

DISSERTATION

**TITLE: DECARBONIZATION AND ITS SOCIO-
ECONOMIC IMPACT ON OIL PRODUCING
SIDS**

SUB-TITLE; A CASE STUDY OF GUYANA

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A dissertation submitted to the World Maritime University in partial
fulfilment of the requirements for the award of the degree of Master of
Science in Maritime Affairs

2025

Declaration

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views and are not necessarily endorsed by the University.

(Signature):

(Date):

Supervised by:

Supervisor's affiliation:

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Abstract

Title of Dissertation: Decarbonization and its Socioeconomic Impact on oil producing SIDS; a Case Study of Guyana.

Degree: **Master of Science**

This study examined the socioeconomic impact of decarbonization of SIDS Guyana. Like most nations, NDC targets were promised as an international obligation to the Paris Agreement addressing the issue of climate change.

To carry out this study, research was done on the energy sector of the nation and how transitioning from conventional fossil-fuel generation to renewable energy (RE) of wind, solar and wave would impact the nation's social, economic and environmental spheres.

To arrive at the findings empirical data was reviewed, and an electronic survey was circulated to gather primary data on the nation.

To process the data, renewable energy potential was calculated for each source using a mathematical model in Python 3, investments costs and LCOE for each project was calculated using an accounting model in excel, a decision analysis and a socioeconomic impact assessment were conducted to measure the impact on the three spheres.

It was discovered that Guyana has strong energy potential for (RE) particularly solar and wind and can facilitate the transition. Socially and economically the nation is positioned for the transition and environmentally has the potential to abate CO₂ emissions of 13.3MtCO₂ MWh/Yr, surpassing its 2041 targets by 3.3M with wind and solar alone.

Additionally, it was discovered that projected RE energy production exceeds their energy demands by 1098% for 2025, 422% for 2030 and 186% for 2041. Recommendations for the reallocation of those excesses were given for the maritime sector.

KEYWORDS: SIDS, Guyana, Decarbonization, Socioeconomic, Renewable Energy.

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List of Abbreviations

CAPEX	Capital Expenditure
CF	Capacity Factor
CQC	Categorize, Quantify and Compare
CRF	Capital Return Factor
DBIS	Demerara Berbice Interconnection System
ETI	Energy Transition Index
GDP	Gross Domestic Product
GEA	Guyana Energy Agency
GEF	Global Environment Facility
GHG	Green House Gas – GHG
GPL	Guyana Power & Light
GSDS	Green State Development Strategy
GY\$	Guyana Dollars
HECI	Hinterland Electrification Company
HFO	Heavy Fuel Oil
IEA	International Energy Agency
JET	Just Energy Transition
K	Thousand
KPI	Key Performance Indicators
KW	Kilowatt
kWh	Kilowatt hour
kWp	Kilowatt-peak
LCA	Life Cycle Assessment
LCDS	Low Carbon Development Strategy
LCOE	Levelized Cost of Energy
LFO	Light Fuel Oil
M	Million
m/s	Meters per second
MW	Megawatts
MWh	Megawatt hour
NDC	National Determined Contributions
OPEX	Operational Expenditure
OWC	Oscillating Water Column
PV	Photovoltaic
RQ	Research Questions
SDG	Sustainable Development Goals
SEIA	Socioeconomic Impact Assessment
SIDS	Small Island Developing States
UNFCCC	United Nations Framework Convention on Climate Change
US\$	United States Dollars – US\$
WEC	Wave Energy Converter

Chapter 1 Introduction

1.1 Background

Over the decades, the world encountered numerous challenges, one of which was underestimated and deemed insignificant until it impacted nations on a global scale. Climate change: one of humanity's greatest threats of the era, has significantly shaped the way of life both above and below water. Human activities, particularly the burning of fossil fuels above pre-industrial levels and deforestation, have emitted green-house gas (GHG) on high concentrated atmospheric levels, causing the Earth's standard exterior temperature to rise.

Consequently, there have been a cascade of GHG induced events such as life-threatening heatwaves, droughts, floods, storms and other natural disasters that led to further and longer-term impacts like food insecurity, unpacifiable poverty, and entrenched economic losses (Nations, 2022).

At the United Nations Climate Change conference in Paris, COP 21 in the year 2015 a call to climate action was made that involved both state and non-state actors comprised of national governments, cities, regions, sub-national entities, international organisations, indigenous peoples, youth, women, academic institutions, civil societies and businesses to work together or as individual entities to accelerate actions of the pre-2020 era and onwards (UNFCCC, 2017).

The United Nations Framework Convention on Climate Change (UNFCCC) has a near universal membership of (198 Parties) since its establishment and adaptation in June of 1992 and is the parent treaty of the 2015 Paris Agreement (UNFCCC, 2023a). The study seeks to be in alignment with Sustainable Development Goals (SDG) 3, 7, 9, 11, 13, and minimal focus on 14. Each country was expected to outline and communicate their Nationally Determined Contributions (NDCs) being their post-2020 climate actions to mitigate global warming (UNFCCC, 2019).

Small Island Developing States (SIDS) were among the first nations to become party to the convention given they are among the developing nations, contributes less than 1% of global GHG emissions, are prone to severe environmental impacts and stand to lose the most economically. It's imperative that domestic mitigation measures be taken to ensure the fulfilment of their NDCs and to secure a safe and inhabitable environment for current and future generations. For this study, the socioeconomic impact of decarbonization will be explored in the case of Guyana wholistically, not just maritime with the main scope being the energy sector.

According to Nations (2022) 1 in 3 persons are currently exposed to deadly heat trauma, a threat of which has a global projected increase of 76% by the end of the century 2100, 1 billion people are projected to live in coastal zones threatened by floods by 2050, being more than 1 in 10 people, and ghastly, 3.45 billion people, nearly half of the world's population, are extremely vulnerable to the impacts of climate change.

These and other effects have a direct correlation with many critical sectors around the world that are heavily dependent on the energy sector for consistent operations, these critical sectors are agriculture, manufacturing, technology, housing, business and transportation which encompasses maritime, aviation, road & rail.

Without urgent action, GHG emissions from these and other sectors can bring those staggering figures of 2050 & 2100 to reality with SIDS being among the statistics.

According to UNFCCC (2023b), implementation of the Paris Agreement will require economic and social transfiguration relying on the best accessible science.

Notably, such science is not available in most SIDS. Additionally, SIDS rely heavily on imported fossil fuels for the efficient operations of their energy sector that serves the other critical sectors of their economies and societies. However, there are a few SIDS, particularly Guyana and Trinidad & Tobago that are oil producing nations that depend on oil revenues for economic and social development, at the same time

implementing transition plans to achieve their NDC targets, otherwise, continued reliance and use of fossil fuels will be counterproductive to their NDCs. Factored into those transition plans would be the uptake of renewable energy being a decarbonization strategy towards the mitigation of climate change.

According to Davda (2024), the fuel & energy industry is the number one polluting industry in the world. The effects of this reality are driving the transitions to renewable energy that's set to reduce GHG emissions among nations.

While there seems to be a conflict between the reliance on fossil fuels and decarbonization, Norway, an oil producing nation, has successfully transitioned to a decarbonized economy, being sixth in the world with an Energy Transition Index (ETI) score of 69.9% of renewable energy production, and Brazil, Guyana's neighbour, in twelfth place with an ETI score of 65.7% at the end of 2024 (Bazilian et al, 2024).

However, while some nations have achieved commendable levels of success, the process may not be the same for SIDS; high transition costs, economic, social, environmental, policy issues and political pressures are some of the barriers and challenges that are faced. Nevertheless, the evidence of positive outcomes from successful nations are drivers and motivation for change and have created a roadmap for other nations to follow.

1.2 Problem Statement

Climate action for most developing nations is an ever-growing but slow process due to the many challenges they generally face. The Paris Agreement proposed high expectations to which many SIDS had subscribed, and ambitious NDC targets were submitted with the promise of fulfilment.

For SIDS, achieving their NDC targets are both practicable and exigent. Environmentally, SIDS are home to a seamless supply of renewable energy sources

such as solar, wind, wave and hydro due to their tropical climates, yet the technology, infrastructure and technical expertise to ensure a successful and sustainable transition are lacking.

According to Havea et al. (2024), SIDS are distinctively placed at the confluence of predisposition and possibility. By channelling renewable energy sources, they can effectually palliate GHG emissions, enhance energy reliability, strengthen resilience, and pioneer energy transition, however, these expectations cannot materialize without policymakers, stakeholders' co-operation, and scientists to address the many technical, socioeconomic, and environmental issues that are roadblocks for SIDS (Havea et al., 2024).

Additionally, green technology, energy efficiency programs, infrastructure to support renewable energy, high levels of debt and other financial constraints all augment the high transition costs needed for a successful and sustainable decarbonized future. In the case of Guyana, its energy generation is almost completely dependent on fossil fuels, specifically heavy fuel oil (HFO) with their electricity charges being among the highest in the region at US\$0.32 per kWh (ITA, 2025).

Consequently, regions of the country have unstable electricity supply and are prone to frequent blackouts, historically, the country's ability to provide value added processes have been limited due to high electricity costs, hence high operations costs among businesses (ITA, 2025).

Another pressing issue would be the nation's energy legislation which monopolizes state owned Guyana Power and Light (GPL) over energy generation, which poses challenges to potential investors seeking to capitalize on renewable energy opportunities (ITA, 2025).

Nevertheless, the nation has huge potential for renewable energy transition, due to its tropical climate, unoccupied lands and vast stretch of shoreline that can particularly cater to solar, on and offshore wind turbines and wave power projects, the likes of which will be assessed in this study.

Energy transition is inevitable and necessary to ensure resilience and sustainability. To limit global warming to 1.5°C, the world must generate three times the amount of renewable energy capacity by 2030, equivalent to 11,000 GW (UNEP, 2017). To this end, SIDS, in this case, Guyana, must actively implement their decarbonization strategy, and contribute to the global mitigation efforts by achieving their NDC targets.

1.3 Aim and Objectives

This study aims to propose a comprehensive analysis of oil producing SIDS, Guyana to ascertain the best decarbonization projects the nation should undertake to achieve economic, social and environmental viability that satisfies their NDC targets in keeping with the Paris Agreement.

The research will be guided by three main objectives:

1. Identify the costs of solar, wind and wave energy projects.
2. Identify the social, economic and environmental impact of the projects.
3. Identify the best energy mix for Guyana to reduce the nation's dependence on fossil fuels for energy generation and aid in establishing stable supplies.

1.4 Research Questions

1. Does Guyana have a decarbonization policy?
2. What is Guyana's energy demand?
3. What is the average CAPEX, OPEX & Decommissioning costs of solar, wind and wave energy projects?

4. How will the implementation of the projects impact the social, economic and environmental spheres of the nation?
5. What is the required renewable capacity for Guyana?
6. What is the best energy mix for Guyana?

1.5 Methodology Overview

The methodology algorithm by which this study will be carried out is as follows:

Data collection methods:

- Systematic literature review aimed at gathering secondary empirical data on Guyana's energy demand, decarbonization plan, CAPEX, OPEX and Decommissioning costs of solar, wind and wave energy projects, with the aim of answering research questions RQ 1, 2 & 3. The data will be input for the accounting model. and the results after processing will be input data for the socioeconomic impact assessment.
- Download energy potential data of wind, solar and wave for Guyana from the Copernicus website (Europe's Eye on Earth) as input data for the mathematical model. The results will be input data for the accounting model.
- Carry out 2 electronic survey to gather primary social data from citizens and businesses from three coastal regions that are the proposed locations to establish the renewable energy (RE) projects and to gather primary economic data from Guyana Energy Agency and Guyana Power and Light. This data as well as the results from the accounting model calculations will be input for the Socioeconomic Impact Assessment.

Data Analysis Models:

- Calculate available power and energy from Copernicus data sets using a mathematical model in Python 3 as the tool.
- Calculate levelized cost of energy using secondary data extracted from the literature and the energy output results from the mathematical model using an accounting model in excel as the tool.

- Carry out a decision analysis by using scenario and comparative analysis as a forecasting technique and an evaluation method respectively to propose Guyana's RE capacity, and RE mix respectively.
- Carry out a socioeconomic impact assessment (SEIA) to determine the sustainability of the proposed RE projects by measuring their impacts on the society, economy and environment.

1.6 Ethical Issues and Timeline/Budgets.

To satisfy the standards of the World Maritime University's (WMU) as explained in the research methodology of this study, a systematic literature review geared at identifying any gaps and missing data surrounding the research topic was conducted. Data was collected via an electronic survey. Before all interviews, consent was sought, and their identities and confidentiality were protected according to their privacy rights outlined by the ethics committee.

All data sources be it recordings, hard and soft copies of documents, working papers, and emails, were secured and were deleted after the conclusion of this dissertation. The timeline for data collection began as soon as approval was granted for this research. No budgets were required.

1.7 Expected Results.

The outcome of this research is expected to present a comprehensive analysis regarding renewable energy of wind, solar and wave, and their recommended capacity needs based on Guyana's energy demands and the best energy mix, based on each projects' performance, CO₂ abatement, economic returns, and social benefits.

- Proposing the most cost effective and sustainable renewable energy projects that will replace or compliment Guyana's current energy generation plants, reduce reliance on fossil fuels and its associated CO₂ emissions.

- To highlight Guyana's decarbonization strategy and its stages of development to date. Identifying gaps, current decarbonization projects, and directions that Guyana should undertake based on their available and accessible resources.
- Finally, adding to the literature surrounding the topic area by synthesizing the findings into one framework/roadmap for other developing nations and SIDS to follow.

