNC (2017), this peak was due mainly to the combustion of diesel for the production of electricity. Additionally, the shares of GHG emissions were dominated by energy industries (mainly electricity production) and transportation. In this regard, the energy industries accounted for 45% and the transportation industry 41% of GHG emissions in 2014. It must be noted here that the shares can change once the split between domestic and international shipping and aviation can be ascertained.

The growth in GHG emissions is a reflection of the continued reliance on fossil based fuels for electricity production and transportation. However, renewable energy technologies became a feature, albeit with minimal uptake, in the electricity market. In this regard, PV technology dominates the market, while EVs are becoming a feature for transportation.

The Grenada Electricity Services (GRENLEC, 2016) reports on the uptake of PV systems into the generation mix. Figure 3-4 shows the installed capacity of PV into the electricity system since 2007. The graph reveals a steady increase in the installation of PV systems by both the company and customers, with approximately 48.8% of the installations by customers.

However, the GRENLEC reports (GRENLCE 2016) that only 1.12 MW (DC) of power is produced by PV renewable energy systems. This may account for approximately 3.5% of the company's peak generating capacity. The data presented is official data taken from the interconnection policy implemented by the GRENLEC. It is reported that there may be other installations outside of this formal arrangement.

Figure 3-4: Solar PV installed in Grenada, 2007-2016



Graph constructed using data from GRENLEC, 2016

Considering the transportation sector, as a sub-sector, Grenada has four (4) electric plug-in vehicles on its roads. Three of these vehicles are owned and operated by the GRENLEC. The company has conducted key research and in this regard, EVs appear to be a viable option for transitioning the current fleet of vehicles. In this regard, the performance of this technology is captured in a technology fact sheet attached in appendix 1. At a meeting with the TNA Committee (held 28-02-2018) to present the TNA report and to make a final decision on the technologies to be brought forward for further analysis it was agreed that EVs should be considered as the sole technology for further analysis in the transport sub-sector.

Additionally, the Government of Grenada and the private sector, especially the tourism sector, has signaled its intention to focus on several renewable energy and energy efficiency projects. According to the SNC (2017), in the tourism sector, "The main source of electricity demand is generally air conditioning, accounting for up to 48% of the electricity demand. However, mitigation actions such as improved energy efficiency and improved energy management can achieve substantial savings, and Grenada's hotel sector has seen GHG reductions of 5,800 tCO_2 annually (Duffy-Mayers, 2014). This reduction represented approximately 1.4% of Grenada's emissions in 2014."

Additionally, the SNC (2017) concludes that "as one of Grenada's principal mitigation actions, the development of a geothermal electricity generation plant has been commenced, including exploratory drilling. The current ambition is to complete a 15 MW installation at Mt. St. Catherine by 2025 if the required funding can be obtained (see mitigation action ID 30)."

3.2 Decision context

The main decision context is founded on the vision for climate change and the targets established by the NDCs (see chapter 2, but repeated here for reference).

The climate vision is: "An empowered Grenadian population capable of managing the risks from climate change with emphasis on pursuing a low carbon development pathway and building resilience at the individual, community and national levels".

While the NDC targets are established as: ""Grenada commits to reducing Greenhous gas emission by 30% of 2010 by 2025, with an indicative reduction of 40% of 2010 by 2030"

More specifically, the Grenada National Energy Policy (NEP, 2011), although dated, is the accepted policy to guide the transition towards a sustainable energy sector. It therefore provides guidance to the Government of Grenada on achieving a sustainable energy system, and has the following purpose, to:

- Create an appropriate, enabling and dynamic incentive regime, both regulatory and institutional, to achieve a more diversified and sustainable energy sector;
- Place energy sector management and development within the framework and principles of sustainable development to facilitate the transition to sustainable energy production and use;
- Use energy as a tool for sustainable development and build resilience into a newly restructured economy to guarantee its citizens a sustainable quality of life

The NEP goes on to develop a number of goals, which include renewable energy targets now superseded by the NDCs and energy efficiency. In this context the energy efficiency goal is to: "Reduce the national rate of energy consumption while increasing economic growth (decoupling), by adopting energy efficiency and conservation".

The NDC (2015) seeks to integrate the deployment of renewable energy technologies and energy efficiency as the key to meeting the GHG reduction targets. In this regard, the NDC, (2015) envisions a 30% reduction in emissions through electricity production, with 10% from renewable energy and 20% from energy efficiency.

The decision context was agreed by the TNA- Coordinator and was also presented to the Sustainable Development Council which is a cabinet appointed body of a wide spectrum of stakeholders. Moreover, the context was also agreed to by the stakeholders attending the TNA workshop and finally endorsed by the TNA Committee. Both of these meetings were previously mentioned in chapter 2.

The main aim/goal of the TNA analysis therefore is to address the use of renewable energy technologies for energy (electricity) production, while analyzing potential technologies for energy efficiency.

3.3 An overview of possible mitigation technology options and their mitigation potential and co-benefits

The potential technologies for analysis were selected from the suggested list in the TNA Guidebook (Annex 7). This list focused on energy production and energy efficiency technologies. Again the list was shared with the TNA- Coordinator, Environment Division, Ministry of Agriculture, Lands, Forestry and the Environment; the Energy Division and Economic and Technical Cooperation Division, Ministry of Finance and Energy and with stakeholders at the Sustainable Development Council. Suggestions were discussed and accepted, where appropriate for addition to the list. A list of thirteen technologies was agreed and three (3) experts were convened to produce fact sheets for each. This section, table 3-3, provides an overview of each of these technologies, with the more comprehensive fact sheets attached in Annex 1.

Table 3-3: Long list of Technology options and descriptions

Technology options	Descriptions
Wind (onshore)	• Wind Turbines use the power of the wind to drive a generator in order to produce electricity. The output depends on the wind speed. Hence, when there is no or not sufficient wind there is no electricity. At the same time when there is too much wind the turbines are turned off for safety reasons. • Grenada has a long history of using wind power as may be seen in the ruins of several wind mills along the east coast. There is a steady breeze from the eastern direction. Wind databases like IRENA's Global Atlas for Renewable Energies and the World Bank's globalwindatlas.info indicate average wind speeds of at least 7 m/s along the eastern corridor as well as Carriacou and Petite Martinique.

Technology options	Descriptions
	• 10 MW with 3,000 assumed full load hours would provide 30 GWh per year or 14 % of the current overall production. • The above mentioned potential of PV electricity could reduce Grenada's greenhouse gas emissions by 19 kT of CO_2 equivalent through the replacement of diesel fuel for electricity generation.
OTEC	• Ocean Thermal Energy Conversion (OTEC) uses a temperature difference between cold deep water and warm shallow water to run a heat engine (usually a Rankine cycle) which produces useful work usually in the form of electricity. • The first OTEC plant (100 kW) was built by the Japanese on the island of Nauru in the Pacific. The two major centers of research on OTEC are Saga University (Japan), which operates two 50 kW double Rankine cycle units on Kume island and the Natural Energy Laboratory of Hawaii Authority in Hawaii, which has a 100 kW system. • OTEC works best with a temperature differential of 20 -25 degrees Celsius, so tropical waters are most suitable, including the Caribbean Sea. It is noted that the existing experimental plants are on tropical islands. • Assuming the construction of a 10 MW OTEC plant and the use of seawater cooling (air conditioning) at large building complexes (e.g. St. Georges' University and the Airport), it is estimated that approximately 33% (one third) of the emissions from the electricity sector could be avoided. This would equate to ~ 40,000 tonnes of CO_2/year.
MSW gasification with electricity production	• Unlike incineration, where the useful end product is high-temperature heat, the thermal gasification of the organic component (anything containing carbon) of municipal solid waste (MSW) produces a synthesis gas. • Grenada produces approximately 100 tonnes of MSW per day. This is a relatively small quantity and there would be significant economy of scale penalties. • Assuming annual national emissions of ~ 250,000 tonnes of CO_2 equivalent, with approximately half coming from the electricity sector, and that a MSW gasification WTE facility would displace 10% of the diesel used for electricity generation, would equate to an annual mitigation potential of ~ 12,500 tonnes of CO_{2eq}
Batteries	• Batteries are devices used to transform electrical energy into chemical energy, store the chemical energy and transform it back to electricity when needed. • With an increasing number of variable Renewable Energy (vRE) systems connected to the grid, storage of some kind, becomes inevitable. Due to their good scalability and fast response, batteries

Technology options	Descriptions
	are suitable to close the gap between demand and supply in a system with a high amount of vRE. • Batteries by them self don’t mitigate greenhouse gases. However they enable other technologies like solar photovoltaics and wind power to achieve their full mitigation potential.
Geothermal	• Geothermal energy is thermal energy (heat) generated and stored in the earth. Whenever hot matter comes close to the surface - less than 4,000 m – it can be used to produce steam, which generates electricity in a turbine. • Grenada is of volcanic origin indicating the existence of geothermal energy. During the last three years Grenada received international assistance form the Governments of New Zealand and Japan to investigate the country’s geothermal potential. • According to the 3Gs analyses – Geological, Geophysical and Geochemical studies - there is a potential to produce 30 MW of electric power in an area which is adjacent to the Mount Saint Catherine region. Assuming an annual capacity factor of 90 % up to 237 GWh of electric energy could be produced. This would be more than GRENLEC’s 2016’s total production of 218 GWh. • At the same time a geothermal power plants with a capacity of 30 MW could reduce emissions from diesel generators by a total of 144 kT of CO_2 equivalent. Consequently the total greenhouse gas mitigation potential is 115 kT of CO_2 equivalent.
LEDs	• Light emitting diodes (LED) are semiconductors that transform electricity to light in a very efficient manner. Invented in 1962, it took LEDs more than forty years to advance from a niche application to a mainstream light source. Due to their superior efficiency, their longevity, their low environmental concerns, their variability in regard to size (accumulation of diodes), color, and intensity, LEDs have become the fastest growing lighting technology. • Given the undisputed advantages of LED lighting devices, this technology has the potential to cover 100 % of the market. • Based on Grenada’s 2016 electricity generation, and assuming 15 % are attributed to lighting, using only LEDs could reduce Grenada’s greenhouse gas emissions by 14 kT of CO_2 equivalent.
Landfill Gas Recovery	• Landfill gas recovery or utilisation is the process of collecting and processing the LFG, and using it as a vehicle fuel or for cooking, space heating/cooling (absorption chillers) or combusting it to produce electricity. • Assuming a 50% collection efficiency, the mitigation potential of this technology is estimated at ~ 12,500 tonnes of CO_2 equivalent per year (using the emissions estimate from the NDC).

Technology options	Descriptions
Mass burn with electricity generation	• Incineration is the thermal decomposition of the organic component of the municipal solid waste (MSW). The end product of incineration is high-temperature heat, which can be used to produce steam in a heat exchanger and the energy in the steam converted into electrical energy in a turbine or can be used in combined heat and power systems (with the heat used primarily for space heating). • According to the 2016 GRENLEC Annual Report, the utility company generated 217 GWh of electricity that year. Using the more conservative EPA figures, a 100-tonne /per day Waste-to-Energy plant could produce approximately 22 GWh per year or ~ 10% of the national supply. However, incinerators suffer significant economy of scale penalties. 100 tonnes per day may not be enough waste to make the technology competitive. • Assuming annual national emissions of ~ 250,000 tonnes of CO_2 equivalent, with approximately half coming from the electricity sector, and that a mass burn WTE facility would displace 10% of the diesel used for electricity generation, would equate to a annual mitigation potential of ~ 12,500 tonnes of CO_{2eq}
Pumped storage	• Pumped storage, also referred to as pumped hydroelectric energy storage (PHES), is a method of storing potential energy in the form of water stored at a high elevation. Water is pumped from a reservoir at a lower elevation to a reservoir at a higher elevation during low-cost off-peak periods and released from the higher elevation reservoir through turbines to produce electricity during periods of high cost peak demand allowing the utility company to balance its load demand. • There is currently no pumped storage in Grenada and commercially there is no off-peak differential in electricity prices. • According to Grenada's NDC, total GHG emissions in 2010 were ~ 250,000 tonnes of CO_2 and electricity generation made up 48% of all emissions. Assuming that pumped storage resulted in a net 2% reduction in GHG emissions from the electricity sector, the mitigation potential of pumped storage would equate to ~ 2,400 tonnes of CO_2/year
Solar PV-grid tied	• Photovoltaics (PV) is a technology that directly converts solar energy (sun light) into electricity. The output of a PV system mainly depends on the sun light impinging the PV modules or panels. • Being a country within the tropics, Grenada receives a lot of sun. Irradiation ranges between 1750 kWh/m² a in the north west of Grenada and 2200 kWh/m² a in the south of the Island as well as Carriacou and Petite Martinique. • However, its mountainous terrain and the scarcity of flat land for agriculture and dwellings reduces the potential of land for large

Technology options	Descriptions
	scale ground mounted PV systems. Nonetheless, there should be sufficient space available for approximately 10 MW to 20 MW of open space PV systems. • In addition there is a lot of suitable roof space, from small residential houses to large commercial and industrial roofs. Assuming one third of all roofs is suitable and strong enough there should be a potential of at least 50 MW for roof mounted PV systems producing approx. 75 GWh. • The above mentioned potential of PV electricity could reduce Grenada's greenhouse gas emissions by 64 kT of CO_2 equivalent through the replacement of diesel fuel for electricity generation.
Solar PV- off grid	• Photovoltaics (PV) is a technology that directly converts solar energy (sun light) into electricity. The output of a PV system mainly depends on the sun light impinging the PV modules or panels. • Off-grid PV systems are usually used in areas without interconnection to the public grid. Consequently, they either use some kind of storage technology or an additional backup source to provide electricity when needed or they supply loads/consumers that don't require a permanent output like a water pump with a reservoir. • However, since most of the populated parts of the island have the grid within reasonable distance there is no need to go off-grid for most consumers. Yet, there is potential in the agricultural sector for water pumping in order to replace diesel pumps. According to a report prepared by Mr. Dinesh Aggarwal for the Japan-Caribbean Climate Change Partnership there are approximately 100 agricultural pumps with capacities between 5 HP to 20 HP. In addition there are areas that are dwellings in the interior that use diesel generators due to the absence of the public grid. In total it seems reasonable to assume that there is a potential for off-grid PV systems in the range of 1 MW. • Assuming replacing small scale diesel generators and diesel pumps with PV systems could lead to a greenhouse gas reduction of approx. 1.8 kT of CO_2 equivalent.
Biogas	• Biogas is the product of an anaerobic (without air) process that breaks down biodegradable matter. Various types of microorganisms are involved in the process that finally produces biogas, a mixture of methane and carbon dioxide. Methane is also the main ingredient of natural gas. The methane when oxidized (burned with air) releases thermal energy that can be used for

Technology options	Descriptions
	heating and cooking or when burned in a gas engine can produce electricity or propel vehicles. • Grenada's agricultural sector produces a considerable amount of organic waste from manure, fruit and vegetable wastes and green cut to effluents of distilleries. However, most entities are, compared to international standards, are rather small. This makes it challenging to assess the potential and find proper applications. • The emission factor is 3.03 kg of CO_2 equivalent per kg for LPG and 2.68 kg of CO_2 equivalent per kg for diesel. Consequently the total greenhouse gas emission reduction potential through the use of biogas is between 1.5 kT and 1.9 kT of CO_2 equivalent.
High efficient HVAC systems	• High efficiency heating, refrigeration and air conditioning systems (HVAC) can be defined as technologies that have the potential to reduce energy consumption, while providing a high quality of service (heating or cooling). In tropical countries such as Grenada, refrigeration and air-conditioning or RAC systems are mostly used for cooling buildings, industrial refrigeration and other commercial refrigeration applications, such as in supermarkets. • High efficiency HVAC systems have tremendous potential to be widely deployed in Grenada. In this regard, many of these technologies already exists in the market. For example, in the hotel sector where a majority of these systems were installed, the potential for energy cost savings and GHG emission reduction was demonstrated • The quantification of the reduced GHG emissions is not possible as, there is lack of data on such equipment installed to determine the quantities. However, in the tourism sector in Grenada, where it is estimated that approximately 48% of electricity consumption is from HVAC, the implementation of energy efficient HVAC equipment in that sector resulted in avoiding approximately 5,800 TCO2eq per year being emitted into the atmosphere. This demonstrates the tremendous climate change mitigation potential that can be derived form a national energy efficient project targeting the HVAC market.

Technology	Description
Electric plug-in vehicle	Generally, electric vehicles use electricity to change a battery and transform that energy to mechanical energy to drive the wheels of the vehicle. There are many types of electric vehicles, these include: • Hydrogen fuel cell vehicles • Battery electric vehicles

	• Hybrid electric vehicles The fuel cell electric vehicle obtains its power from the power grid or any other power source. However, the vehicle has a fuel cell built into it that stores energy that can be used to recharge the battery when needed. This will extend the range of the vehicle The battery electric vehicle also gets it power from the power grid, which changes a battery. The power from the battery is used to propel the vehicle. The hybrid electric vehicle has a small internal combustion engine. This vehicle also obtains its power from the grid, but the internal combustion engine is used to recharge the battery, if needed, thus extending the range of the vehicle.

3.4 Criteria and process of technology prioritization

The prioritization of the above listed technologies was done at a two-day workshop held on the 31 January and 1 February, 2018. The prioritization was conducted using the multi-criteria decision analysis method. In this regard, the process started with technology factsheets presentation and discussion; criteria selection and weighing and ended with evaluating the long list of technologies for eventual prioritization.

On day one of the workshop participants were first introduced to the TNA-mitigation project and the main outcomes of the project. The entire process for prioritizing the technologies was established at the beginning of the workshop. As the first step, stakeholders were introduced to the long list of technologies. The factsheets which were previously prepared were shared with the participants via email. The majority of the entire first day was spent introducing the majority of the factsheets. There was a comprehensive presentation on each technology and very long and intense discussions on each. It was agreed that participants will have the night to further digest the technologies introduced. However, at the end of the day, four (4) technologies were not completed and these were discussed on day 2: OTEC, gasification, landfill gas recovery and high efficiency HVAC systems. Participants had the factsheets for these technologies and were urged to review them.

At the end of day one participants were introduced to the MCA process. Participants were first taken through a generic but comprehensive presentation on the selection of criteria, the assignment of weighs and proposed approach to scoring. Firstly, based on the context that was established at the workshop, it was agreed that the criteria to be selected will be categorized as cost, social, environmental, economic and technical. The Grenada TNA-adaptation report, other

TNA's and guidance documents were consulted for suggestions of criteria. To ease the process, a first set of criteria were suggested by the consultant. Participants were to consider these overnight and to make further suggestions for improving, omitting and/or adding to the proposed criteria. It was agreed that the TNA-adaptation criteria will serve as the 'best' guide for criteria selection, as the two reports will form the TNA for Grenada as a whole. Therefore, where possible, alignment should be sought.

On day two (2) the four remaining technologies were presented and there was a presentation by the GRENLEC on the performance of the electric vehicles (EVs). The remainder of the entire second day was spent on the set of final steps, which were finalizing the criteria for prioritizing the technologies, assigning weights and evaluating the technologies. Aspects of the Excel template were used to guide the development of the process.

As was indicated previously, a set of criteria grouped according to cost, environment, social, economic and technical were suggested to participants on day 1. After much discussion and debate, participants finally agreed to the set of criteria shown in table 3-4 The table also provides an interpretation/explanation of each of the criteria.

The next step was to identify the weights for each of the criterion. It was agreed that the budget allocation approach will be used. In this regard, a budget of 100 was considered to be shared among all the criteria. However, participants agreed that the budget should be first allocated to the criteria categories and then this will be apportioned to each of the criteria under the category. This criteria, categories and weight allocation finally agreed by the participants are shown in table 3-5.

Table 3-4: Explanation/interpretation of criteria

Category	Criteria	Interpretation/explanation
Cost	Initial Cost for design/install	All costs associated with the design and construction of the technology
	O&M costs	All cost associated with operating the system, maintaining and possible repairs
Economic	Job creation and sustainability	The potential for the technology to create additional jobs; putting additional people to work
	Improved energy security	The potential of the technology to provide services when needed in the time of crisis or in the face of volatile market prices
Social	Social acceptability/Public ownership	The ease for that technology to be bought into or accepted by society
	New Skill development	The potential for the technology to create new skills required to design, install, operate and maintain the technology

Category	Criteria	Interpretation/explanation
	Energy affordability	The ease of access to that technology by persons who are energy impoverished and the ability of that technology to improve energy equality
Environmental	GHG reduction potential	Potential to mitigate climate change
	Impact on local environment	The negative impacts that the proposed technology may have on the local ecosystems
Technical	Ease of implementation	Ease with which the technology can be constructed/built

Table 3-5: Criteria category and criteria weights

Category	Weight	Criteria	Weight
Cost	30%	Initial Cost for design/install	15%
		O&M costs	15%
Economic	20%	Job creation and sustainability	10%
		Improved energy security	10%
Social	20%	Social acceptability/Public ownership	5%
		New Skill development	5%
		Energy affordability	10%
Environmental	25%	GHG reduction potential	20%
		Impact on local environment	5%
Technical	5%	Ease of implementation	5%

The criteria scoring was then decided. Since from the technology factsheets, costs and other critical indicators such as GHG emissions were all estimated and were not related to the Grenada situation, it was decided that the sores for each criterion will be based on a scale of 15. In this regard, the best performing option was assigned a score of 5, while the least performing option was assigned 1. Table 3-6 describes the high score rating for each of the criterion. The table shows that for ‘cost’ in general, that highest score ‘5’ is assigned to the option that has the lowest initial and O&M cost. In other words the option with the lowest cost will be the best performs based on these criteria. Conversely, the option that has the potential to avoid the highest quantity of greenhouse gases to be emitted into the atmosphere will be the best performer, and hence scored ‘5’.