1.8 Key Assumptions and Potential Limitation.

1. The research is focused solely on energy transition in the case of Guyana, which limits the scope of investigation to the country.
2. Much focus is not placed on the Maritime Sector in this study but rather, the nation's energy sector which has a direct impact on all the other sectors including maritime.
3. The study is limited to the three most densely populated administrative regions of Guyana, being regions 3, 4 (the nation's capital) & 6, all of which are coastal regions.
4. It is assumed that the three regions will have the highest demand of energy and consumption based on population size proving to be the best areas of sample for data collection and assessment.
5. The research is limited to renewable energy analysis of wind, solar and wave; no consideration is given to alternative fuels or other decarbonization strategies in this study.
6. Assumptions will be made regarding the capacities of the wind, solar and wave farms based on the general manufacturing size of each technology which will derive from the literature and the results be limited to these assumptions.
7. Assumptions will be made regarding the CAPEX, OPEX, and Decommissioning costs of each project as well project discount rates and lifespan based on empirical project information derived from the literature.

Chapter 2 Literature Review

To carry out the study a systematic literature review; the process of which is displayed in *figure 1* was done to gather empirical qualitative, & quantitative data from scholarly articles, reports, government websites, and books. The method was narrowly focused on information between 2020-2025 using inclusion and exclusion criteria. The exercise was geared at answering RQ 1, 2 and 3 which served as input data for the analysis models that answered RQ 4, 5 and 6. For historical context in some aspects of the review, information between 2011-2019 were utilized:

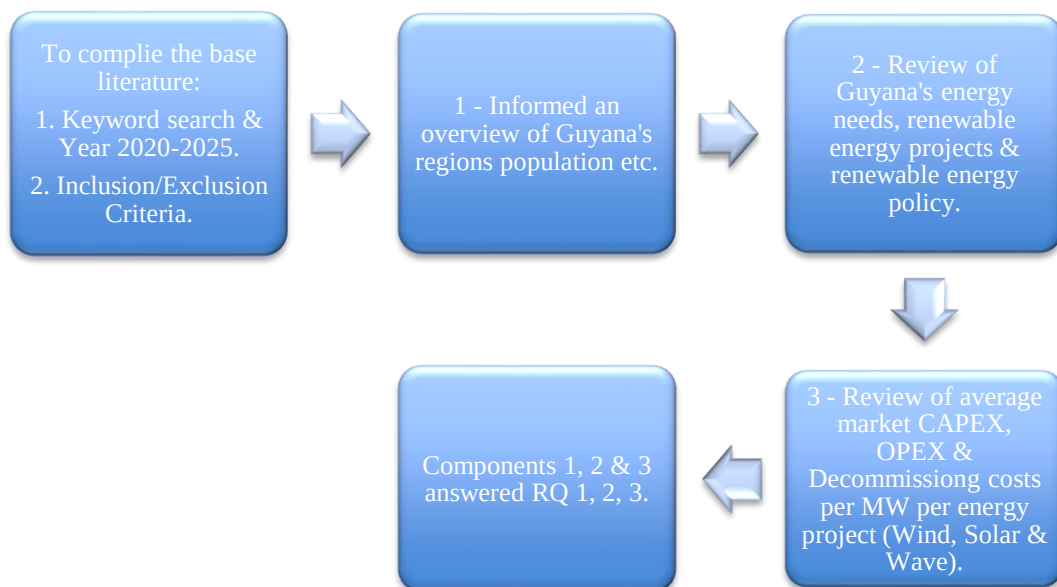


Figure 1: Summary of Literature Review Process & Purpose.

(Source: Created by Author using Microsoft word, 2025).

2.1 Guyana Overview

Guyana, the only English-speaking country in South America is geographically demarcated by 83,000 square miles and is bordered by the Atlantic Ocean to the north, Suriname to the east, Brazil to the south, Venezuela to the west and is classified as a SIDS.

She gained her independence from the British on May 26, 1966, and has since been governed by a semi-presidential system. Prior to the discovery of oil in 2015, Guyana was the poorest country in South America and the Western Hemisphere.

The Nation is divided into ten administrative regions of which region four, Georgetown, is its Capital. According to Statista (2025b), Guyana's current population stands at around 800,000 people. This is consistent with World Bank's data that states 90% of the 800,000 inhabitants resides on the coastal plain which is merely 10% of the country's total area (World Bank, n.d). This implies that most of Guyana's energy needs are consumed and concentrated on a small portion of the Nation's landmass.

Therefore, for the purpose of this study, the three densely populated regions of the coastal plain; being regions 3, 4, and 6 will be considered for samples of study to measure energy needs, consumption, socioeconomic impacts and renewable energy potential for the deployment of energy projects.

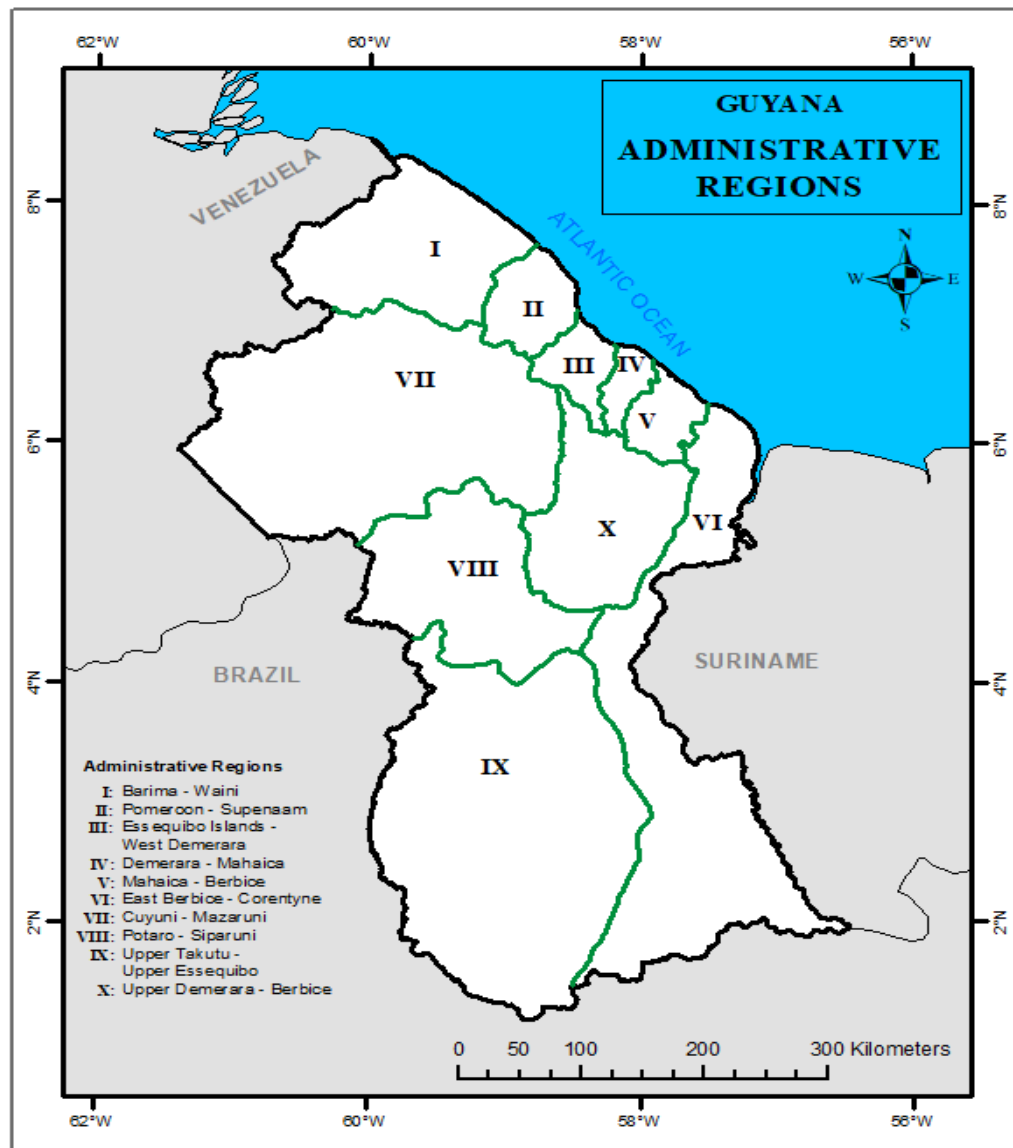


Figure 2 The ten (10) Administrative Regions of Guyana by name and number

(Source: Guyana Lands and Survey Commission, n.d.)

Figure 2 displays all ten administrative regions of Guyana, besides areas of assessment and data collection, regions 3, 4 & 6 will also serve as pilot projects implementation sites with a wind farm at region 3, a solar farm at region 4 and a wave farm at region 6 assuming installed capacities of 4 megawatts (MW), 3MW, and 4MW respectively.

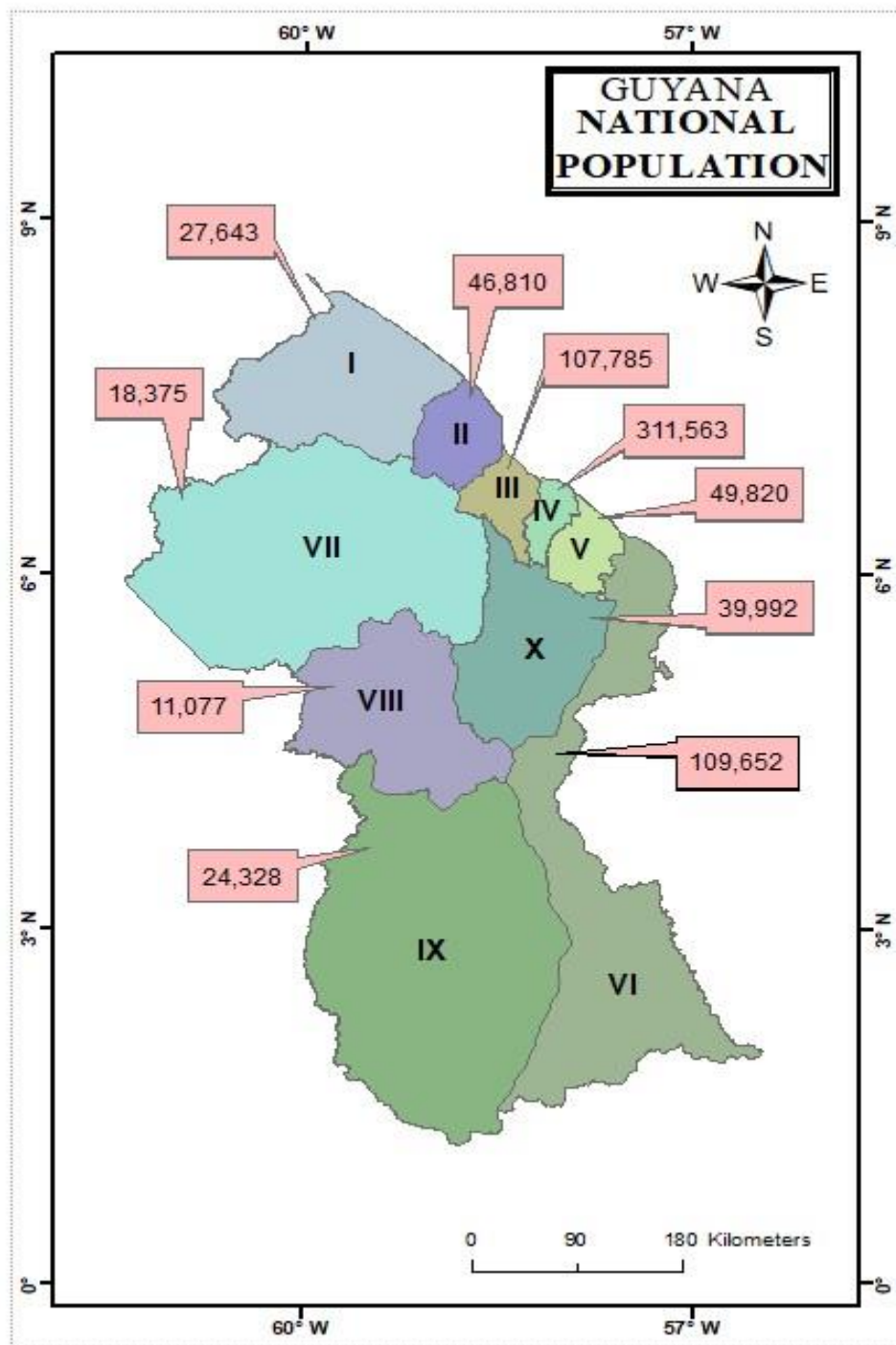


Figure 3 Guyana's Population by region based on its 2012 Census

(Source: Guyana Lands and Survey Commission, n.d.)

Figure 3 displays the population size of each region based on Guyana's 2012 census which has since increased. For simplified calculations of each region, the population data is round up to the nearest thousand.

- Region Three – Essequibo Islands West Demerara is rounded to 108,000 inhabitants,
- Region Four – Demerara Mahaica is rounded to 312,000 inhabitants, and
- Region Six – East Berbice Corentyne is rounded to 110,000 inhabitants.

The three regions represent 66% of the nation's population which is a substantial sample size to carry out this study. Based on conducted studies, results have shown that energy consumption has a direct correlation with population size and growth. According to Muzayanah et al. (2022) population density positively influences the total consumption of fuel and electricity, the author further stated that the inclusion of population growth, minimizing energy inequality and unbalanced spatial distribution are crucial for national energy plans.

Other studies have shown that population density may have reducing effects on fossil fuel energy consumption, but restricted effects on electricity consumption (Ma et al., 2024). However, another study conducted by Wang et al, (2024) found that population density and energy consumption does not have a transparent relationship, positive or negative effects are debatable.