Table 3-6: Explanation of scoring for evaluating technologies

Criterion	Criteria category	Unit Chosen	Value Preferred (High, Low)	Comments, details
Initial Cost for design/install	Cost		High	Option with lowest estimated initial cost, scored 5
O&M costs			High	Option with lowest perceived cost for O&M, scored 5
Job creation and sustainabilit	Economic		High	Option with potential to create most sustained jobs, scored 5
Improved energy security			High	Option with highest potential to improve energ security, scored 5
Social acceptability/Public ov	Social		High	Option with best social acceptablility; scored 5
New Skill development			High	Option with highest potential to generate new skills; scored 5
Energy affordability			High	Option with hightest potential to improve energy affordability; scored 5
GHG reduction potential	Environmental		High	Option with hightest GHG mitigation potential; scored 5
Impact on local environment			High	Option with least local ecosystem impacts; scored 5
Ease of implementation	Technical		High	Option with least technical building requirements; scored 5

With the weights and scoring agreed, participants then proceeded to evaluate the technology options. It was agreed that two (2) technologies, batteries and pumped storage will be evaluated, but that since they were technologies that support intermittent technologies such as wind or solar, that they will not be carried forward for further evaluation if they were ranked high.

The evaluation was done by two (2) groups, and one individual (who had to leave before the end of workshop). The three (3) group evaluation scores were then averaged and these scores were entered into an Excel template created to rate and rank the technology options. The evaluation was done using a similar approach to the TNA-adaptation, where the score for an option, was multiplied by the weigh for that criterion. So for example, a weigh of 15 was assigned to O&M cost; for technology option 1, a score of 5 was assigned, therefore for that option and criteria, the rating is 75.

There was one argument on the weighing of the environment category, with one participant suggesting that local environment should be weighed higher than GHG emissions. However, the participant was satisfied with a sensitivity test that did not significantly affect the original results.

The final results for the technology option selection are shown in the preceding section.

3.5 Results of technology prioritization

The results of the evaluation of the technology options, using the average scores are shown in table 3-7 and the ranking of the technologies are shown in table 3-8. The top ranking technology is solar PV- grid tied/connected. Within the first eight technologies, there are basically two categories: energy production and energy efficiency. Based on the overall objectives of the TNA analysis, which is to select technologies that can effective transition the energy sector to renewable and energy efficient technologies, it was agreed that the top seven (7) technologies be taken forward for further analysis.

Table 3-7: Evaluation results based on average scores from groups/individual

		Option Evaluation																									
Criteria	Weight	PVG	PVSA	WOS	BIOG	GeoT	LEDs	Batt	PSTO	OTEC	MSWG	HERAC	LGR	MSWC	PVG	PVSA	WOS	BIOG	GeoT	LEDs	Batt	PSTO	OTEC	MSWG	HERAC	LGR	MSWC
Initial cost	15	4	3	3	4	2	4	3	2	1	2	4	3	2	60	45	45	60	30	65	45	30	15	30	60	45	30
Operation & maintenance	15	5	4	3	4	2	4	3	3	2	1	4	3	1	75	60	45	60	30	60	45	45	30	15	60	45	15
Job creation & sustainability	10	5	5	4	4	3	3	3	3	3	3	4	3	3	50	50	40	40	30	30	30	30	30	30	40	30	30
Improved energy security	10	4	4	3	4	5	4	3	3	3	2	3	3	2	40	40	40	40	50	40	30	30	30	20	30	30	20
Social acceptability/Public ownership	5	4	4	3	4	2	5	4	2	3	3	4	4	2	20	20	15	20	10	25	20	10	10	15	20	20	10
New skills development	5	4	4	4	4	4	3	3	3	3	3	3	4	3	20	20	20	20	20	15	15	15	15	15	15	20	15
Energy affordability	10	4	4	3	4	4	5	3	3	2	2	4	3	2	40	40	30	40	40	47	30	30	30	20	40	30	20
GHG reduction potential	20	4	3	3	2	4	4	3	4	3	3	3	3	3	80	60	60	40	80	80	60	80	60	60	60	60	60
Impact on local environment	5	4	4	4	3	2	4	1	3	3	3	5	3	3	20	20	20	15	10	22	5	15	15	15	20	15	15
Technical	5	4	4	3	4	3	4	4	3	3	3	5	3	3	20	20	15	20	15	22	20	15	15	15	20	15	15
	100														425	375	330	355	315	405	300	300	250	235	365	310	230

Table 3-8: Ranking of technology options

Technology Options	Score	Rank
Solar PV Grid Connected (PVG)	425	1
LEDs	405	2
Solar PV Stand alone (PVSA)	375	3
Hgh Efficiency Refrigeration and Air conditioning Systems (HERAC)	365	4
Biogas (BIOG)	355	5
Wind- Onshore (WOS)	330	6
Geothermal (GeoT)	315	7
Landfill methane recovery and use for power (LFG)	310	8
Batteries (Batt)	300	9
Pumped Storage (PSTO)	300	10
Ocean Thermal Energy Conversion (OTEC)	250	11
MSW gasification for large scale elcectricity (MSWG)	235	12
MSW combustion for direct electricity	230	13

The technologies suggested for further analysis grouped according to energy efficiency and energy production from renewable energy technologies are shown in table 3-9a.

Table 3-9a: Final technology options suggested to the TNA Committee

TNA Objective	Technology options	Score/rank
Energy production from renewable technologies	Solar PV- grid tied	425/1
	Solar PV- stand alone	375/3
	Biogas	355/5
	Wind onshore	330/6
	Geothermal	310/7
Energy efficient technologies	LEDS	405/2
	High efficient HVAC Technologies	365/4

Table 3-9b: Final technology options for further analysis

(Sub) sector	Technology options
Electricity production and consumption	Solar PV- grid tied and stand-alone
	LEDs
	Biogas
	High efficient HVAC Technologies
Transportation	Electric plug-in vehicle

The report was tabled at the TNA Steering Committee Meeting on the 28-02-2018. At this meeting it was decided that five technologies will be brought forward for further analysis and that the electric vehicles (EVs) will also be considered for further analysis as the only technology for the transportation sector. The technology options that will be considered under the barrier analysis and enabling framework phase of the project are shown in table 3-9b.

Chapter 4: Summary and conclusions

The TNA process commenced with a comprehensive analysis of existing policies on climate change mitigation and the sustainable development of Grenada. In this regard, a number of strategic objectives were noted as key for the sustainable development of Grenada. The main policy driver for climate change was taken from the vision articulated in the climate change policy. However, the main goal in the Nationally Determined Contributions and the sectors therein were the focus of analysis of the technologies. In this regard, “Grenada commits to reducing Greenhous gas emission by 30% of 2010 by 2025, with an indicative reduction of 40% of 2010 by 2030”. Four sectors were selected by the GoG for mitigation action: electricity; transport; waste and forestry.

When these findings were presented to wider stakeholders groups and the TNA Coordinator, it was agreed that the final sector for analysis will be the energy sector, with transportation and waste considered as subsectors.

With the sustainable development and climate change priorities established and the sector for analysis decided it was further agreed that a main aim for the technology options analysis would be to selected technologies focused on electricity production from renewable energy sources and energy efficient technologies.

Finally at a two (2)-day workshop held on the 31 January and 1 February, 2018, the prioritization of the technologies was conducted. The process began with a presentation of the technologies through technology factsheets, the introduction and agreement of the decision context and using the multi-criteria analysis process for deciding on the rank of each technology. At the conclusion of the workshop, seven technologies were suggested for further analysis. These are:

(Sub) sector	Technology options
Electricity production and consumption	Solar PV- grid tied and stand-alone
	LEDs
	Biogas
	High efficient HVAC Technologies
Transportation	Electric plug-in vehicle

The next steps for the TNA-mitigation are to formally adopt these technologies for further analysis, through the barriers analysis and enabling framework process. This will occur stakeholder engagement and deeper analysis of barriers to technology diffusion.

Once this final process is successful, then a technology action plan will be completed, with suggested project concepts for implementation. The entire TNA-mitigation process is due to be completed by end May 2018.

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Annex 1: Technology Factsheets

Technology: Wind Turbines (On Shore)

Definition and description

Wind Turbines use the power of the wind to drive a generator in order to produce electricity. The output depends on the wind speed. Hence, when there is no or not sufficient wind there is no electricity. At the same time when there is too much wind the turbines are turned off for safety reasons.

Wind turbines are available in various sizes and types. From small scale types often seen on yachts to 250 m high power plants everything is possible. Furthermore, wind turbines can be installed on shore, off shore or even flying. This fact sheet will discuss onshore applications even though the coastal areas east off Grenada could in theory be used for off shore applications too. Furthermore this fact sheet concentrates on utility scale systems.

Due to the potential occurrence of hurricanes, wind turbines deployed in Grenada either have to be able to withstand wind speeds of more than 250 km/h or should have a mechanism to retract the whole system. Though it is technically possible to build a wind turbine that would survive a category five hurricane it most likely will not be economic. Consequently it might be more reasonable to use medium scale retractable systems in this region.

Potential in Grenada[1]

Grenada has a long history of using wind power as may be seen in the ruins of several wind mills along the east coast. There is a steady breeze from the eastern direction. Wind databases like IRENA's Global Atlas for Renewable Energies and the World Bank's globalwindatlas.info indicate average wind speeds of at least 7 m/s along the eastern corridor as well as Carriacou and Petite Martinique. These values have been confirmed by measurements performed by GRENLEC. GRENLEC investigated several promising potential locations including one on Carriacou. Based on the results, full load hours of more than 3,000 h seem realistic for the best locations. This compares to very good locations in the UK and even off-shore systems in the North Sea.

However, due to the relatively dense populated coastal corridor on the east coast it will be difficult to find locations where there is enough clearance between the turbine(s) and dwellings to avoid a nuisance in terms of noise, light flicker, etc. In order to increase the number of possible locations mountain tops have been considered, however, in addition to environmental issues this would most likely not be economic. Consequently, there is a limited number of possible locations leading to an overall potential of approx. 10 MW. In order to achieve higher capacities larger none retractable turbines would have to be deployed at the risk of taking harm during hurricanes.

[1] Due to the lack of detailed analyses the potential has been estimated based on available data and assumptions.

10 MW with 3,000 assumed full load hours would provide 30 GWh per year or 14 % of the current overall production.

Mitigation to climate

The above mentioned potential of PV electricity could reduce Grenada's greenhouse gas emissions by 19 kT[2] of CO_2 equivalent through the replacement of diesel fuel for electricity generation.

Advantage(s)

- Proven, mature and reliable technology
- High capacity factor in the region
- Job opportunities for technically skilled (tertiary education) people in the field of operation and maintenance

Disadvantage(s)

- Environmental (potential bird strike) and health concerns due to noise and shadow/flicker
- Variable source of energy increasing the demand for storage and/or backup capacities
- Limited human capacity and expertise in Grenada increasing the risk of malfunctioning systems
- Due to small market size and high cost of capital, system and energy generation costs are still considerably above international average despite good wind situation
- High upfront costs

Costs and other financial requirements

So far there are only a small number of micro to small scale pilot systems in Grenada. Consequently no data on actual costs is available. In 2014 the Government issued a tender for a MW wind park in Carriacou. However, the bids received exceeded the budget making the project not economic. This shows that due to the virginity and small size of the market system costs are high compared to international averages.

On an international level electricity generation cost (levelized cost of electricity, LCOE) varies between 0.04 US$/kWh and 0.15 US$/kWh depending on system size and wind potential for mid to large scale systems with IRENAs global weighted average in 2017 being 0.06 US$/kWh. Consequently, provided system costs and cost of capital can be brought to a reasonable level, wind power should be cost competitive to current diesel generation. Furthermore wind power, like solar photovoltaics, geothermal and other non-fuel based renewables will have a constant price over the life time making electricity production independent of volatile global fuel markets.

Status of the technology in Grenada

[2] Based on UNFCCC "Standardised baseline: Grid emission factor for Grenada" and an electricity generation distribution of 95.7 % in Grenada, 3.9 % in Carriacou and 0.4 % in Petite Martinique.

A few micro to small scale pilot projects have been installed in Grenada. However, none of the systems is operational today.

A 2 MW development has not become reality due to uneconomic bids.

Technology – Ocean Thermal Energy Conversion

Definition and Description

Ocean Thermal Energy Conversion (OTEC) uses a temperature difference between cold deep water and warm shallow water to run a heat engine (usually a Rankine cycle) which produces useful work usually in the form of electricity. It has been estimated that approximately 88,000 TWh/yr of electrical energy could be produced sustainably from the Earth's oceans. OTEC systems produce energy constantly and can be used to meet baseload demand.

Systems may be closed, open cycle or hybrid. An open-cycle system uses seawater vapour to run the turbines. Closed-cycle systems run with low boiling point working fluids like ammonia or refrigerants like R-134a. In a hybrid system, warm seawater enters a vacuum chamber and is flash-evaporated (similarly to the open-cycle). The steam vaporizes the working fluid of a closed-cycle loop on the other side of a vaporizer. The vaporized fluid then drives a turbine to produce electricity. The steam condenses within the heat exchanger and provides desalinated water.

Cold water can be brought to the surface either by direct pumping or by desalination.

The first OTEC plant (100 kW) was built by the Japanese on the island of Nauru in the Pacific. The two major centers of research on OTEC are Saga University (Japan), which operates two 50 kW double Rankine cycle units on Kume island and the Natural Energy Laboratory of Hawaii Authority in Hawaii, which has a 100 kW system[3].

In addition to electricity production OTEC can be used, inter alia, to:

- produce desalinated water (a 1 MW plant can produce 4,500 m^3/day of freshwater)[4]
- provide air conditioning for buildings (seawater cooling technology)
- provide water high in nutrients for aquaculture

Potential in Grenada

OTEC works best with a temperature differential of 20 -25 degrees Celsius, so tropical waters are most suitable, including the Caribbean Sea. It is noted that the existing experimental plants are on tropical islands. Ocean Thermal Energy Corporation (OTE) has plans for two 10 MW OTEC plants in the USVI and a 5 – 10 MW facility in the Bahamas. The same company (OTE) has designed the world's largest seawater air conditioning system for a resort in the Bahamas. Martinique expects to build a 10.7 MW (net) OTEC facility by 2020. Therefore, it seems reasonable to assume that there is the potential for at least one 10 MW OTEC plant in Grenada.

[3] https://www.makai.com/ocean-thermal-energy-conversion/
[4] http://www.otecnews.org/what-is-otec/

Mitigation to Climate

Assuming the construction of a 10 MW OTEC plant and the use of seawater cooling (air conditioning) at large building complexes (e.g. St. Georges' University and the Airport), it is estimated that approximately 33% (one third) of the emissions from the electricity sector could be avoided. This would equate to ~ 40,000 tonnes of CO_2/year.

Advantages

- Scalable baseload capacity
- Significant additional benefits (e.g. desalination, seawater cooling, aquaculture)
- No waste products
- No fossil fuel consumption

Disadvantages

- No reliability or cost data from commercial size (> 5 MW) plants are available.
- Environmental impacts (adverse or beneficial) of bringing large volumes of cold, nutrient-rich water to the surface have not been determined.
- High initial capital costs

Costs and other financial requirements

Cost data for commercial plants are not available. One study has estimated that an OTEC plant could generate electricity at around US$0.07/kWh[5].

Status of the Technology in Grenada

Currently, there is no OTEC or seawater air conditioning technology deployed in Grenada.

[5] https://en.wikipedia.org/wiki/Ocean_thermal_energy_conversion

Technology: MSW Gasification with Electricity Generation

Definition and Description

Unlike incineration, where the useful end product is high-temperature heat, the thermal gasification of the organic component (anything containing carbon) of municipal solid waste (MSW) produces a synthesis gas. The composition of the syngas will vary depending on the feedstock and the type of gasification process but is typically 30 to 60% carbon monoxide (CO), 25 to 30% hydrogen (H_2), 0 to 5% methane (CH_4), 5 to 15% carbon dioxide (CO_2), with some traces of ammonia, and hydrogen sulphide[6].

To produce this syngas, two processes occur. Firstly, at temperatures less than 600^{o}C, through pyrolysis, the volatile components of the waste stream are released. A char is produced as a by-product. After pyrolysis, the volatile components are either reacted with steam or hydrogen (reforming) or combusted in oxygen rich air at high temperatures and pressures to form the syngas. Reactors can be fixed bed (< 1 MW) or fluidized. Fluidized beds are more suitable for larger scale plants. The heterogeneity of the MSW poses significant challenges for this technology. Some form of pre-treatment to homogenise the waste (e.g. produce refuse-derived pellets) prior to gasification is preferable.

Another form of gasification is plasma arc technology, which uses extreme heat to produce plasma which converts the waste into a synthesis gas. This technology has been used successfully to treat some forms of hazardous waste. However, the variable composition of MSW has proven to be challenging.

The syngas is then cleaned (e.g. particulates removed) and used in a gas turbine for electricity production or for combined heat and power.

Potential in Grenada

Grenada produces approximately 100 tonnes of MSW per day. This is a relatively small quantity and there would be significant economy of scale penalties. Gasification of MSW (unlike gasification of coal) is in its infancy. There is limited potential for the use of this technology on a national scale to produce electricity. Barbados' recent experience with proposed developers of plasma arc gasification technology is instructive[7].

[6] https://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/syngas-composition

[7] https://www.barbadostoday.bb/2016/05/13/cahill-project-dead-confirms-lowe/

Mitigation to Climate

Assuming annual national emissions of ~ 250,000 tonnes of CO_2 equivalent, with approximately half coming from the electricity sector, and that a MSW gasification WTE facility would displace 10% of the diesel used for electricity generation, would equate to an annual mitigation potential of ~ 12,500 tonnes of CO_{2eq}

Advantages

- Extends the life of the landfill
- Provides baseload electrical energy
- Has the potential to be more efficient than conventional mass burn technology
- Slag by-product is a useful construction material

Disadvantages

- High upfront capital costs
- Economics may rely upon a tipping fee or government subsidy
- May require pre-treatment of the waste (homogenisation)

Costs and other financial requirements

As with mass burn, the economics of MSW gasification and energy recovery are dependent upon the type of gasification technology, the size of the plant, the tipping fee that is imposed, and the selling price of the baseload energy. The capital costs may be slightly lower for gasification plants because less flue gases are produced and there is less need for air pollution technology. However, there may be higher upstream costs associated with having to produce a homogenous refuse-derived fuel. A study in the USA estimated the processing costs of gasification at US$36/tonne as compared to conventional mass burn at US$51/tonne[8].

Status of the Technology in Grenada

There is currently no MSW gasification technology with energy recovery in Grenada.

[8] Jenkins, S.D., 2007. Conversion technologies: A new alternative for MSW management, Earthscan.

Technology: Batteries (for grid tied storage)

Definition and description

Batteries are devices used to transform electrical energy into chemical energy, store the chemical energy and transform it back to electricity when needed. The first battery was invented by the Italian physicist Alessandro Volta in 1800. Ever since, a large number of different types using various materials have been developed. Over time energy density and cycle stability has improved significantly making it possible to even power electric sports cars today.

Some modern battery technologies require rare earth metals that are scarce, expensive and sometimes release toxins during mining. Additionally, mining some of those materials is quite energy intensive. These facts have brought increased scrutiny on the sector. However, there are several technologies available and in development that solve most of those problems.

This fact sheets focusses on batteries for grid tied energy storage ranging from residential storage systems with capacities of several kWh to utility scale systems with more than 1 MWh of storage capacity.

With an increasing number of variable Renewable Energy (vRE) systems connected to the grid, storage of some kind, becomes inevitable. Due to their good scalability and fast response, batteries are suitable to close the gap between demand and supply in a system with a high amount of vRE.

In addition, batteries in combination with distributed vREs have the potential to make Grenada's electricity system more reliable and resilient to natural disasters. In a centralized system, like it is today, one failure can lead to a whole system shut down while in a distributed system parts of the grid would remain operational.