This implies that the relationship between energy consumption and population density is relative to varying factors. Therefore, by examining the three most densely populated regions of Guyana, the findings of this study can present insight on these and other complexities.

2.2. Guyana's Energy Infrastructure, Needs & Consumption

Like most SIDS, Guyana depends heavily on imported fossil fuel for energy generation. Despite vast renewable potential, the installed electricity capacity is driven by diesel-engine generators, consequently, the average electricity charges are US\$0.32 per kilowatt-hour (kWh) which is among the highest regionally and the power distribution is unstable in many regions of Guyana due to deplorable transmission lines that are in dire need of replacement; roughly 26% of grid capacity is lost (EIA, 2024). Ram (2023) also confirms the charges of US\$0.32 being eight times higher than regional oil producing SIDS Trinidad and Tobago, which is the highest among the CARICOM states.

According to a report by GEA, (2024a) if there is no transition from the current energy source of heavy fuel oil (HFO), consumer costs and greenhouse gas emissions will remain high, the 2021 costs of fuel was approximately US\$150M.

Electricity is distributed by the Guyana Power and Light (GPL) and Hinterland Electrification Company Inc (HECI) via 12 public grids, the largest of the grids is the Demerara Berbice Interconnection System (DBIS) which consumes 78% of the total fuel costs (GEA, 2024a). According to Stacy, (2024), the daily consumption was approximately 391K barrels in 2023. The DBIS primarily serves regions three, four, five, six and some parts of region two. According to GEA, (2025) scheduled for 2025, the grid will reduce the utilization of HFO and take on an energy mix of natural gas, hydro, solar, and wind with the entire mix being integrated by 2027.

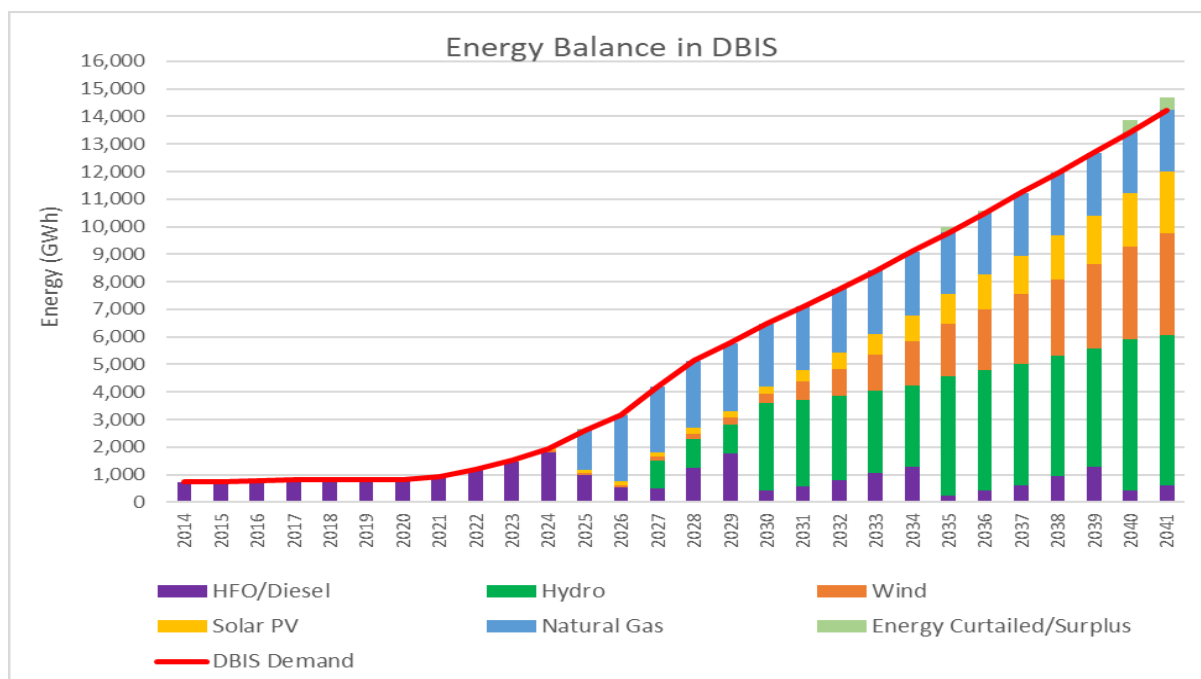


Figure 4: Energy demand projections and DBIS energy mix integration 2014-2041.

(Source: Guyana Energy Agency, 2025).

According to Low Carbon Power (2024) Guyana's electricity demand growth is likely driven by its progressing economic growth. Based on figure 4's visuals Guyana's energy demand remained stable during the years 2014 to 2021 and indicated gradual increases from 2021. This was due to oil revenues from petrol exports that started in late 2019 and early 2020 that financed new roads and lighting infrastructure, new housing schemes, new businesses such as hotels to boost the tourism industry and other key sectors that will require increased electricity services.

Furthermore, the mixed energy demand is projected to be approximately 6 times the demand of 2025's projection by 2041 at 14,000MWh. This is assuming that 2025's projected demands remain the same at 2500MWh at the end of the year. Mid-term projection in 2030 reflects 6500MWh for that year almost 3 times 2025's projections. It is therefore extremely important that all energy transition goals be met within their time frames, which entails the enhancement of the electricity grid, the uptake of

renewable energy sources, and increased capacity to satisfy the economic growth of the nation which has a strong correlation with energy demand.

2.3. Guyana's Energy Policy: Low Carbon Development Strategy (LCDS), 2030.

In keeping with their nationally determined contributions, SIDS have indicated by way of climate action plans, time bound decarbonization goals and objectives, capsulized by projects, that are financed either by their national treasury, or borrowings from international financial institutions, all of which are driven and influenced by policy.

According to Katrien Steenmans (2020) climate change has become a matter of urgency for the Guyana Government and they have since put laws and policies in place to foster climate adaptation through local and private climate finance. Instituting strong policy towards energy transition is paramount and same must be implemented with a wholistic approach taking sustainability into consideration. Kit Fai Pun (2023) states the importance of eco-services provided by the ecosystem to humans and the need for policies that ensures an environmental management framework that falls under the umbrella of sustainability.

Ketwaru et al. (2025) also mentioned Guyana's LCDS, 2030 as the national all-embracing policy for sustainability. The implementation of the strategy is realized by plans for the use of fossil fuel revenues to develop low carbon and renewable energy sources like wind, hydro, solar, biomass and natural gas that are being engineered through a compilation of investments in energy infrastructure that transforms the transmission and generation systems; policies that will drive the use of renewable energy within households and businesses, and improved energy efficiency investments; said infrastructure will be funded by the Government's national budget, revenues generated from climate forest services, and investments from the private sector (Government of Guyana, 2024).

The plan is further outlined in three phases; 2022-2028; 2028-2032 and 2032 onwards with full execution projected by 2041 (Government of Guyana, 2024).

- 2022-2028 – Demands for electricity is projected to triple but will be met with the infusion of hydropower and natural gas to the DBIS integrated with solar power and batteries to serve the urban coastal and off-grid areas (Government of Guyana, 2024).
- 2028-2032 – Less reliance to be placed on HFO with a greater increase of solar and the uptake of wind energy to meet further increases of energy demands, this will be coupled with the commissioning of a second hydro power plant, the site of which is scheduled to be identified in 2025 (Government of Guyana, 2024).
- However, based on figure 4's projections there will be gradual integrations of solar and wind and larger integration of natural gas in 2025 greatly decreasing reliance on HFO. 2026 shows natural gas dominance while 2027 projects the integration of hydro as the most dominant among the mix beginning in 2030.
- 2032 and onwards will cater to further expansions based on persuasive market conditions expecting the costs of technology and adequate storage devices to reduce because of greater maturity and efficiency enabling wind and solar plants' services to increase storage capacity and output while downscaling the costs of electricity (Government of Guyana, 2024).

Government of Guyana (2024) further estimated in their plan that by 2041 renewable energy will be the domineering supply of electricity in the nation while reducing and keeping CO2 emissions at 2018 levels.

Taking the overview into full consideration, the following key information are noted:

- Guyana's full population is 800,000.
- Regions 3, 4 & 6 which are densely populated at 108,000, 312,000 & 110,000 respectively, represents 66% of the full population and will inform the analysis process.

- Energy potential data will be calculated, analysed and compared with 2024's projections as the base year due to 2024 being the most recent and completed period on the data site Copernicus.
- Guyana's Low Carbon Development Strategy (LCDS), 2030 is their driving policy behind energy transition.
- Their energy mix consists of solar, wind, natural gas, hydro and HFO, however, no consideration was given to wave energy which is an area of study in this dissertation.
- Renewable energy projections were given for 2025 to 2041, therefore 2024 energy results will be compared with 2025, 2030 & 2041 projections which represents assumed short, mid and long-term periods of the plan.

2.4. Costs of Renewable Energy Projects.

Transitioning to renewable energy requires not only the energy potential of wind, solar, wave, hydro, and other renewable sources, but also the availability of the necessary technologies, expertise, infrastructure, stakeholder buy-in, policies and finance to effectively execute and establish the nations planned projects.

Based on the report (IEA, 2024) renewable project implementation face challenges that falls under four key groupings and varies by country; one of such grouping is inadequate financing in developing and impending economies.

In the case of Guyana, finance was a significant challenge, however, due to the nations recent oil wealth and revenues generated from oil exports, adequate funds from the national treasury, the private sector and finances raised from climate forest services have been allocated to execute their renewable energy plans, with the aim of fulfilling their NDC targets and goals.

Moreover, Mohan (2022) explains that while the Paris Agreement validates the assistance of developed countries and provides a substructure of financial support through the Global Environment Facility (GEF), the funds needed to aid in the energy

transitions to net-zero among SIDS and developing nations far exceeds the commitment of these systems.

It is therefore crucial for SIDS like Guyana and other developing nations to accumulate domestic finance to buffer the deficits even if aided by GEF and other frameworks of its nature.

According to Howell (2025), solar, onshore and offshore wind are the most affordable sources of renewable energy with solar being the cheapest in history since 2021, this was an escalation from 2010 that saw solar photovoltaic (PV) prices taking a downward trend by 80% that further reduced in 2024. Further, according to IRENA (2025) as of 2023 and 2024 there was a more than 10% decrease in overall installation costs of renewable power across all technologies save for offshore wind which remained proportionately fixed.

However, pinning precise costs for renewable energy projects across the board is not ideal since the budgets vary based on country, energy demands, design, grid capacity, the chosen technologies, energy stock and potential, land allocation, and many other critical factors comprised with CAPEX costs. Examples would be the Life Cycle Assessment (LCA) of the technologies chosen and their associated externalities when covering from cradle to grave to recycling.

Wind

Nevertheless, according to Switch Pal (2024) the industry average for commercial onshore wind turbines would be £1.2 to £1.6M per MW of capacity which does not include site assessments, operations costs, or permit acquirement which would incur several thousand pounds more and maintenance which is roughly 1-2% of the initial investment.

However, a 2011 study by Bruckner et al. (2019) confirmed that in China, some of the cheapest wind farms were installed at 1M to 1.3M per MW which included turbines, conveyance to site and installation, grid connectivity, civil works, environmental assessment, permits/licensing and other costs.

Taking inflation into consideration and the fact that wind technology has reduced over the years, when converting the costs £1.2 to £1.6M per MW to US\$ via the exchange rate of £1 being equivalent to US\$1.34, onshore wind projects can be assumed at US\$1.6M to US\$2.1M dollars per MW, this is assuming Guyana will source their wind turbine technology from China.

Wave

The government's LCDS and master plans did not express wave energy as part of their renewable energy mix, nevertheless, Guyana has a northeast coastline of 430 km and an extended continental shelf of roughly 724km (Oyedotun & Burningham, 2021). It may be feasible to explore and calculate wave potential, not only to fill the research gap and add to the literature, but that this information will later inform policies at a national level and the resource can be considered as either an addition, alternative or adjustment to their current plans.

According to Srinivasan Santhakumar et al., (2023), it is expected by the IEA in 2050, global ocean energy being tidal and wave energy will be contributing 293,000 (293K) MW of renewables to the global mix. A November 2023 report by 'Ocean Energy Systems' states that by 2050, 300K MW of tidal and wave energy could be generated which is sufficient to supply approximately 225 million homes with electricity (Rooke, 2024).

The author further wrote however, that the costs associated with wave projects are generally expensive since conducting any project in the ocean is difficult; it is a

corrosive, energy intensive and tyrannical environment that requires robust structures to last the lifetime of the project being twenty to thirty years; at a commercial scale it may cost around US\$120 – 470 per MWh (Rooke, 2024).

According to Guo et al., (2023) this cost, US\$470/MWh – US\$120MWh represents the decrease of LCOE from the maximum to the minimum as the CAPEX and OPEX costs substantially decrease; the author also noted that the cost of wave energy extraction is still much higher than that of other renewables hence making it less competitive on the market. However, ETIP Ocean, (2022) highlights the average CAPEX cost of wave projects is €6.4M per MW with OPEX cost at €0.5M per MW. When converted to US\$ with an exchange of US\$1.15 to €1.00, the CAPEX cost is US\$7.36M per MW and OPEX at US\$0.575M per MW.

Solar

However, solar remains the lowest of CAPEX and OPEX costs making solar farms the cheapest renewable investment. According to Smith (2024), utility scale farms are at a median cost of US\$ 0.98 per watt as of 2025 which does not include land acquisition, the standard farms to satisfy utility services starts at 1 MW which aggregates to US\$ 980K, factors that may affect the final costs of these projects are labour, location, design, insurance, permits, and taxes.