Potential in Grenada[9]

Quantifying the potential for batteries to support the grid is difficult as they would only be required in combination with variable Renewable Energy technologies like solar photovoltaics and wind power. Consequently, the future energy mix is essential to quantify the demand/potential for batteries. Provided Grenada wants to transform its electricity sector to 100 % Renewable Energies the following scenario could be used to do an estimation:

Assuming a total demand (including system losses) of 300 GWh/a with 200 GWh/a of supply coming from Geothermal power plants would require another 100 GWh/a of supply from wind (10 MW and 30 GWh/a) and solar (45 MW and 70 GWh/a). Further assuming that geothermal covers baseload this would require vREs and batteries to cover all peaks and periods of low sun and wind. In theory this means that storage systems would have to be able store the complete production of vREs during days of low demand. This could lead to extremely high storage capacities. Studies for Germany indicated that the demand for short term storage would be in the range of 0.07 % of total demand in order to achieve 100 % Renewables. In Grenada's case this would mean approx. 200 MWh of storage capacity. However, if longer term storage would be

[9] Due to the lack of detailed analyses the demand /potential has been estimated based on assumptions.

included, which in Germany is envisioned to be covered by other technologies, the storage demand would increase to 5 %. This would mean 1,500 MWh for Grenada.

Mitigation to climate

Batteries by them self don't mitigate greenhouse gases. However they enable other technologies like solar photovoltaics and wind power to achieve their full mitigation potential.

Advantage(s)

- Very good scalability making it perfect for distributed generation
- Job opportunities for technically skilled (tertiary education) people in the field of operation and maintenance
- Low environmental risks at the place of use
- Essential for a major deployment of variable renewable energies

Disadvantage(s)

- Limited capacity and expertise in Grenada increasing the risk of malfunctioning systems
- High upfront costs
- Fire and explosion potential with some technologies
- Environmental issues at the place of material's origin with some technologies
- Most promising technologies are rather new
- If deployed as none utility or IPP owned it could increases the risk of social inequality[10]

Costs and other financial requirements

Currently, costs for batteries are still quite high making it difficult to realize economic cases for islands the size of Grenada. However, most experts expect prices to fall below 100 US$/kWh of storage capacity (0.02 US$/kWh stored at 5,000 cycles) within the next five years. This would make PV plus storage and wind plus storage economic.

Furthermore, new technologies like new solid state batteries could further decrease costs in the future. Consequently, batteries may play a vital role in electricity systems around the world and especially in island systems.

Status of the technology in Grenada

Mature battery technologies (lead) are used in off-grid PV systems in Grenada. Grid tied systems are new to the country.

[10] Compare Technology fact sheet on grid tied photovoltaics

Technology: Geothermal Power Plants

Definition and description

Geothermal energy is thermal energy (heat) generated and stored in the earth. Whenever hot matter comes close to the surface - less than 4,000 m – it can be used to produce steam, which generates electricity in a turbine.

In order to produce steam, wells have to be drilled to reach the resource. These drillings are large infrastructure developments that require access roads and water supply to the drilling site. Due to its complexity a geothermal development takes several years to be executed.

Once operational, a geothermal power plant is able to deliver base load energy, meaning that it produces electricity on a continuous basis. It is also possible to reduce the power output to adapt to the demand. However, this will reduce the economy of the system.

Furthermore, in addition to steam, other gases like carbon dioxide (CO_2), hydrogen sulfide, methane and ammonia could be released. Additionally, the brine, which is the waste fluid from the separator in a geothermal power plant system, can contain trace amounts of toxics like mercury, arsenic, boron and antimony. However, modern geothermal power plants can handle those substances to minimize environmental risks.

In some cases geothermal power plants were known to have created land stability issues. Subsidence occurred in at least two places around the world.

Potential in Grenada

Grenada is of volcanic origin indicating the existence of geothermal energy. During the last three years Grenada received international assistance form the Governments of New Zealand and Japan to investigate the country's geothermal potential.

According to the 3Gs analyses – Geological, Geophysical and Geochemical studies - there is a potential to produce 30 MW of electric power in an area which is adjacent to the Mount Saint Catherine region. Assuming an annual capacity factor of 90 % up to 237 GWh of electric energy could be produced. This would be more than GRENLEC's 2016's total production of 218 GWh.

However, the results of the previous studies will have to be proven by actual drillings. To enable phase two, the Government is currently attempting to secure funding for exploratory drillings, which will consist of a three stage approach starting with temperature gradient wells (500 m), which depending on the success will be followed by slim hole wells (1,500 m) and, if successful, full size wells (up to 3,000 m).

Mitigation to climate

As mentioned in the first paragraph CO_2 is likely to be release from underground deposits during the production process. On average geothermal power plants emit approximately 0.122 kT of CO_2/GWh. With an assumed potential of 237 GWh per year this would lead to emissions of 29 kT of CO_2. At the same time a geothermal power plants with a capacity of 30

MW could reduce emissions from diesel generators by a total of 144 kT[11] of CO_2 equivalent. Consequently the total greenhouse gas mitigation potential is 115 kT of CO_2 equivalent.

Advantage(s)

- Proven, mature and reliable technology
- Baseload technology
- Job opportunities for technically skilled (tertiary education) people in the field of operation and maintenance
- Hurricane resilient

Disadvantage(s)

- Environmental and health concerns due to hazardous gases and toxics
- Limited human capacity and expertise in Grenada increasing the risk of malfunctioning systems
- Very high upfront costs
- Potential sites in virgin territory
- Major infrastructure development (roads and water supply) required

Costs and other financial requirements

The government currently plans to tender a 15 MW power plant. The installation of this plant including all required studies, permits, infrastructure work and exploratory drilling is estimated to cost approx. 130,000,000 US$.

A geothermal development is a high risk venture because until the final stages of the development there is a risk that the resource will not be sufficient. Consequently a developer will ask for high risk premiums. In order to mitigate the risk and reduce the actual price an investor will ask for per kWh of electricity generated, the Government is attempting to secure as much international financial assistance as possible to do the second phase of the project on their own.

Introducing a private investor at a later stage will potentially reduce the price per kWh significantly. Current estimates are looking for kWh prices between 0.15 US$ and 0.18 US$. This is more than the current fuel charge of approx. 0.14 US$ but with the oil price rising it should be a reasonable value to stabilize electricity tariffs.

Status of the technology in Grenada

So far there is no experience with geothermal power production in Grenada.

[11] Based on UNFCCC "Standardised baseline: Grid emission factor for Grenada".

Technology: LED lights

Definition and description

Light emitting diodes (LED) are semiconductors that transform electricity to light in a very efficient manner. Invented in 1962, it took LEDs more than forty years to advance from a niche application to a mainstream light source. Due to their superior efficiency, their longevity, their low environmental concerns, their variability in regard to size (accumulation of diodes), color, and intensity, LEDs have become the fastest growing lighting technology. In 2017 approx. 12 % of all lights installed globally and more than 25 % of newly sold lights have been LEDs. This makes LEDs the only technology with increasing sales numbers while sales of all other technologies are either stagnating or decreasing.

In addition to the undisputed efficiency of LEDs, longevity is often an issue. Depending on the quality of the semiconductor material, the assembly, the environmental conditions (temperature and humidity) as well as the quality of electric supply, LEDs can last up to 100,000 hours of operation. In contrast incandescent light bulbs usually only last 1,000 hours. However, complaints have been made that normal consumer type LEDs don't fulfil the expectations. In order to address these concerns there are two different types of LED failure. One is the complete failure of the device, which is usually an assembly problem, and the other one is the reduction of efficacy as a result of the degradation of the semiconductor. Even cheap semiconductors should allow for a lifetime of 10,000 to 15,000 hours of operation. Lifetime in this case means that the devices still emit 50 % of their nominal value. Completely failing devices on the other hand are an indication of either deficient assembly or serious issues with the quality of electricity. This said, customers should be informed and look for certifications and manufacturer guarantees.

Potential in Grenada[12]

Given the undisputed advantages of LED lighting devices, this technology has the potential to cover 100 % of the market. However, attributing a number of lighting devices to those 100 % is difficult without knowledge of existing units of any technology in the country.

Mitigation to climate

In order to estimate the greenhouse gas mitigation potential several assumptions have to be made. It is fairly easy to determine the energy saving potential of LEDs compared to CFLs and incandescent light bulbs or other technologies based on their rated wattage. However, the question is how big is the share of each technology today and how many hours are the different technologies operated on average. Furthermore the total consumption of the lighting sector has to be estimated.

The average global share of the lighting sector in electricity demand is approx. 15 %. On a global scale, today's shares of the various technologies are as follows: fluorescent technologies 66%; LEDs 12 %; halogen and others 10 %; and incandescents 2 %. These numbers will most likely

[12] Due to the lack of detailed analyses the demand /potential has been estimated based on assumptions.

not cover the situation in Grenada. Consequently, the following assumptions have been made: fluorescent technologies 65%; LEDs 5 %; halogen and others 10 %; and incandescents 20 %.

Based on these assumptions, shifting completely to LEDs could reduce energy consumption by nearly 70 %, this directly translates to the mitigation potential. Further based on Grenada's 2016 electricity generation, and assuming 15 % are attributed to lighting, using only LEDs could reduce Grenada's greenhouse gas emissions by 14 kT[13] of CO_2 equivalent.

Advantage(s)

- High energy saving potential
- High lifetime
- Low lifecycle cost
- Low environmental concerns

Disadvantage(s)

- High upfront costs
- Disposal of replaced fluorescent devices bears environmental risks

Costs and other financial requirements

Currently, standard LED bulbs are available in Grenada at costs between 15 XCD and 40 XCD. Consequently, when compared to incandescent light bulbs they are quite expensive. Furthermore, it has to be assumed that the cheaper once are of lower quality.

However, due to their lower consumption and longer lifespan, lifecycle costs of LEDs are unbeaten. Lifecycle costs means the overall cost including consumption and replacement. For example: a quality LED may cost 40 XCD. It will last 15,000 hours of operation and consume 105 kWh or at today's electricity tariffs 94.50 XCD. Hence the lifecycle cost is 134.5 XCD. An incandescent only costs 2 XCD. However it will only last 1,000 hours. Consequently you need 15 of them. Furthermore those 15 bulbs will consume 900 kWh costing 810 XCD. The comparable lifecycle cost is 840 XCD.

Depending on quality and price of LEDs their lifecycle cost is between 75 % and 90 % lower than that of incandescents and between 30 % and 70 % of fluorescent devices.

Status of the technology in Grenada

LEDs are available and used in Grenada. Exact numbers are not known.

[13] Based on UNFCCC "Standardised baseline: Grid emission factor for Grenada" and an electricity generation distribution of 95.7 % in Grenada, 3.9 % in Carriacou and 0.4 % in Petite Martinique.

Technology: Landfill Gas Recovery

Definition and Description

Landfill gas (LFG) is the gaseous product of organic waste decomposition in a landfill. LFG is 40 – 60% methane (CH_4) with the remainder being primarily carbon dioxide (CO_2), nitrogen, water and a mix of other trace gases (e.g. hydrogen sulphide). Landfill gas recovery or utilisation is the process of collecting and processing the LFG, and using it as a vehicle fuel or for cooking, space heating/cooling (absorption chillers) or combusting it to produce electricity.

After about its first year of operation, a landfill will move from aerobic to anaerobic digestion and starts to produce LFG. Leachate can be re-circulated to speed up decomposition and the production of LFG, and operate the landfill like a bioreactor (wet cell)[14]. This LFG is collected either passively (vents) or actively by a series of pipes and blowers (under vacuum). The collected LFG is either flared (converted into CO_2) or is treated for energy recovery.

Moisture (the gas is saturated with water which has to be removed prior to use), particulates and other impurities (e.g. siloxanes, hydrogen sulphide and sulphur dioxide) may be removed using condensers and filters. The cleaned gas may be compressed if fed into a pipeline (e.g. mixed with natural gas). The type of treatment applied to the LFG depends upon the intended end use.

Potential in Grenada

Grenada produces approximately 100 tonnes of municipal solid waste (MSW) per day. According to Grenada's NDC[15], approximately 10% of national emissions is from anaerobic decomposition of waste in the national landfill. This would equate to approximately 25,000 tonnes of CO_2 equivalent per year, or converting to methane would equate to approximately 1,000 tonnes of methane per year. Using typical conversion rates from other data sources (i.e. approximately 120 kg of methane produced per tonne of MSW[16]), would equate to ~ 4,400 tonnes of methane per year. Therefore, Grenada's NDC may be underestimating the amount of methane being generated by MSW.

However, the national landfill at Perseverance has caught fire on several occasions over the last decade, which may have reduced the amount of stored LFG. There is currently no collection (passive or active) of LFG at Perseverance nor is there any history of LFG recovery.

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[14] https://www.epa.gov/landfills/bioreactor-landfills

[15] Grenada, 2015. Nationally Determined Contribution

[16] Lohila, Annalea, et. al. "Micrometeorological Measurements of Methane and Carbon Dioxide Fluxes at a Municipal Landfill." Environmental Science & Technology, 41.8 (2007): 2717-2722.

Mitigation to Climate

As the sides of the landfill are not lined with a material of low permeability to gases, some LFG would continue to escape even if a collection system was constructed. Assuming a 50% collection efficiency, the mitigation potential of this technology is estimated at ~ 12,500 tonnes of CO_2 equivalent per year (using the emissions estimate from the NDC).

Advantages

- Reduces odour and increases safety at the landfill
- Reduces the environmental impact of the landfill
- LFG is available even after the landfill closes
- Can be used to meet both baseload and peak electricity demand

Disadvantages

- Difficult to model the amount of LFG that is available
- Economic feasibility usually linked to the price of natural gas
- Some environmental groups (e.g. Sierra Club) are opposed to accelerated decomposition of waste and are concerned about increasing fugitive methane emissions.

Costs and other financial requirements

Collecting and combusting LFG is one of the simplest and cheapest ways of recovering energy from MSW. Particularly, if the landfill operator is bound by regulation to at least collect and flare the LFG. It is noted that there is no such regulation in Grenada. The cost of a LFG to Energy project vary depending on the type, size and layout of the landfill. The LFG can be used in an internal combustion engine, gas turbines or microturbines. Installation cost estimates for using an internal combustion engine are between $1,700/kW and $2,300/kW. The EPA estimates that a privately owned and operated project with a 3 MW turbine and no previously installed capture system would cost approximately $8.5 million to install[17].

Status of the Technology in Grenada

Currently, there is no deployment of landfill gas collection, recovery and/or utilisation technology in Grenada.

[17] http://www.eesi.org/papers/view/fact-sheet-landfill-methane

Technology: MSW Mass Burn Incineration with Electricity Generation

Definition and Description

Incineration is the thermal decomposition of the organic component of the municipal solid waste (MSW). The end product of incineration is high-temperature heat, which can be used to produce steam in a heat exchanger and the energy in the steam converted into electrical energy in a turbine or can be used in combined heat and power systems (with the heat used primarily for space heating). About 12% of the MSW in the USA is incinerated to produce energy, whereas in Sweden and other European countries close to half the MSW is incinerated in waste-to-energy (WTE) plants[18].There are several types of mass burn (combustion of the waste without significant prior sorting or treatment) technologies:

- Fixed grate – a simple, brick-lined cell, with a fixed metal grate and an ash pit below.
- Moving grate – the most commonly used technology in modern incinerators, the waste is introduced by a crane at the "throat" of the grate and then moves down the descending grate to the ash pit at the end.
- Fluidized bed – a powerful air current is used to churn sand particles, and then the waste and fuel are added. The violent churning ensures full circulation in the furnace.
- Rotary kiln – has two chambers. In the primary chamber, the solid fraction of the waste is converted to gas (volatilization, partial combustion), the gases are combusted in the second chamber

MSW incinerators (moving grate) produce:

- A bottom ash (collected in the ash pit)
- A fly ash (collected from cleaning the flue gases)
- Flue gases

Incinerators reduce the mass of the original waste by 80-85% and the volume by 85 - 90%. In some countries both the fly ash and bottom ash are considered hazardous, and the disposal of the ash is regulated. The flue gases may contain particulates, sulphur oxides, nitrogen oxides, carbon monoxide, carbon dioxide, hydrochloric acid, heavy metals, dioxins and benzofurans. Up to 50% of the capital costs of mass burn incinerators is the pollution control technology, which may include:

- Baghouse filters
- Electrostatic precipitators
- Afterburners
- Wet and dry scrubbers

Potential in Grenada

[18]https://www.wsj.com/articles/does-burning-garbage-for-electricity-make-sense-1447643515

According to Danish researchers, one tonne of MSW can produce 0.66 MWh of electricity and 2 MWh of district heating[19]. Therefore, 100 tonnes of MSW/day (Grenada's current solid waste generation rate) could produce approximately 66 MWh of electricity and 200 MWh of district heating (or district cooling if combined with a heat pump). According to the USEPA[20], one short ton of MSW (0.9 metric tonnes) can produce 550 kWh of electrical energy. Using the EPA figures, 100 metric tonnes could produce ~ 61 MWh of electrical energy (equivalent to a 2.5 MW plant running 24 hours).

According to the 2016 GRENLEC Annual Report, the utility company generated 217 GWh of electricity that year. Using the more conservative EPA figures, a 100-tonne /per day Waste-to-Energy plant could produce approximately 22 GWh per year or ~ 10% of the national supply. However, incinerators suffer significant economy of scale penalties. 100 tonnes per day may not be enough waste to make the technology competitive.

Mitigation to Climate

Assuming annual national emissions of ~ 250,000 tonnes of CO_2 equivalent, with approximately half coming from the electricity sector, and that a mass burn WTE facility would displace 10% of the diesel used for electricity generation, would equate to a annual mitigation potential of ~ 12,500 tonnes of CO_{2eq}

Advantages

- Extends the life of the landfill
- Provides baseload electrical energy
- Is the most common WTE technology for MSW

Disadvantages

- High upfront capital costs
- Economics may rely upon a tipping fee or government subsidy
- May compete with some recycling programmes (e.g. plastics)
- Complex mechanical systems that require maintenance
- Ash considered hazardous

Costs and other financial requirements

The costs of a mass burn incinerator with energy recovery vary depending on the size of the plant. According to the World Bank[21], the technology is not suitable for waste streams less than

[19] *Waste to Energy in Denmark". Ramboll. 2006.*
[20] https://www.epa.gov/smm/energy-recovery-combustion-municipal-solid-waste-msw

[21] World Bank, 2000. A Decision Maker's Guide to Municipal Solid Waste Incineration

50,000 tonnes/year. Grenada is currently at ~37,000 tonne/year. Unlike other energy systems, operators of WTE systems usually get two sources of revenue- a tipping fee for receiving the waste (e.g. US$ 20 - 40/tonne) and a sale price for the electricity produced (e.g. US$0.05 – 0.2/kWh). The World Energy Council[22] has estimated the capital costs of mass burn incineration with WTE at US$7,000 – 10,000/kW. A 3MW plant would therefore cost ~ US$21 – 30 million assuming no economy of scale penalties.

Status of the Technology in Grenada

There is currently no mass burn incineration technology with energy recovery in Grenada.

[22]World Energy Council, 2016. World Energy Resources. Waste to Energy

Technology: Pumped Storage

Definition and Description

Pumped storage, also referred to as pumped hydroelectric energy storage (PHES), is a method of storing potential energy in the form of water stored at a high elevation. Water is pumped from a reservoir at a lower elevation to a reservoir at a higher elevation during low-cost off-peak periods and released from the higher elevation reservoir through turbines to produce electricity during periods of high cost peak demand allowing the utility company to balance its load demand.

Pumped storage can also increase the efficiency of intermittent sources of energy like solar and wind by providing the generator with the option of storing surplus energy from these renewable energy sources. Although the reservoirs used for pumped storage are relatively small when compared to hydroelectric dams and typically have the capacity to generate electricity for less than 12 hours, pumped storage, according to the US Department of Energy, accounts for 96% (168 GW) of all energy storage capacity globally[23]. A pumped storage unit is a net user of electricity (friction losses etc) however efficiencies can be as high as 80%[24].

In 2017, a research project entitled "Storing Energy at Sea" (StEnSea) successfully tested a pumped storage underwater reservoir. It is envisaged that in the future, hollow spheres approximately 30 metres in diameter will be anchored at depths of around 700 metres offshore (to create the lower reservoir). Each storage unit would produce ~ 20 MWh (4 hours of discharge time through a 5 MW turbine)[25]. These underwater reservoirs could be linked with offshore windfarms.

Potential in Grenada

There is currently no pumped storage in Grenada and commercially there is no off-peak differential in electricity prices. However, there is potential for the privately-owned electric utility in Grenada (GRENLEC) to enter into an agreement with the state-owned water authority (NAWASA) to deploy this technology. Pumped storage hydropower can balance loads, provide stability, and network frequency control (turbine generators can respond quickly to frequency deviations). Pumped storage could be used to balance the load and allow a large geothermal plant (Grenada is actively pursuing geothermal energy) to reach its peak efficiency.

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[23] http://www.energystorageexchange.org/
[24] http://energystorage.org/energy-storage/technologies/pumped-hydroelectric-storage
[25] http://forschung-energiespeicher.info/en/projektschau/gesamtliste/projekt-einzelansicht/95/Kugelpumpspeicher_unter_Wasser/

The topography of Grenada in particular, the presence of natural reservoirs in the firm of crater lakes e.g. Grand Etang – (elevation of ~ 550 metres) and Lake Antoine (elevation ~ 8 metres) would appear to imply that pumped storage may be a feasible technology to deploy. It is noted that Grenada is actively pursuing solar, wind (Intermittent) and geothermal (constant base load) generation technologies, all of which can be made more efficient if associated with pumped storage.