Another article by Chungfat (2024) also states that due to advanced technology, the costs of stationing large-scale solar farms have been reducing over the years, the median costs span from US\$ 1 to 1.50 per watt which calculates a 1MW project to be US\$ 1M to 1.5M. The article further coincides with Smith (2024), highlighting the other factors that may affect the final costs such as location, size and scale, technology used, regulations and permits etc.

Furthermore, the 2011 study by (Bruckner et al., 2019) states that a 0.5MW to 1MW fixed tilt utility PV farm had cost US\$2.7M to 5.2M with annual OPEX costs at 0.5 and 1.5% of initial investment. Applying the same logic of inflation and reduced PV technology costs over the decades, it is safe to assume that a 1MW fixed tilt utility PV farm should be approximately US\$ 1M to 1.5M inclusive of land and other associated costs for its full operation.

However, what was not highlighted by these sources were the energy storage technology costs, it can only be assumed they were part of the CAPEX costs mentioned, such technology is compulsory especially for **wind** and **solar** which are heavily dependent on volatile weather patterns, on cloudy/rainy days and at night there will be no sun light, therefore storage to capture excess energy from the sun is vital, same for wind, wind may not always be available at the required speed or at all to harness the required energy needs that ensure consistent and stable power. Therefore, when establishing the projects, the costs of storage must be factored into the budget.

Decommissioning Costs of Wind, Wave & Solar Projects

Wind

According to Cohen (2024), decommissioning charges per onshore wind turbine varies between US\$ 114K and 195K. Furthermore, U.S. Department of Energy (2022) states that when estimates of salvage were included, decommissioning charges reduces to a net value of US\$ 67K to US\$ 150K per turbine. Guyana's assumed pilot wind project will carry a capacity of 4MW comprised of two turbines at 2MW each, therefore, decommissioning charges at the end of the project's life will be assumed at US\$150K per turbine. Project lifespan is 25 years.

Solar

According to Solarnplus, (2024) fix tilted solar farms are usually decommissioned at US\$ 368K per MW after a life span of 25-30 years. Guyana's pilot PV project will be assumed at 3MW with decommissioning charges at US\$ 368K per MW.

Wave

Research conducted by (Amélie Têtu & Chozas, 2021) determined that decommissioning charges associated with wave projects can be reasonably placed at 10% of CAPEX, this covers all costs related to the wave energy converter's removal, mooring, electrical cables, and foundation. According to ETIP Ocean, (2022), wave projects are estimated at US\$ 7.3M per MW, therefore decommissioning costs will be US\$ 730K at the end of the project's life. Guyana's wave project is assumed at 4MW with a lifespan of 25 years.

The capacity factors (CF) of each project will be calculated in chapter 4 of this study. The CF is a measure of average generated electricity during a period compared to its maxed capability (van et al., 2024). According to Centre of Sustainable Systems University of Michigan (2024), the average capacity factor for onshore wind turbines measures between 9% to 53% but is median at 37%. Coe et al., (2021) states that solar PVs usually have CFs of approximately 25% depending on clouds and the sun's angle at the place of deployment. Lavidas, (2020) found that CF for wave projects varies between 25-32% but highlights that it depends on the region and device. The consideration of the CF is important since it measures the realistic performance of the farm that has a direct impact on LOCE.

2.5. Conclusion

Having reviewed the literature it was discovered that Guyana has a renewable energy policy, a decided energy mix, and a short-, mid- and long-term projection of the nation's energy needs by 2025, 2030 & 2041 respectively. It was also discovered that the nation has huge renewable energy potential of hydro, wind, solar and wave, of which the first three are part of their energy mix and various projects were commissioned that commenced the integration process of the renewables into the public grids.

To test Guyana's energy potential and if it will meet their energy projections over the respective periods of 2025, 2030 and 2041, assumptions of 11MW of installed capacity will be used being a 4MW offshore wind farm in region 3, a 3MW Solar PV farm in region 4 and a 4MW wave farm in region 6 being the first case. The capacity assumptions were based on real world start up projects since RE started to build momentum and became a competitive energy source on the market as well as general manufacturing specifications.

According to A. Jäger-Waldau (2013), PV systems, especially grid connected showed strong growth in developed countries, during 2006, approximately 1.5GW of PV was installed which is 1500MW during that year. Wind turbines were manufactured at 2.5 to 3MW capacity with blades at 50 metres length able to power on average, above 1500 European Union families (European Wind Energy Association, 2016).

According to Lavidas & Blok, (2021), common specifications of wave energy converters is that they have a formal capacity below 1MW. Therefore, based on these real-life cases, the assumptions were made.

To extend the analysis a scenario analysis of two more cases being scenario 1 and 2 will be conducted with scenario 1 being 7MW of installed capacity and scenario 2 being 6MW of installed capacity.

Financial data at approximate market values were also reviewed in the literature for wind, wave and solar and reasonable assumptions were made based on the empirical findings. All assumed data were extracted to 'Table 1' of this study which served as input data for the calculation of LCOE using the accounting model. Data regarding the socioeconomic impact of the projects will be reviewed and measured under three themes; Economic, Social and Environment with the following KPIs as respective subthemes; green job creation, economic diversification, electricity cost reductions, energy access & equity, improved public services, community engagement,

environmental trade-offs, marine biodiversity impacts and CO₂ abatement. Therefore, the secondary data and assumptions uncovered from the literature will inform the analysis and serve as input data for the various models.

Input Data for LCOE Calculation

Table 1 displays input data extracted from the literature to compute LCOE in the accounting model.

Table 1: Assumed CAPEX, OPEX & Decommissioning Costs of Wind, Wave & Solar Projects extracted from the literature review.

Cost \$	Wind	Wave	Solar
CAPEX	1.6M per MW	7.3M per MW	1.5M per MW
OPEX	0.032M per Yr.	0.575M per Yr.	0.0225M per Yr.
Decommissioning	150K per turbine.	730K.	368K per MW.
Capacity	4MW	4MW	3MW
Project Lifespan	25Yrs	25Yrs	25Yrs
Discount Rate	8%	8%	8%
Further Description	Capex costs cover all investments that ensures full operations. Opex is 2% of Capex per year.	Capex costs cover all investments that ensures full operations. Opex is 8% of Capex per year.	Capex costs cover all investments that ensures full operations. Opex is 1.5% of Capex per year.

(Source: Literature Review).

Chapter 3 Methodology

This study is based on energy transition from conventional energy generation by use of fossil fuels, particularly heavy fuel oil (HFO) and light fuel oil (LFO) to renewable energy generation in the case of Guyana while assessing the socioeconomic impact of the transition. The data collection and analytical methods are visualized in figure 5.

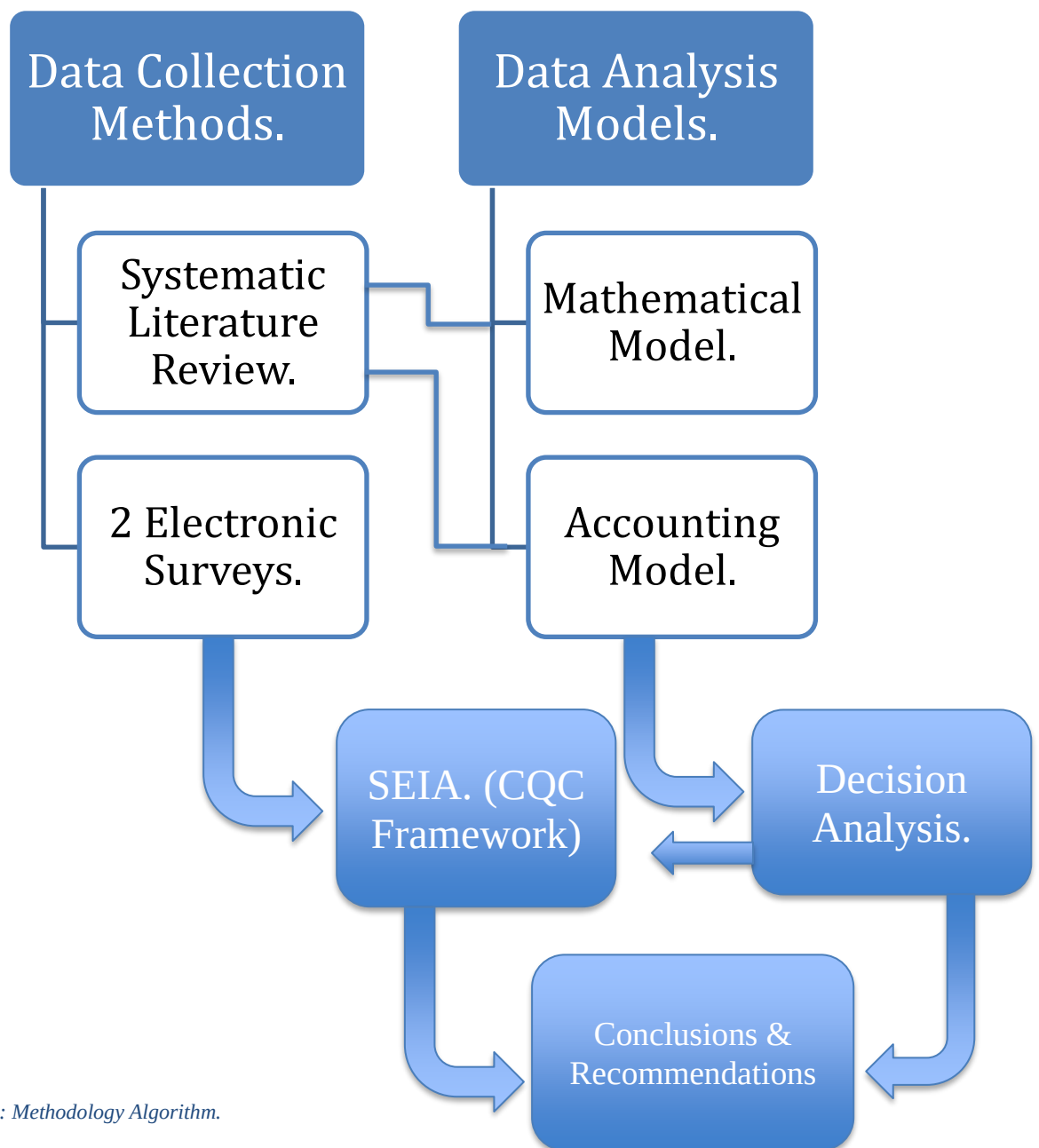


Figure 5: Methodology Algorithm.

(Source: Created by Author using Microsoft Word, 2025.)

3.1 Data Collection Method

Electronic Survey

To carry out the SEIA, primary data was gathered by way of an electronic survey circulated using a link via WhatsApp to citizens and businesses of regions 3, 4 & 6 of Guyana, the proposed locations of the wind, solar and wave projects respectively. The survey was created using aidaforms tool comprised of 17 questions, 15 of which were used in the assessment. The data served as input information for the SEIA.

Download energy potential data for wind, solar and wave from the Copernicus website (Europe's Eye on Earth) which is a European Union approved data store.

3.2 Data Analysis Models.

The extracted quantitative and qualitative data from the literature and the survey, served as input data for the following models displayed in *figure 6*.

The data analysis models entailed four aspects: RE energy calculations using a mathematical model, cost analysis using an accounting model, decision analysis using scenario and comparative analysis and a socioeconomic impact assessment using the categorize, quantify and compare framework (CQC).

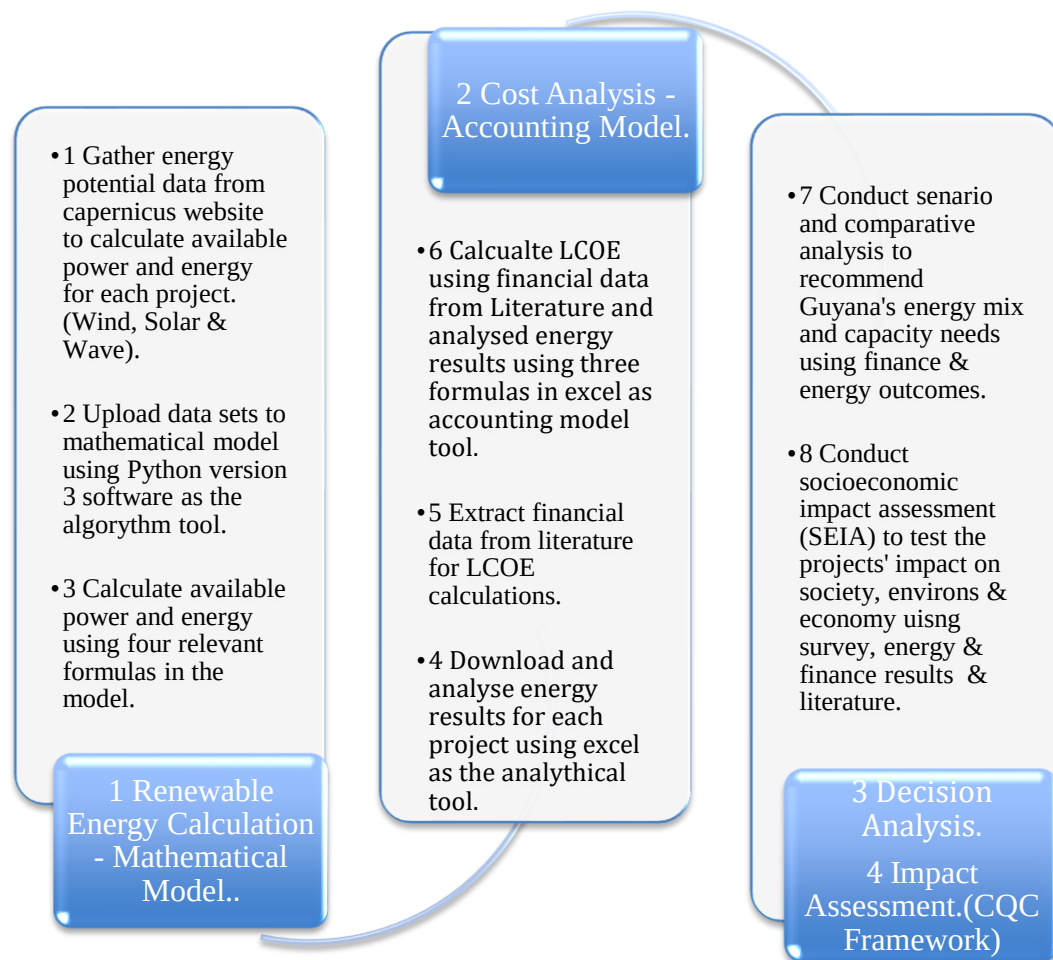


Figure 6:Data Processing and Analytical Models

(Source: Created by Author using Microsoft Word, 2025).