If underwater reservoirs prove to be commercially feasible, all small island states with easily accessible deep water (~700 metres) offshore would have significant potential to deploy this technology.

Mitigation to Climate

To estimate the mitigation potential in Grenada, data from the USA has been reviewed. A report on pumped storage from the DOE (2015)[26] indicated that a mix of fixed speed and variable speed pumped storage units could reduce the curtailment of solar and wind power plants by up to 22%, resulting in a 2% reduction in GHG emissions. In the USA pumped storage can store about 2% of the electrical energy used, whereas in Japan pumped storage represents 10% of capacity. 5-10% of capacity in Grenada would equate to 1.5 – 3 MW of storage potential.

According to Grenada's NDC, total GHG emissions in 2010 were ~ 250,000 tonnes of CO_2 and electricity generation made up 48% of all emissions. Assuming that pumped storage resulted in a net 2% reduction in GHG emissions from the electricity sector, the mitigation potential of pumped storage would equate to ~ 2,400 tonnes of CO_2/year

Advantages

- High efficiency energy storage potential
- Provides ancillary grid benefits
- Low lifecycle costs with a long service life of up to 75 years
- Allows for a higher penetration rate of intermittent generation technologies

Disadvantages

- Open loop systems that use natural reservoirs may have environmental impacts
- Moderate to high upfront capital costs with significant economy of scale penalties
- May require an off-peak price differential

[26] DOE, 2015. Pumped Storage and Potential Hydropower from Conduits. Report to Congress February 2015.

Costs and other financial requirements

Pumped storage is currently the most cost effective means of storing energy, even taking into account evaporation losses, 70 – 80% economic efficiency is achievable. However, small facilities will experience economy of scale penalties. Large-scale (> 1,000 MW) pumped storage units have had capital costs ranging from USD300 – 2,000/kW. The cost of storing a kilowatt-hour in batteries is about $400, it has been estimated that pumped storage could be as low as $100/kWh, depending on utilisation rates.

Status of the Technology in Grenada

A study in 1981 indicated that Grenada had about 7 MW of potential hydropower. In 1991, a further study confirmed the feasibility of small hydropower plants at (Birchgrove – 720 kW & Belvidere – 380 kW). None of these projects have been pursued (UNIDO 2013)[27]. There is currently no pumped storage technology deployed in Grenada.

[27] UNIDO 2013. World Small Hydropower Development Report 2013.

Technology: Photovoltaics grid tied

Definition and description

Photovoltaics (PV) is a technology that directly converts solar energy (sun light) into electricity. The output of a PV system mainly depends on the sun light impinging the PV modules or panels. Consequently modules have to be kept clean and unshaded. Another important factor is the PV module temperature; the higher the temperature the lower the output.

Grid tied PV systems feed some or all electricity produced into the public grid. The electricity fed into the grid can replace electricity from other sources like diesel. Grid tied PV systems can be small scale systems on residential roofs, to mainly supply the needs of the household, up to utility scale solar parks owned by Independent Power Producers (IPP) or the utility.

Potential in Grenada[28]

Being a country within the tropics, Grenada receives a lot of sun. Irradiation ranges between 1750 kWh/m² a in the north west of Grenada and 2200 kWh/m² a in the south of the Island as well as Carriacou and Petite Martinique. To put this into perspective, irradiation in the Sahara desert is around 2400 kWh/m² a while in most parts of the UK there is less than 1000 kWh/m² a. Consequently, irradiation conditions in Grenada are very good.

However, its mountainous terrain and the scarcity of flat land for agriculture and dwellings reduces the potential of land for large scale ground mounted PV systems. Nonetheless, there should be sufficient space available for approximately 10 MW to 20 MW of open space PV systems. These systems could produce 16 GWh to 32 GWh of electricity. This compares to a total electricity production of 218.5 GWh in 2016.

In addition there is a lot of suitable roof space, from small residential houses to large commercial and industrial roofs. Assuming one third of all roofs is suitable and strong enough there should be a potential of at least 50 MW for roof mounted PV systems producing approx. 75 GWh.

In total the potential for electricity production from grid tied PV systems in Grenada, Carriacou and Petite Martinique should be at least 100 GWh.

This potential however, can only be harnessed in combination with storage technologies, as the installed capacity exceeds current (32 MW) and medium-term future peak demand. Storage technologies will be discussed in a separate fact sheet.

[28] Due to the lack of detailed analyses the potential has been estimated based on available data and assumptions.

Mitigation to climate

The above mentioned potential of PV electricity could reduce Grenada's greenhouse gas emissions by 64 kT[29] of CO_2 equivalent through the replacement of diesel fuel for electricity generation.

Advantage(s)

- Proven, mature and reliable technology
- Very good scalability making it perfect for distributed generation
- Job opportunities for technically skilled (tertiary education) people in the fields of installation as well as operation and maintenance
- Very low health and environmental risks
- On an international level hardware costs have reduced by more than 80 % in the last 15 years and continue to decrease making PV the cheapest form of electricity generation in some parts of the world

Disadvantage(s)

- Variable source of energy increasing the demand for storage and/or backup capacities
- Limited human capacity and expertise in Grenada increasing the risk of malfunctioning systems
- Due to small market size and high cost of capital, system and energy generation costs are still considerably above international average despite very good irradiation
- High upfront costs
- Increases the risk of social inequality – medium to high income households can bear the upfront cost and enjoy lower electricity costs while low income households will be threatened by high non-fuel costs from the utility

Costs and other financial requirements

Due to the small market size PV technology is comparatively expensive in Grenada. The small volumes imported lead to high prices since there is no leverage for negotiations with wholesalers or manufacturers. Additionally, shipping costs are higher with smaller volumes leading to prices

[29] Based on UNFCCC "Standardised baseline: Grid emission factor for Grenada" and an electricity generation distribution of 95.7 % in Grenada, 3.9 % in Carriacou and 0.4 % in Petite Martinique.

for small scale systems ranging between 2,500 US$/kW and 3,500 US$/kW. This is 50 % to 80 % more than in some parts of Europe or the United States.

Furthermore, the lack of experience and appropriate financial products increases cost of capital making PV systems less viable.

High investment costs and cost of capital result in electricity generation cost (levelized cost of electricity, LCOE) between 0.18 US$/kWh and 0.33 US$/kWh. To put this in perspective the current fuel charge is approx. 0.14 US$/kWh and IRENAs global weighted average LCOE in 2017 was 0.10 US$/kWh.

Status of the technology in Grenada

Approx. 2.3 MW of grid tied PV systems are under operation in Grenada. Half of the capacity is owned and operated by GRENLEC the other half belongs to residential and commercial customers. Grid tied PV systems cover approx. 1.8 % of Grenada’s total electricity demand.

Technology: Photovoltaics off-grid

Definition and description

Photovoltaics (PV) is a technology that directly converts solar energy (sun light) into electricity. The output of a PV system mainly depends on the sun light impinging the PV modules or panels. Consequently modules have to be kept clean and unshaded. Another important factor is the PV module temperature. The higher the temperature the lower the output.

Off-grid PV systems are usually used in areas without interconnection to the public grid. Consequently, they either use some kind of storage technology or an additional backup source to provide electricity when needed or they supply loads/consumers that don't require a permanent output like a water pump with a reservoir. Off-grid PV systems are available in all sizes from small appliances like a calculator to large scale systems to supply electricity to remote industrial consumers like mines (usually in combination with other energy sources).

Potential in Grenada[30]

Being a country within the tropics Grenada receives a lot of sun. Irradiation ranges between 1750 kWh/m² a in the north west of Grenada and 2200 kWh/m² a in the south of the Island as well as Carriacou and Petite Martinique. To put this into perspective irradiation in the Sahara desert is around 2400 kWh/m² a while in most parts of the UK there is less than 1000 kWh/m² a. Consequently, irradiation conditions in Grenada are very good.

However, since most of the populated parts of the island have the grid within reasonable distance there is no need to go off-grid for most consumers. Yet, there is potential in the agricultural sector for water pumping in order to replace diesel pumps. According to a report prepared by Mr. Dinesh Aggarwal for the Japan-Caribbean Climate Change Partnership there are approximately 100 agricultural pumps with capacities between 5 HP to 20 HP. In addition there are areas that are dwellings in the interior that use diesel generators due to the absence of the public grid. In total it seems reasonable to assume that there is a potential for off-grid PV systems in the range of 1 MW.

Mitigation to climate

Assuming replacing small scale diesel generators and diesel pumps with PV systems could lead to a greenhouse gas reduction of approx. 1.8 kT[31] of CO_2 equivalent.

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[30] Due to the lack of detailed analyses the potential has been estimated based on available data and assumptions.
[31] Assuming 1.3 kG CO_2/kWh of a diesel generator and a specific yield 1400 kWh/kW_p a of the PV systems

Advantage(s)

- Proven, mature and reliable technology
- Very good scalability
- Very low health and environmental risks

Disadvantage(s)

- Limited capacity and expertise in Grenada increasing the risk of malfunctioning systems
- New technology for farmers to adapt to
- High upfront costs
- Batteries have to be replaced every 2 to 10 years depending on battery type and quality

Costs and other financial requirements

Due to the small market size PV technology is comparatively expensive in Grenada. The small volumes imported lead to high prices since there is no leverage for negotiations with wholesalers or manufacturers. Additionally, shipping costs are higher with smaller volumes. The exact determination and comparison of costs of off-grid PV systems is quite complicated since the amount and quality of batteries used may vary significantly from system to system. Experience shows that the viability of such systems in Grenada depends on the security of supply. If the consumers agrees to have a lower security, meaning that in times of continuous cloud cover for several days the system might fail, off-grid systems are competitive.

Status of the technology in Grenada

Off-grid PV systems are known in the country. Due to the lack of a register it is nearly impossible to assess an exact number but there should be a 100 kW of installed applications.

Technology: Biogas

Definition and description

Biogas is the product of an anaerobic (without air) process that breaks down biodegradable matter. Various types of microorganisms are involved in the process that finally produces biogas, a mixture of methane and carbon dioxide. Methane is also the main ingredient of natural gas. The methane when oxidized (burned with air) releases thermal energy that can be used for heating and cooking or when burned in a gas engine can produce electricity or propel vehicles. Biogas can be compressed for storage and transportation and it can be purified to increase the methane content to achieve natural gas quality. However, this only makes sense on a large scale as the process is energy intensive.

Methane has a very high global warming potential, which is 28 to 33 times higher than that of carbon dioxide. When burnt however, it becomes carbon dioxide. Since the organic matter can only release as much carbon (dioxide) as it previously took from the atmosphere, it is considered climate neutral and a form of renewable energy. This however, only applies if no more than 3 % to 4 % of the methane leaks from the closed system to the environment.