Mathematical Model

This model is comprised of four formulas: wind power, solar power, wave power and power to energy conversion. The Python version 3 software was the tool used to compute the available power and energy outputs for each project. The input data sets for Wind, Solar & Wave for Guyana for the period January to December 2024 were downloaded from the Copernicus website (Europe’s eye on Earth). The algorithm is as follows:

Equation 1 Wind Power Formula

$$P_{wind}(t) = \min(f(v(t)), 1) \times capacityW$$

$$v(t) = \sqrt{u_{100}(t)^2 + v_{100}(t)^2}$$

$$f(v) = \begin{cases} 0 & v < v_{cutin} \text{ or } v \geq v_{cutout} \\ 1 \left(\frac{V - v_{cutin}}{V_{rated} - v_{cutin}} \right)^3 & v_{cutin} \leq v \leq v_{tared} \\ 1 & v_{rated} < v < v_{cutout} \end{cases}$$

Components:

$u_{100}, v_{100} \rightarrow$ horizontal wind components at 100 m per second."

$v \rightarrow$ scalar wind speed at 100 m meters per second.

$v_{cut} - in = 3 \rightarrow$ wind speed where turbine starts generating.

$v_{rated} = 12 \rightarrow$ wind speed where turbine reaches maxed output.

$v_{cutout} = 25 \rightarrow$ wind speed where turbine shuts down for safety.

Function $f(v)$

$\rightarrow$ tells how much of rated power the turbine delivers, by wind speed.

Capacity_w $\rightarrow$ the nameplate capacity (maxed rated power in W).

Min function $\min(f(v), 1) \rightarrow$

ensures you never exceeds 100% of capacity.

(Source: Duport et al., 2018).

The formula was adjusted to best suit the assumptions of this study. It was assumed that the wind farm will consist of two turbines at 2MW capacity per turbine being 4MW of installed capacity. At wind speeds below 3 meters per second (m/s) the turbine blades won't be able to overcome inertia and therefore won't produce power, however, between 3 – 12 m/s power will begin to generate and by 12-25 m/s will be capped at the rated power of 4MW which is the plants max capacity. At wind speeds above 25 m/s the turbines will automatically shut down for safety capturing and storing all generated energy at that moment. The calculated result was therefore based on this formula and its assumptions. The result was input data for the calculations of LCOE for this project using the accounting model in excel.

Equation 2 Solar PV Power Formula

$$P_{solar}(t) = capacity_w \times clip\left(\frac{I(t)}{1000}, 0, 1\right)$$

$$I(t) = \frac{\Delta R(t)}{3600}, \Delta R(t) = R(t) - R(t - \Delta t)$$

Components:

$ssrd \rightarrow R(t) \rightarrow$ accumulated surface solar radiation $\left(\frac{J}{m^2}\right)$.

$\Delta R(t) \rightarrow$ increment per timestep $\left(\frac{J}{m^2}\right)$.

$3600 \rightarrow$ number of seconds in one hour,

$\rightarrow$ converts energy $\frac{J}{m^2}$ to average irradiance $\frac{W}{m^2}$.

$I(t) \rightarrow$ average solar irradiance during that hour $\left(\frac{W}{m^2}\right)$.

$1000 W/m^2$

$\rightarrow$ reference irradiance ("1sun"), the standard condition for PV rating.

$clip(..., 0, 1) \rightarrow$ ensures fraction stays between 0 and 1.

$capacit_W \rightarrow$ maximum rated output of solar farm (W).

(Source: Duffie et al., 2020, pp. 45–140).

The solar farm is assumed to be 3MW of installed capacity, the calculated result was based on the assumption that at 1000 watts per meters square (W/m^2) of irradiance the plant will be producing at its max rated output of 3MW, however, if the irradiance is around $500 W/m^2$ the plant will produce half its rated output etc, if in rare occasions it is greater than ($>$) $1000 W/m^2$ it will be capped at the max capacity of 3MW capturing and storing all power in that instant. The result was input data for the calculation of LCOE for this project using the accounting model in excel.

Equation 3 Wave Power Formula

$$P_{wave}(t) = \min(P_{available}(t), capacity_W)$$

$$P_{available}(t) = P'(t) \times capture_{width} \times \eta$$

$$P'(t) = \frac{p g^2 H_s(t)^2 T(t)}{32\pi}$$

Components:

$H_s = swh \rightarrow$ significant wave height(m).

$T = mwp \rightarrow$ mean wave period(s).

$p = 1025 \rightarrow$ seawater density kg/m^3 .

$g = 9.81 \rightarrow$ gravitational acceleration m/s^2

$P' \rightarrow$ wave power flux per meter of wave crest(W/m).

$capture_{width} 50\ m$

$\rightarrow$ effective width of wave energy converter (sum of wave front it interacts with.

$\eta = 0.35$

$\rightarrow$ capture efficiency (fraction of wave energy converted to electricity.)

$P_{available} \rightarrow$ electricity power available from the device(W).

$Capacity_W \rightarrow$ nameplate maxed rated output of the wave farm (W).

$\min(\dots) \rightarrow$ ensures device never outputs above its nameplate.

(Source: Dronkers, 2025).

The wave farm's total installed capacity was assumed to be 4MW. The formula calculates tall waves (H_s) and longer period waves (T) as carrying high energy with physical constants scaling the power correctly. Captured width and efficiency of 35% accounts for the actual device size and conversion losses, the result is capped at the plant's rated power of 4MW, all of which is input data for the calculation of LCOE for this project using the accounting model in excel.

Equation 4 Energy Conversion Formula

$$E(kWh) = \frac{P(W) \times T(hrs)}{1000}$$

Components:

P = Power in watts

T = 3600 seconds per hour

1000 = watts per kilowatt.

Results = kWh per timestep.

(Source: Inch Calculator, 2022).

After calculating available power for each farm, the output was converted the energy units of kWh using the energy conversion formula. The results were downloaded and analysed in excel. After the analysis, the results were filtered to the accounting model as input data for the LCOE calculations.

Accounting Model

To arrive at the LCOE this model was comprised of three formulas. The input data of computation was based on assumptions being project costs (CAPEX, OPEX & Decom), project capacity, project lifespan, and discount rate, all of which were extracted from the literature coupled with the projects' energy results from the mathematical model. Excel was the tool used to compute the results; the algorithm is as follows:

Equation 5 Capacity Factor Formula

$$Capacity\ Factor = \frac{Energy\ sent\ out\ (MWh)}{365(days) \times 24(hours) \times nameplate(MW)} \times 100\%$$

Components:

Energy sent out (MWh) – total energy produced during 2024 in MWh.

366 Days – total days of 2024 (Leap Year).

24 Hours – total hours in each day.

Nameplate (MW) – total capacity of each farm.

(Source: Australian Energy Regulator, 2020).

The capacity factors (CF) of each project were calculated since they are vital to the LCOE formula. It is used to allocate the associated costs of generation across each MWh of energy produced (Australian Energy Regulator, 2020). It is a percentage of the actual energy produced by a farm over a period (mostly a year) compared to the maximum capacity it can produce over that period. It impacts the denominator of the final step of the LCOE calculation.

Equation 6 Capital Recovery Factor

$$\text{Capital Recovery Factor: } CRF = \frac{r(1+r)^N}{(1+r)^N - 1}$$

Components:

r – Interest Rate.

N – Number of annuities.

(Source: NREL, 2025.)

To simplify the model of the LCOE and its calculations the CRF was added to the formula. It is the ratio of a constant annuity to the present value of recovering that annuity over a specific period (NREL, 2025).

Equation 7 LCOE Formula

$$LCOE = \frac{\sum_{t=0}^n \frac{C_t}{(1+r)^t}}{\sum_{t=0}^n \frac{E_t}{(1+r)^t}}$$

LCOE Components:

C_t – All costs (CAPEX, OPEX and Decommissioning) at year t .

E_t – Energy generation at year t .

r – Discount rate.

N – Project lifetime.

(Source: U.S Department of Energy, 2015).

LCOE Calculation Steps

$$\text{Compute Capital Recovery Factor: } CRF = \frac{r(1+r)N}{(1+r)N - 1}$$

CRF is used to annualized CAPEX and Decom into one annual payment that will be spread across the lifespan of the project, this is based on the discount rate.

$$\text{Compute PV of Decommissioning: } PV_{decom} = \frac{DecomN}{(1+r)N}$$

Because decommissioning is usually scheduled to be paid at the end of the project's life, it was calculated to take time value for money into account since what is worth today will be less in value in the future.

$$\text{Annualized CAPEX} + PV_{decom} = (CAPEX + PV_{decom}) \times CRF$$

After calculating the PV of Decom, it is added to the CAPEX and calculated by the CRF to become a series of equal annual payments over the lifespan of the projects.

$$\text{Annual cost} = \text{Annualised CAPEX with}_{decom} + \text{Annual OPEX}$$

Then the annualized cost is added to OPEX which is already a fixed yearly cost.

$$LCOE = \frac{\text{Annual Cost}}{\text{Annual Energy (MWh/yr)}}$$

Then divide the total sum, which is the annual cost, by the annual energy output, in this case MWh/yr to arrive at LCOE per farm.

Assumptions:

The formula will treat CAPEX as paid at year $t = 0$

Treat decommissioning cost (Decom) as paid at year $t = N$.

The LCOE is a critical determinant of this research, its outcome will in a great way shape the decision analysis and by extension, the final conclusions and recommendations of this study. It is a focal metric used to measure financial feasibility of RE projects, its systematic evaluation allows comparisons among RE sources, aiding stakeholders to make instructed decisions on RE investments (Morgan, 2024).

The formula was also adjusted to include decommissioning cost. According to Lerche et al., (2024) it is a cost that is omitted by most researchers and analysts. Decommissioning cost forms an important part of the calculation Yildiz et al. (2024). It gives a realistic total cost of the projects over their lifespan. All extracted financial data from the literature review *table 1* and the energy results from the mathematical model served as input data for the calculations.

Decision Analysis

The results of the mathematical and accounting models being the energy analysis and LCOE outcomes were further analysed by way of a scenario analysis and a comparative analysis. The purpose of the scenario analysis was to determine the sufficient capacity and energy needs of Guyana based on final investment costs and energy output. The comparative analysis was used to determine the best energy mix; the projects to be undertaken by Guyana based on LCOE.

Scenario Analysis

As a combined project the initial assumed capacity was 11MW and the calculated results were compared to Guyana's LCDS projected energy demands of 2025, 2030 & 2041. To extend the analysis and further assess the demands, adjustments were made

to the capacity in the Python scrip reducing initial capacity of 11MW to 7MW and 6MW being scenario 1 and 2 respectively, recalculating the power and energy which was compared to the LCDS projected demand periods also. The most favorable outcome was based on reduced cost and output meeting Guyana's energy demands and above, which influenced the decision of Guyana's energy demands and capacity needs. The energy results were presented as percentages and compared to the projected LCDS demands measuring excesses or deficits over each the periods of 2025, 2030 and 2041. The formula used was:

Equation 8 Energy Production by Percentage Formula

$\Sigma \text{ MWh Produced} / \text{Projected MWh} \times 100\%$.

Components:

ΣMWh – Total energy produced during 2024 for each case.

Projected MWh – Total energy projected, figure 4 of this study.

(Source: Author, 2025).

Comparative Analysis

Using the same adjustment criteria the comparative analysis was carried out on LCOE calculations after adjusting the key impacting variables of the formula.

- Installed Capacity – (MW) (nameplate) from 11MW to 7MW and 6MW which impacts the CAPEX & OPEX.
- Capacity Factor – (CF) which is automatically impacted by the change in installed capacity.
- Discount Rate – (r) which impacts the present values (PV) of CAPEX & Decommissioning costs ultimately affecting the LCOE outcome.

The various outcomes were compared side by side to measuring the performance of each farm from the LCOE perspective. The most favorable outcome informed the decision of best energy mix for Guyana.

Socioeconomic Impact Assessment

The SEIA was divided into three themes, Social, Economic and Environment with three subthemes each in the form of KPIs to measure the projects' sustainability.

The exercise was carried out to measure public awareness of RE, acceptance of RE as an alternative to conventional energy use, monthly utility expenditure, economic expectations, and environmental expectations. The simple Categorize, Quantify and Compare (CQC) framework was used to analyse the data.

- Categorize – the data was categorized by respondent type, citizens and businesses by region and further by theme and subthemes.
- Quantify – To quantify, percentages were calculated and displayed on two separate tables at below each theme, the sentiment coding from the survey questions were used (yes, no, maybe, somewhat etc.)
- Compare – the results were compared by category and region.

To add to the assessment, secondary data relevant to the themes were used from the literature as well as relevant financial results from the scenario and comparative analysis outcomes. Additionally, CO₂ abatement calculation was done to measure the environmental impact of the projects assuming the wind and solar plants at 4MW and 3MW respectively were in operation during the year 2024. This was compared to Guyana's 2024 emissions projection from the literature as a baseline.

Equation 9 CO₂ Abatement Formula

$$CO_2 \text{ Abatement} = Activity \times Emission \text{ Factor}$$

Components:

- Activity = Total MWh produced for year 2024. (HFO displacement).
- Emissions Factor = Emissions Factor equivalent for HFO burned at Electricity Plants.

(Source: Soares, 2025)

Input Data

- Wind Farm Energy Production Results.
- Solar Farm Energy Production Results.

Emissions Factor for wind and solar power generation activities in Guyana,
0.661tCO₂/MWh
(UNFCCC, 2019).

Chapter 4 Decision Analysis

4.1. Chater overview

This chapter covers the energy output results of each farm, and the cost of each project that was analysed and discussed in the various scenario cases. The LCOE calculation results of each project, and the comparative analysis discussion.

All with the aim of uncovering Guyana's energy potential, proposed energy capacity and proposed energy mix based on the most favorable outcomes. Equations one to four as defined in chapter three comprised the mathematical model used in Python. For the Python script and all calculations of the mathematical model see appendix 1, 2, 3, 4 and 5.

The results for each farm were downloaded from Python and further processed in excel. For fair and clear comparisons with the projected energy demands of Guyana, the results were converted from kWh to GWh and presented in appendix 6, 7 and 8.

Equations five to seven comprised the accounting model used in excel that calculated the LCOE results. See appendix 9, 10, and 11 for all calculations.

4.2. Scenario Analysis

Figure 7 displays the hourly power output for the first seven days of the farms and the daily energy output during the year 2024 at 11MW of installed capacity.

A deeper analysis was conducted on Guyana's energy demand to ascertain their monthly needs, and it was found that during 2025 it will be 208.33GWh, 2030 will be 541.67GWh and 2041 will be 1233.33GWh.

Based on the farms' production during 2024, demands of 2025, 2030 and 2041 would be met at installed capacity of 11MW but energy storage contingency must be in place

to cover low productions during Jun, Jul, Aug and Sept which had extremely low outputs from wind and wave.

Cases two at 7MW reviled the same results as case one, but case three at 6MW reviled that Guyana should commence scaling up in capacity during or after 2030 to meet 2041 demands since the projections were not met during the months of Jun, Jul and Aug. However, all cases showed strong yearly productions meeting the demands of all the periods.

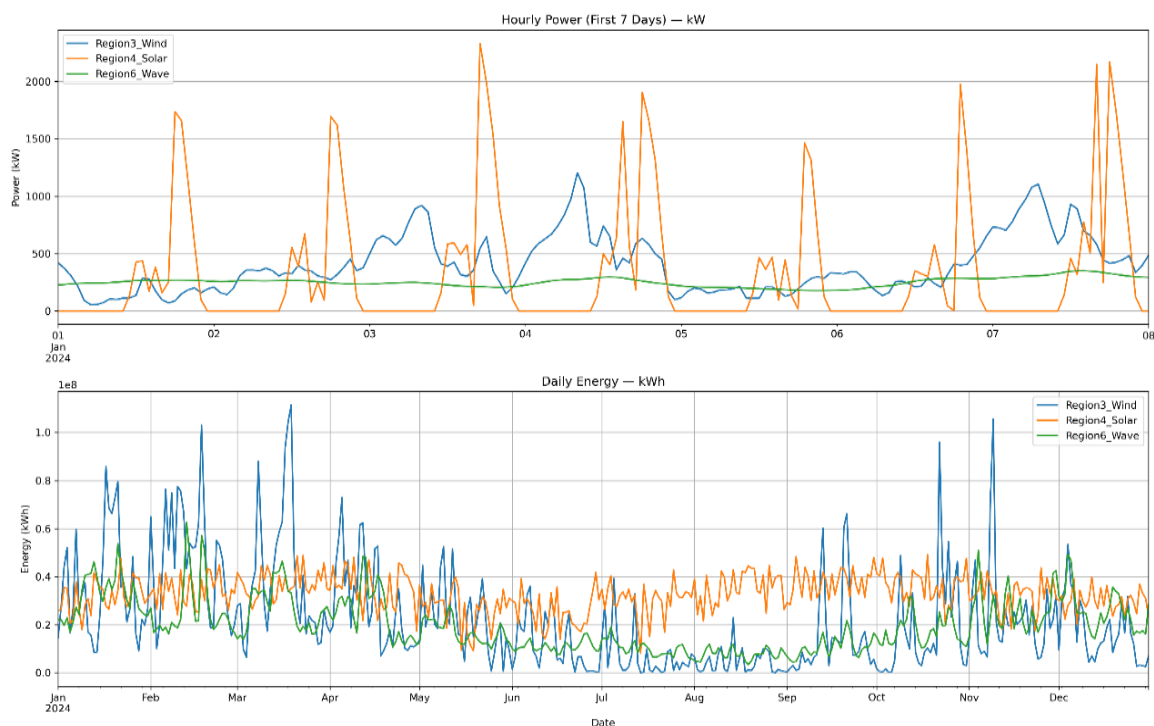


Figure 7 Energy Farms Results in kWh.

(Source: Created by Author using Python Software)

Based on table 2, the combined energy of the three farms would have met the projected electricity demands of the DBIS grid in excess of 1,098% for 2025, 422% for 2030 and 185% for 2041. The excess kept declining every period as the energy demands grew. However, even with the decline, by 2041, the surplus was substantial. In this case Guyana may not need to invest in 11MW of capacity for the short or mid-term

periods of 2025 and 2030 respectively but rather, lesser capacities and scale-up as the energy demands grow.

Table 2 Case One - Excess Energy - 11MW

GEA Projections by year	GEA Projected Energy Demand GWh	Energy Excess %	Energy Results Wind 4MW GWh	Energy Results Wave 4MW GWh	Energy Results Solar 3MW GWh	Combined Total Energy Results 11MW GWh
2025	2500	1,098%	8281.56	7221.39	11958.11	27461.07
2030	6500	422%	8281.56	7221.39	11958.11	27461.07
2041	14800	186%	8281.56	7221.39	11958.11	27461.07

(Source: Create by Author using Microsoft Word).

Table 3 displays the energy farms' output after adjusting the capacity being case 2 of the scenario analysis, it was found that even after the change in capacity for case 2, the wave energy output remained the same, this is because in the python program the available wave power subjects the energy captured to the waves produced during that season, and the wave technology's capacity was capped.

This means that no matter the capacity of the device, the output will not change unless the wave is strong enough to exceed the cap. During 2024, wave power available did not reach or exceeded 1MW, see appendix 7, the power available each month was below 1MW which was essentially the output, therefore even after changing the capacity, the output remained unchanged.

The capacity of each farm in this case was 2.5MW each for wind and solar and 2MW for wave. At the changed respective capacities, the other farms produced less being 5,175.97MWh for wind, 9,965.09MWh for solar and wave remained the same at 7,221.39MWh with wind producing less than wave in this case.

Base on table 3 the combined results in this case met and exceeded Guyana's demands for 2025, 2030 and 2041 at 894%, 344% and 151% respectively. This case confirms that Guyana may not need to invest in 11MW of installed capacity since at 7MW the excess output remained substantial at less investment costs.

Table 3 Case Two - Excess Energy at 7MW

GEA Projections by year	GEA Projected Energy Demand GWh	Energy Excess %	Energy Results Wind 2.5MW GWh	Energy Results Wave 2MW GWh	Energy Results Solar 2.5MW GWh	Combined Total Energy Results GWh 7MW
2025	2500	894%	5175.97	7221.39	9965.09	22362.46
2030	6500	344%	5175.97	7221.39	9965.09	22362.46
2041	14800	151%	5175.97	7221.39	9965.09	22362.46

(Source: Created by Author using Microsoft Word).

Table 4 displays energy output for the farms at 6MW of installed capacity being case three. Wind farm was 3MW, solar at 2MW and wave at 1MW, as previously explained, the wave output remained the same in this case while wind increased and solar decreased when compared to case two, yet solar remained the highest producer followed by wave then wind.

The farms produced a total of 21404.64MWh during 2024. Like the initial cases of 11MW and 7MW, the excesses were substantial at 856% for 2025, 329% for 2030 and 145% for 2041. When compared to the prior cases it can be proven that Guyana don't need to install 11MW or 7MW of renewable capacity in the mid or short-term periods of 2025 and 2030 but should commence scaling up in or just after 2030.

If wave which has the highest investment cost and LCOE as was proven later in the study was excluded from the energy mix, Wind and Solar's combined capacity at 5MW also met Guyana's energy demands of 2025, 2030 and 2041 at 15,141MWh

using case two results, proving that 6MW can also be reduced to 5MW, but should increase capacity before 2025.

Table 4 Case Three - Excess Energy at 6MW

GEA Projections by year	GEA Projected Energy Demand GWh	Energy Excess %	Energy Results Wind GWh 3MW	Energy Results Wave GWh 2MW	Energy Results Solar GWh 1MW	Combined Total Energy Results GWh 6MW
2025	2500	856%	6211.17	7221.39	7972.08	21404.64
2030	6500	329%	6211.17	7221.39	7972.08	21404.64
2041	14800	145%	6211.17	7221.39	7972.08	21404.64

(Source: Created by Author using Microsoft Excel & Word 2025).

Table 5 displays the investment cost of each farm at the various capacities in each case. The results had proven that at 11MW Guyana's energy demands were met exponentially, while the excess output was high the CAPEX, OPEX and decommissioning cost of US\$44.7M was steep compared to 7MW at US\$25.4M and 6MW at US\$17.5M which in both cases yielded exponential outcomes at reduced costs with 6MW capacity being the best outcome.

Table 5: Investment Costs per Capacity.

Component	Case	One	Case	Two	Case	Three
Capital Cost	US\$	MW	US\$	MW	US\$	MW
Wind	6.4M	4MW	4M	2.5M	4.8M	3MW
Solar	4.5M	3MW	3.7M	2.5MW	3M	2MW
Wave	29.2M	4MW	14.6M	2MW	7.3M	1MW
Upfront Costs	40.1M	11MW	22.3M	7MW	15.1M	6MW
OPEX						
Wind	128K		80K		96K	
Solar	67K		56K		45K	
Wave	2.3M		1.1M		584K	
Total OPEX	2.4M		1.2M		725K	
+Total Opex	42.6M		23.6M		15.8M	
Decommissioning						
Wind	300K		300K		300K	
Solar	1.1M		920K		736K	
Wave	730K		730K		730K	

Total Decom	2.1M		1.9M		1.7M	
+Total with Decom	44.7M		25.4M		17.5M	

(Source: Created by Author using Microsoft Word 2025).

4.3. Comparative Analysis LCOE of Case One., Two and Three.

Tables 6 displays the results of the LCOE calculations of the three cases respectively at 11MW, 7MW and 6MW. Equations five six and seven as outline in chapter 3 of this study were used to calculate and produce the results see appendix 9, 10 and 11.

Based on figure 8, studies have shown that LCOE for wind and solar had drastically declined to US\$0.034 & US\$0.043 per kWh respectively by 2024, no statistic was given for wave based on the report, however, the findings of this study shows that the LCOE are significantly low when compared to figure 8's findings. The outcomes were favourable falling in the ballpark figures displayed in one instant being wind at 11MW but relatively lower in the other instances.

Table 6: Comparative Analysis of Energy Farms' LCOE Results.

	Capacity	Wind	Solar	Wave
LCOE US\$/kWh	11MW	\$0.031	\$0.011	\$0.247
LCOE US\$/kWh	7MW	\$0.018	\$0.009	\$0.059
LCOE US\$/kWh	6MW	\$0.020	\$0.006	\$0.014

(Source: Created by Author using Microsoft Word, 2025).

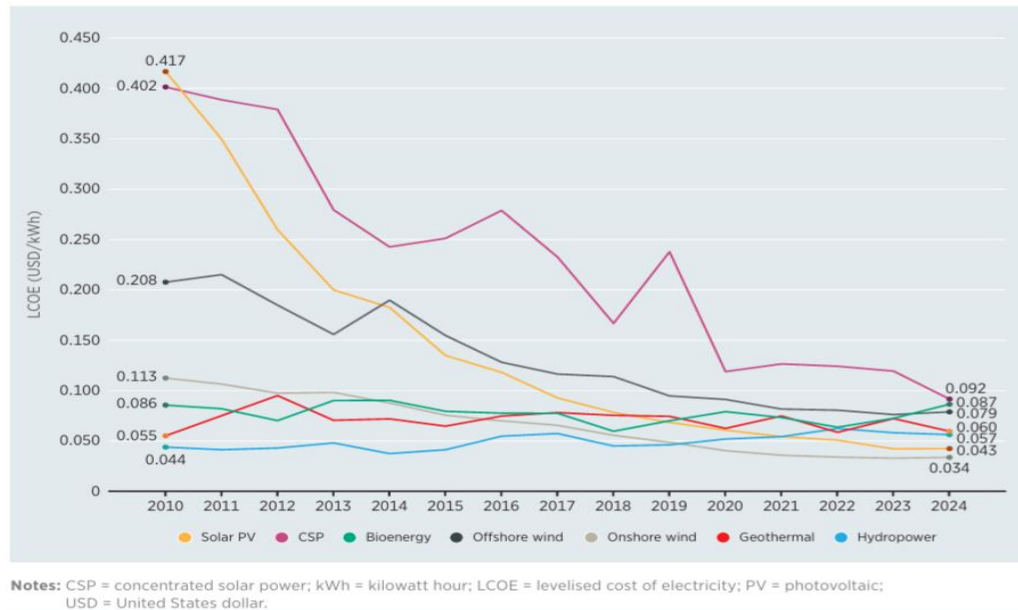


Figure 8 LCOE Decline over the period 2010-2024

(Source: IRENA, 2025)

The outcome is limited by the assumptions made; the CAPEX and OPEX involved, the discount rate, the capacity, other varying factors not considered in this study that influences investment costs and the output of each farm, nevertheless, this further proves that RE is on the decline becoming a worthwhile investments and alternative.