Digesters and fermenters, that is where the biogas is produced in, are available in all sizes making the actual production of biogas scalable. Certain utilizations however, are bound to minimum sizes in order to be economic. Gas engines and generators for example are not economic with small scale systems.

Potential in Grenada[32]

Grenada's agricultural sector produces a considerable amount of organic waste from manure, fruit and vegetable wastes and green cut to effluents of distilleries. However, most entities are, compared to international standards, are rather small. This makes it challenging to assess the potential and find proper applications. A joint project by the Ministry of Finance and Energy, the Ministry of Agriculture, Lands, Forestry, Fisheries, and the Environment, private sector partners Ökobit and Exled Caribbean (who provides the technology, and the installation and maintenance services) and the German Development Cooperation GIZ introduced small scale biogas digesters for farms and agro-processors. So far ten systems have been installed in total in Grenada. According to GIZ, the vision is to have 50 systems in operation in Grenada. The theoretical potential (entities producing sufficient amounts of waste) may be higher but will most likely not be much more than 100 systems.

Each of those small scale systems is supposed to produce 5 m^3 of biogas per day with a methane content of slightly more than 50 %. Provided the potential of 100 systems would be utilized, the methane production could reach approx. 100,000 m^3 per year.

[32] Due to the lack of detailed analyses the potential has been estimated based on available data and assumptions.

There is also potential for medium scale systems, for example with the distilleries. Feasibility studies and execution plans have so far been prepared for Grenada Distillers Ltd. but have not yet materialized. River Antoine Distillery have also expressed their interest in a biogas system. The larger farms in Grenada could also be suitable for medium sized systems.

The planed system for the Clarks Court Distillery was envisioned to produce approximately 200,000 m³ and 250,000 m³ of methane per year. Assuming that there may be potential for four other biogas systems half the size of Clarks Court, the methane production potential from medium sized systems could be in the range of 600,000 m³ to 750,000 m³ per year.

Mitigation to climate

Due to the size of the potential biogas systems, most if not all would be used for some kind of heating/cooking purpose. Consequently, in order to estimate the greenhouse gas mitigation potential the replaced amounts of LPG and diesel have to be calculated. Methane has a net heating value of approx. 10 kWh/m³. LPG has an average net heating value of 12.8 kWh/kg and diesel's net heating value is approx. 10 kWh/l. Assuming that half of the biogas would replace LPG and the other half replaces diesel, the substitution potential for LPG is between 234,000 kg and 293,000 kg and for diesel between 300,000 l and 375,000 l per year. The emission factor is 3.03 kg of CO_2 equivalent per kg for LPG and 2.68 kg of CO_2 equivalent per kg for diesel. Consequently the total greenhouse gas emission reduction potential through the use of biogas is between 1.5 kT and 1.9 kT of CO_2 equivalent.

Advantage(s)

- Proven, mature and reliable technology
- Very good scalability
- Produces organic fertilizer as a by product
- Reduces pollution in waterways because organic waste is better managed by the biogas system and the recommended fertilizer management system

Disadvantage(s)

- Especially the operation of small scale systems is relatively labor intensive for a renewable energy source
- If more than 3 % to 4 % of methane leak into the environment there are no climate mitigation benefits

Costs and other financial requirements

Obviously the costs of a biogas system mainly depends on its size and the ancillaries like storage facilities, compressors or engines and generators. The small scale systems currently introduced in Grenada cost approx. 12,000 XCD. For a system as it was planned for Grenada Distillers Ltd. the cost would be in the range of 2 million XCD. Payback periods for this specific system would be approx. five years.

Status of the technology in Grenada

Biogas technology has been first introduced in Grenada in the early 1970's and 80's. However, those systems are not in operation anymore. Today several small scale systems are in operation.

Technology: High Efficiency HVAC systems

Description and Definition

High efficiency heating, refrigeration and air conditioning systems (HVAC) can be defined as technologies that have the potential to reduce energy consumption, while providing a high quality of service (heating or cooling). In tropical countries such as Grenada, refrigeration and air-conditioning or RAC systems are mostly used for cooling buildings, industrial refrigeration and other commercial refrigeration applications, such as in supermarkets. In the context of this fact sheet the following high efficiency applications are considered: inverter technologies and high efficient refrigerants with low global warming potential.

- Inverter technology constantly regulates the speed of the compressor so as to continually maintain the temperature. With this approach the energy used is reduced as the motor consumes less current, while the temperature for the application, for example comfort cooling is maintained.

- Many refrigerants or the substances used to remove the heat from a space, have high operating efficiencies. For example,

Potential in Grenada

High efficiency HVAC systems have tremendous potential to be widely deployed in Grenada. In this regard, many of these technologies already exists in the market. For example, in the hotel sector where a majority of these systems were installed, the potential for energy cost savings and GHG emission reduction was demonstrated

Mitigation to climate

With the consumption of less power, the emissions of GHG from the source of fuel are reduced. For example, if the source of fuel is fossil based, like diesel for example, then reduced consumption should result in the reduction of carbon dioxide. This indirect emission scenario is true for both technologies under consideration.

With the use of high efficient refrigerants, such as HFC-290, which has a GWP of 5, direct emissions of these substances into the atmosphere will reduce the impacts on the global climate.

The quantification of the reduced GHG emissions is not possible as, there is lack of data on such equipment installed to determine the quantities. However, in the tourism sector in Grenada, where it is estimated that approximately 48% of electricity consumption is from HVAC, the implementation of energy efficient HVAC equipment in that sector resulted in avoiding approximately 5,800 TCO2eq per year being emitted into the atmosphere. This demonstrates the tremendous climate change mitigation potential that can be derived form a national energy efficient project targeting the HVAC market.

Advantage(s)

- Consumes less energy than conventional systems
- Reduced environmental impact
- Lower operational costs
- Less failures
- Parts tend to have a longer life-span, hence longer life-span of the systems

Disadvantage(s)

- Some of the technologies may have safety issues, such as the flammability of hydrocarbon substances
- May be more costly than conventional systems
- Some of the technologies may require more highly skilled technicians for maintenance

Costs and other financial requirements

The initial cost of the systems may be higher than the conventional systems, although as the technologies begin to mature these initial costs are lowered. However, with the advantages highlighted above the savings produced through efficient use of energy, should result in a shorter payback period and lower lifecycle costs.

Status of the technology in Grenada

Many of these technologies are prevalent in Grenada, especially substances used in the unitary air conditioning systems. A survey conducted in 2017, showed that some technologies, especially in the commercial sector rose significantly between 2012 and 2015. However, these technologies employ the use of substances with relatively high GWPs.

Technology: Electric plug-in vehicles

Definition and description

Generally, electric vehicles use electricity to change a battery and transform that energy to mechanical energy to drive the wheels of the vehicle. There are many types of electric vehicles, these include:

- Hydrogen fuel cell vehicles
- Battery electric vehicles
- Hybrid electric vehicles

The fuel cell electric vehicle obtains its power from the power grid or any other power source. However, the vehicle has a fuel cell built into it that stores energy that can be used to recharge the battery when needed. This will extend the range of the vehicle

The battery electric vehicle also gets it power from the power grid, which changes a battery. The power from the battery is used to propel the vehicle.

The hybrid electric vehicle has a small internal combustion engine. This vehicle also obtains its power from the grid, but the internal combustion engine is used to recharge the battery, if needed, thus extending the range of the vehicle.

Potential in Grenada

There are only four (4) battery electric vehicles in Grenada. However, research by the GRENLEC, which owns three of these vehicles, has shown enormous potential for these vehicles in Grenada. Since Grenada is a small island, the range issues associated with the EV can be mitigated as distances between points are generally short. Additionally, GRENLEC reports excellent fuel efficiency with 99 miles per gallon equivalent and fuel savings of about 34%. The table below shows some key relevant data on the potential of these vehicles in Grenada.

GRENLEC further reports that the vehicles are generally powerful, and in this regard, ascending the highest point on a main road on the island, is comparable to a combustion engine vehicle. The charging cycle of the vehicles, which are used every day, is also good, with the utility service van required to be changed every night, and the cars every other day.

Performance indicator	Value
Miles per US gallon equivalent	97
Fuel savings (%)	34
Miles/kWh	2.61
CO2 savings (MT)	6.91

Data taken from GRENLEC, 2016

Mitigation to climate change

The table shows that from the three vehicles about 6.91 MT of CO_2 can be avoided. Grenada national fleet consists of approximately 20,000 vehicles. Assuming that 50% of these vehicles, including cars, SUVs and other small vehicles, are replaced by electric plug-in vehicles, then approximately 20 MT CO2[33] emissions can be prevented.

Advantage(s)

- Reduced carbon dioxide emissions
- Greater fuel efficiency
- Lower maintenance costs , compared to the combustion engine
- Opportunity to create new jobs and build new skill sets
- High public interests

Disadvantage(s)

- Higher perchance cost compared to the conventional combustion engine vehicle
- Lack of charging infrastructure (powered by renewable energy sources)
- Lack of local dealer support
- Concerns with battery life and replacement costs

Costs and other financial requirements

[33] Assuming that each vehicle will avoid 2 MT/year of CO2 emissions using an average of 6.91 MT/year reported by GRENLEC

In context of Grenada, the cost of EVs, are generally higher than the combustion engine vehicles. The main contributor to this high cost is the battery.

Another financial implication associated with this shift is the investment cost required to install and maintain charging stations that are powered by renewable energy sources.

Status of the technology in Grenada

There are only four (4) battery electric vehicles in Grenada. However, research by the GRENLEC, which owns three of these vehicles, has shown enormous potential for the uptake of these vehicles in Grenada.

Annex 2: List of Stakeholder

List of workshop participants

Name of participants	Organization
Leslyn Parris	GSTRI (Solar Energy Company)
Roxanne Bonaparte	National Disaster Management Authority (NADAMA)
Christopher Greenidge	National Water and Sewerage Authority (NAWASA)
Allison Neptune	Grenada Solid Waste Management Authority (GSWMA)
Derek Charles	IICA
Andrea Duncan-Phillip	GOAM
Philipp Vanicek	Energy Division, Ministry of Finance & Energy
Karen Roden-Layne	GSWMA
Kishue Fletcher	Physical Planning Unit (PPU), Ministry of Works
Fabian Purcell	PPU
Marion Gies	GIZ
Curlan Bhola	GIZ
Trevor Thompson	Environment Division, Ministry of Agriculture, Lands and the Environment
Carlyle Ince	Grenada Electricity Services (GRENLEC)
Earle Roberts	GSTRI (Solar Energy Company)