According to AleaSoft Energy Forecasting (2023), the largest decline in LCOE since 2010 have been on onshore wind energy and solar PV at 69% and 89% respectively, these reductions have driven the transition to 100% renewable systems.

When comparing the farms, the most favourable costs of producing renewable energy in all cases was, solar at US\$0.011, US\$0.009, & US\$0.006 per kWh, being the 4MW, 2.5MW & 2MW scenarios respectively, with case two and three having steady declines.

The wind farm's outcome was US\$0.031, US\$0.018 and US\$0.020 per kWh, being 4MW, 2.5MW & 3MW scenarios respectively, the increase in scenario 2 was because of increased capacity in that case.

The wave farm had outcomes of US\$0.247, US\$0.059 & US\$0.014 being 4MW, 2MW and 1MW respectively, there were vast differences in the scenario because in each case regardless of the change in capacity the farm produced the same energy, giving better outcomes in each case because production remained the same but investment costs reduced, yet the LCOE was the most expensive than the previous two, proving that the cost of extraction is still relatively higher than other renewable sources.

4.4. Conclusion

It was discovered that approximately US\$15.1M in upfront investment plus OPEX at US\$725K and Decommissioning at US\$1.7M being 6MW of installed capacity would be Guyana's proposed energy capacity needs for the implementation of the projects, such capacity can meet demands of 2025, and 2030 but increased capacity will be needed before 2041.

This it is relative to the weather volatility of the nation, providing it remains consistent or improves, accurate monitoring of the weather trends can predict future production and energy yields, thus, gaging when to scale up the capacity, and at the same time managing investment costs.

According to Yong (2025), 91% of utility-scale RE projects that were recently commissioned are producing power at minimized costs than those of the most affordable new fossil-based fuel alternatives.

Further, the comparative analysis results clearly indicated that Guyana should embrace wind and solar PV as the most favourable energy mix of the three based on the LCOE outcomes, which coincides with the government's energy mix plans. Wave energy

extraction costs are much higher than other sources and should not be consider as an energy source based on these findings, a cheaper source like hydro as planned by the government can be used.

During 2024 solar PV were at median 41% more inexpensive than the cheapest fossil-fuel alternatives while onshore wind was at 53%, onshore wind trended as the most economical source of RE at US\$0.034/kWh while solar PV was at US\$0.043/kWh (Yong, 2025).

Chapter 5 Socioeconomic Impact Assessment

This chapter examines the sustainability of the projects by assessing their socioeconomic impact on the society, economy and environment.

The results of the survey are displayed on the following figures. The survey comprised 17 questions with 15 being relevant to the themes, the link to the questions can be seen at appendix 12. The intended targets were citizens and businesses of regions 3, 4 & 6 primarily to gather social acceptance of RE as an alternative source of energy with the intent of commissioning an RE plant within the proposed regions respectively displayed on figure 9. The survey reached 293 participants but a total of 100 responded.

- Region 3 – 37 citizens and 0 businesses.
- Region 4 – 43 citizens and 3 businesses.
- Region 6 – 15 citizens and 2 businesses.

Figure 9 displays the proposed locations of the respective plants and the areas of assessment the survey was conducted.

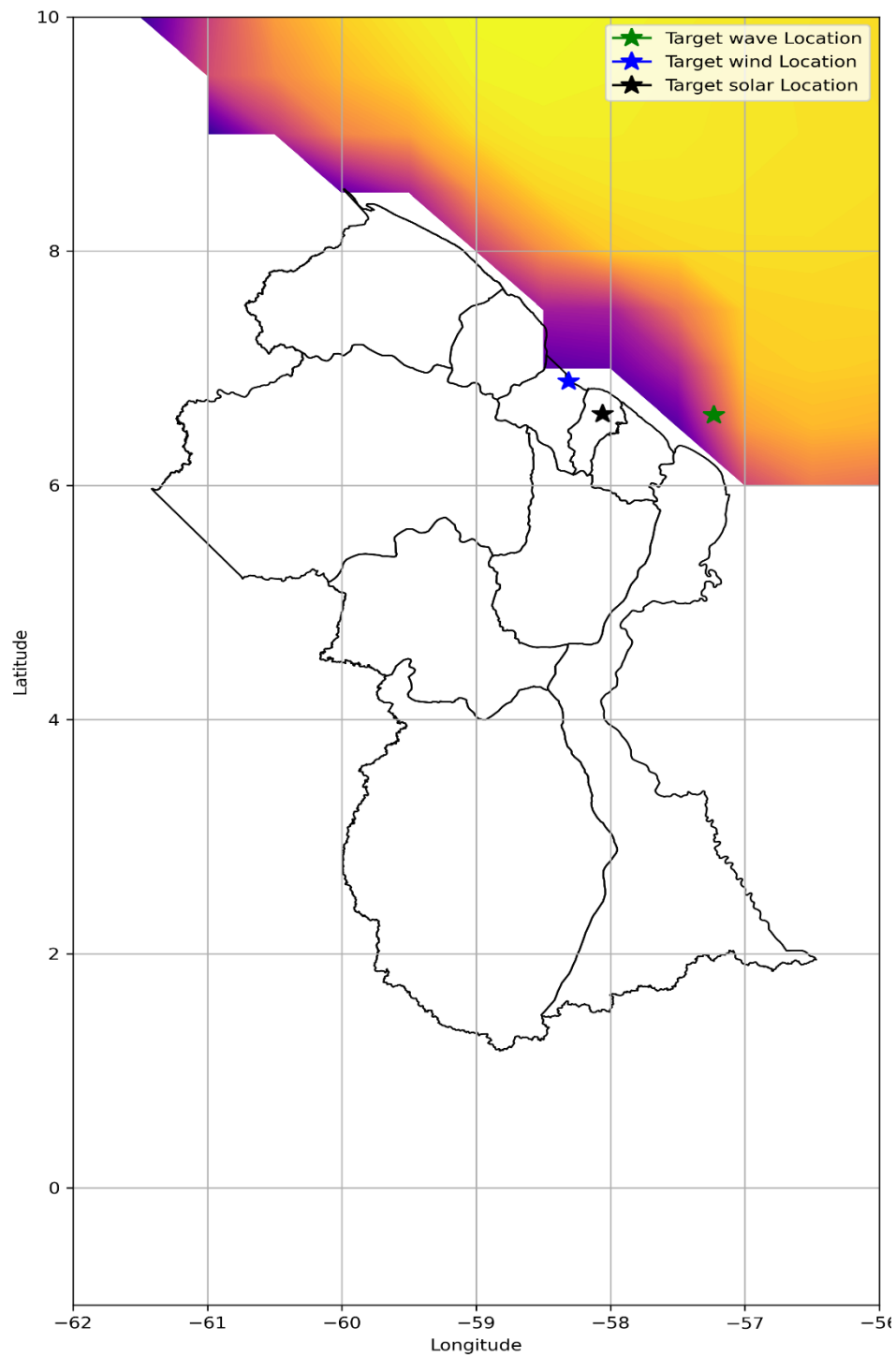


Figure 9 RE Plants' Locations & Areas of Assessment
 (Source: Created by Author using Python Software, 2025).

5.1. Social Impact

The results of displayed on each figure represents the responses by citizens and businesses in the regions outlined in the legions. Region three is blue, region four is orange and region six is green. The question number, responses and percentage of respondents are displayed on the graphs respectively.

These results reflect responses to the KPIs: energy accesses and equity, improved public services and community engagement.

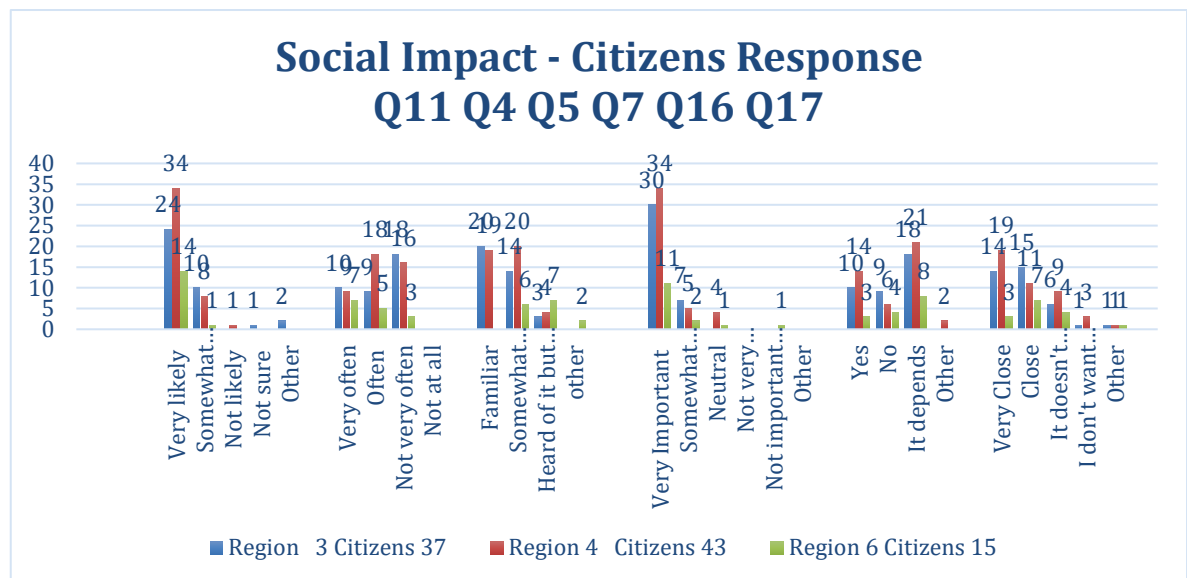


Figure 10 Social Impact Results - Citizens

(Source: Created by Author using Microsoft Excel, 2025).

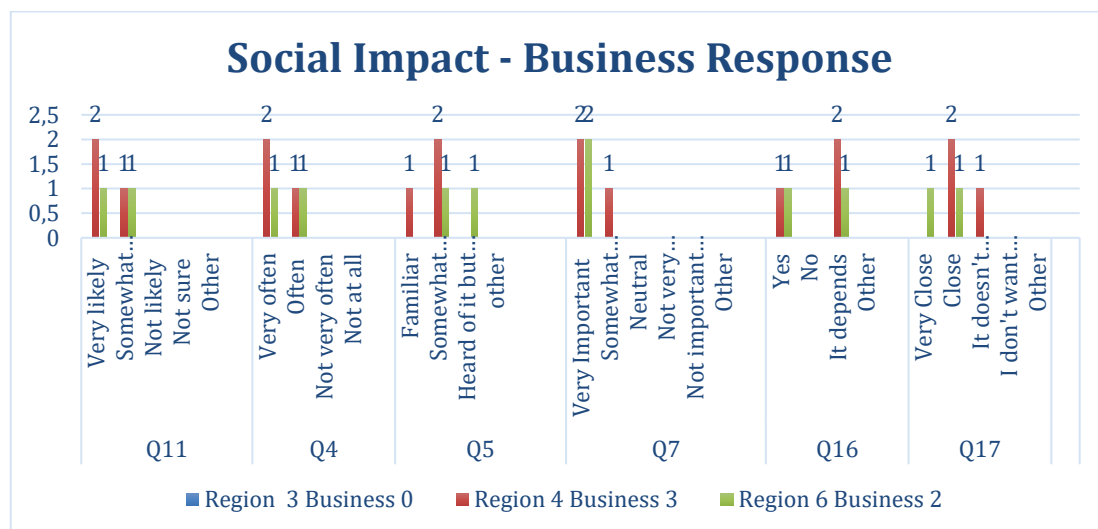


Figure 11 Social Impact Results - Businesses

(Source: Created by Author using Microsoft Excel, 2025).

Energy Access and Equity

To strengthen energy access, fiscal policies and incentives that foster consumer choice were launched where consumers and businesses can invest in and use RE through self-generation, consumers can interconnect their solar PV systems to the public grids and not rely on battery storage, grid feed-in mechanism; consumers are allowed to sell excess RE to the national grid, and fiscal incentives; imported renewable equipment are duty free and VAT exempted (Government of Guyana (GoG), 2022).

24 %, 34% and 14% of citizens in regions 3, 4 and 6 were likely and willing to install solar panels or support RE solutions in their homes, business or community if it became more affordable and available, while 10%, 8% and 1% from regions 3, 4 and 6 were somewhat likely to. 1% from region 3 was neutral, while 1% from region 4 was not willing. Of the five businesses that responded 2% and 1% in regions 4 and 6 were willing, while 1% out of both regions 4 and 6 where somewhat willing. This means that most citizens and businesses are either willing or considering RE as an alternative while a negligible percentage were either unaware of RE benefits or didn't see the need for the transition.

The coastal regions always had equitable access to energy but endured frequent blackouts and instability. The Hinterland regions that are external to the 12 public grids were unconnected for decades, approximately 218 Hinterland communities, a total of 98,500 residents were without electricity; transporting diesel would cost the government three times the cost it would in its capital Georgetown (Government of Guyana (GoG), 2024). With aid from the Government of India, 30,000 150-watt Solar Home Systems were installed during 2024, with the intent of electrifying all Hinterland villages by the interconnectedness of a larger solar PV and/or mini-hydro grid; it is estimated that the project will cost US\$313M and was scheduled for 2023-2028 (Government of Guyana (GoG), 2024).

Improved Public Services

Solar PV systems have seen much growth and implementation in Guyana adding to capacity and improving public services. Both businesses and residence will improve on cost savings financially impacting the economy.

Residents of the Hinterlands (unconnected) communities have been benefiting from the solar PV projects that were commissioned in 2024, youths were able to study and pursue their academic prospects at nights, and many families were able to complete household chores that were otherwise difficult without electricity (Department of Information 2025). Solar PV home energy systems (SHE) have increased installed capacity by 4.8MW across the 10 administrative regions benefitting above 245 communities being 136,863 residents, with 7,300 more systems being distributed as part of a nationwide expansion (Department of Information 2025).

Of the citizens that experienced power outages very often; 10%, 9% and 7% were from regions 3, 4 and 6 respectively, while 9%, 18%, and 5% from regions 3, 4 and 6 experienced outages often, with very often being two to three times a week and often being less than twice a week. In contrast, 18%, 16%, and 3% of citizens from regions 3, 4, and 6 respectively, do not experience outages very often. 2% of the businesses

from region 4 and 1% from region 6 experienced outages very often while 1% from both regions 4 and 6 experience outages often.

Despite RE projects and nation-wide initiatives, based on the statistics, the power outage problem is still prevalent, but seem to slowly be improving.

Region 3's power service is more stable than those of regions 4 and 6. The same cannot be said for the businesses of regions 4 & 6 who seem to experience outages very often/often. The fiscal policies for independent power generation would be a great RE investment for both businesses and citizens to secure personal energy security.

Community Engagement

When executing energy projects in rural communities that operate a non-market economy, challenges surface for both engineers and policy-makers, the top-down approach of electrification presents economic, technical and environmental issues, therefore, to mitigate or avoid those roadblocks, a bottom-up approach involving the communities' participation is recommended, it provides rational, from the base-up decision making from rural residents, engineers and policy-makers, creating an integrated, multi dimension model that fits social and community development from the technical, environmental and economic aspects (Blair et al., 2019).

In 2009 the Guyana and Norway governments would have initiated LCDS to champion conservation of the rainforests to reduce GHG emissions which was a growing concern, at the time of this study it was found that there was a shortage of adequate dialogue and consultation between the government and the rural communities; the author further found that there was no inclusion of the indigenous groups in the initial drafting of the bi-lateral agreement between Norway and Guyana (Airey and Krause 2017).

Nevertheless, based on the literature, many renewable projects were established within the rural communities would have been implemented with their involvement.

The same must be done for the three regions under consideration as stakeholder buy-in, in this case the community, is critical to the implementation and success of any project.

20%, and 19% and in regions 3 and 4 are familiar with RE. 14%, 20% and 2% from regions 3, 4 and 6 respectively report being somewhat familiar. Among those who heard of RE but are unaware of its meaning, 3% are from region 3, 4% from region 4 and 7% are from region 6. For businesses, 1% from region 4 is familiar while 2% and 1% from regions 4 and 6 respectively are somewhat familiar. 1% from region 6 has heard of RE but don't know what it means.

Based on the statistics for both businesses and citizens the majority are either aware or somewhat aware of RE while those that are ignorant are negligible, but this does not mean they were engaged about RE implementation within their communities.

In fact, 14%, 18% and 3% of citizens from regions 3, 4 & 6 respectively claimed they would feel very close to the projects if engaged as stakeholders, another 15%, 11% and 2% in regions 3, 4 and 6 respectively expressed similar sentiments by claiming they would feel close to the projects if engaged while 6%, 9% and 4% from regions 3, 4 & 6 expressed it doesn't matter. 1% and 3% from region 3 and 4 don't want to be engaged. With respect to the businesses, 1% from region 6 claimed they would feel very close while 2% and 1% from regions 4 & 6 respectively claimed they would feel close and a final 1% from region 4 didn't care about engagement. Based on these statistics as well, most citizens and businesses would be vested once engaged.

This is because 30%, 34% and 11% of citizens from regions 3, 4 & 6 respectively agrees that the development of RE for Guyana's future is very important. In regions 3, 4, and 6, 7%, 5%, and 2% respectively consider it somewhat important. Additionally,

4% in region 4, and 1% in region 6 are neutral, while 1% in region 6 do not find it important. 2% of the businesses in both regions 4 and 6 expressed sentiments of very important while 1% from region 4 see it as somewhat important.

In some instances, while communities may buy-in to the prospects of the projects, there is the issue of displacement, especially for small businesses along the coast of Guyana, the establishment of small stalls with tents along the coast which are tourist attractions and recreational spaces is a common practice. 1% of businesses in both regions 4 and 6 agree with relocating to accommodate RE projects while 2% & 1% in the same regions will negotiate. 10%, 14% and 3% of the citizens in regions 3, 4 and 6 respectively agreed to relocate while 9%, 6% and 4% respectively, said no. 18%, 21% and 8% from regions 3, 4 & 6 will negotiate. One participating citizen said as long they are paid a fair market price for their home or business they will accommodate the move, while another will comply if adequate compensation and housing are provided.

According to Sustainability Directory (2025), community engagement plays a material role in RE development's success, roadblocks and potential delays are avoided, trust and transparency is built, and it's understood that project development is not just about the equipment, but people and the communities to which they belong.

5.2. Economic Impact

The results in this section reflect responses to the KPIs: green jobs, economic diversification and electricity cost reduction.

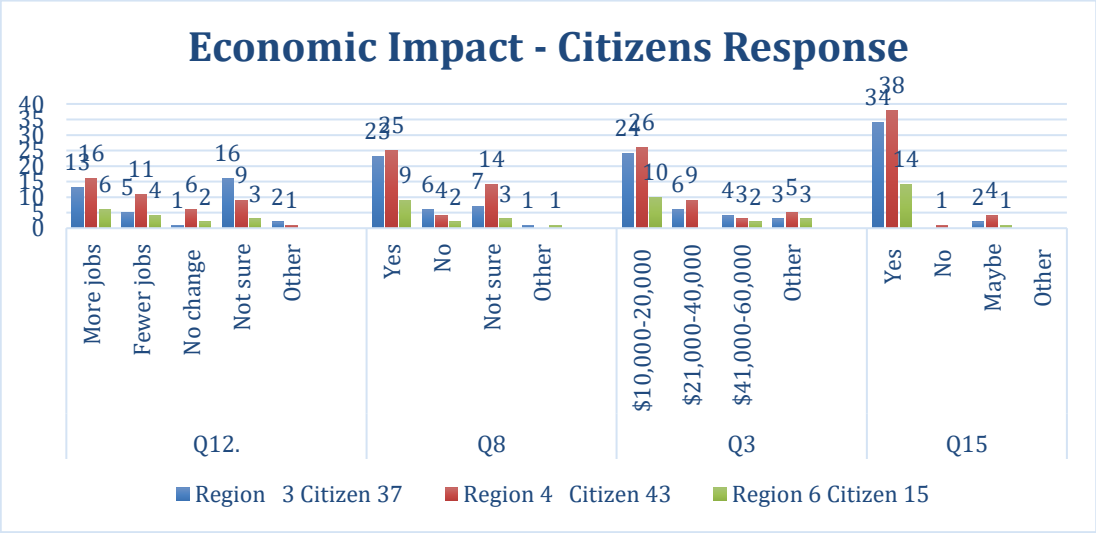


Figure 12 Economic Impact Results – Citizens

(Source: Created by Author using Microsoft Excel, 2025).

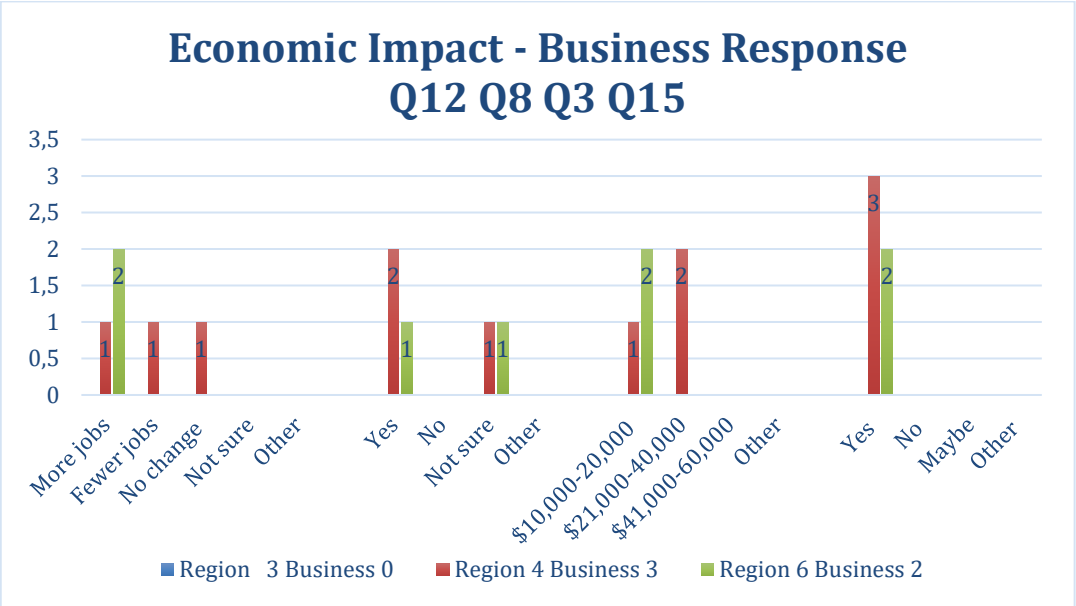


Figure 13 Economic Impact Results – Businesses

(Source: Created by Author using Microsoft Excel, 2025).

Green Job Creation

The Guyana/Norway Government embarked on a project called GUY SOL, distributing 23MW in solar PV plants across the country while training 50 women for solar PV jobs and workforce development with a paid 8-month apprenticeship program in RE, which includes 20 men inclusive of those with disabilities (GPL, 2024).

Additionally, according to the Department of Public Information (2025), more than 70K sustainable jobs were created with 30K of those jobs being in the construction industry particularly due to the distribution of house lots. Consequently, the energy industry was impacted as a direct result of new homes. The energy sector was poised on hiring 1,101 employees equipped with the skillset for green jobs (ILO 2017).

Citizens in regions 3, 4 and 6 being 13%, 16% and 6% respectively are positive that RE will create new jobs while in contrast, 5%, 11% and 4% respectively are in the negative. No change is expected by 1%, 6% and 2% in regions 3, 4, and 6 respectively, while 16%, 9% and 3% respectively are unsure.

The businesses in regions 4 at 1% each expects new jobs, less jobs and no change while those in region 6 at 2% expects new jobs.

A participant from region 4 expects no change in the sense that some jobs would become obsolete while new jobs were created balancing each other out, however, two others from region 3 expects more jobs allowing those in the traditional energy sector to be upskilled and reskilled in RE while the other mentioned the need for skilled technicians to manage the new technology, hence upskilling and reskilling.

Economic Diversification

Countries that experience an economic boom particularly in the oil and gas sector or any highly sought after resource tend to rely on that sector for economic development and neglect the development of other critical sectors, in this context citizens' feedback

on if they would personally support government investment in RE projects even if it required increased taxes or reallocation of funds were found to be, 23%, 25% and 9% in regions 3, 4 & 6 respectively responded in the positive. 6%, 4% and 2% respectively responded in the negative while 7%, 14% and 3% respectively were not sure. 2% and 1% of businesses in regions 4 & 6 respectively were positive responses while 1% from both regions were not sure.

One citizen out of region 6 said yes but there are enough funds to not increase taxes since Guyana is experiencing rapid economic growth due to the oil and gas industry. Implying that oil export revenues can be used to develop RE infrastructure etc. Another response from region 3 was, increased taxes would add financial burdens on its citizens and businesses and the reallocation of funds must be done with much consideration not affecting the health or education sectors.

Sectors that saw improvements because of diverse investments were the infrastructure, education, health, housing and tourism industries (DPI, 2025). With the commissioning of new buildings and facilities, direct impact was made on the energy sector increasing the capacity need for electricity and by extension the increased need for RE investments.

The GUY SOL project is an investment of US\$83.3M aimed at Guyana's energy mix diversification (GPL, 2024). A research by (Lam, 2024) found that through the theory 'the portfolio approach' having a diversified energy mix aids in decreasing the dangers linked with singular reliance on one energy source, in cases where there is an increase in the price of one source, then the other sources can counterbalance the price volatility; and 'the demand approach' implies that energy demands can be receptive to market indicators.

Electricity Cost Reduction

Transition to RE is expected to offer reductions in electricity charges especially as the associated technologies mature and become competitive on the market. Of the citizens in regions 3, 4 and 6, 24%, 26% and 10% respectively spends between US\$47-US\$95 on electric utility per month, 6%, & 9% of regions 3 and 4 spends between US\$100-US\$191, 4%, 3% and 2% in regions 3, 4 and 6 respectively spends US\$196-US\$287 while 3%, 5% and 2% from regions 3, 4 and 6 spends US\$24-US\$43. Another citizen from region 6 spends as much as US\$1,914. In respect of businesses in regions 4 and 6 respectively 1% and 2% spends US\$47-US\$95 while 2% from region 4 spends US\$100-US\$191.

In this light, 34%, 38% and 14% of citizens in regions 3, 4 & 6 are expecting these charges to reduce with the integration of RE. 1% from region 4 expects no reduction while 2%, 4% and 1% reported there maybe reductions. 3% and 2% of businesses in regions 4 and 6 expects reductions.

Currently, electricity charges per kWh in Guyana is US\$0.23 for residential services, US\$0.28 commercial services and US\$0.25 for industrial services, however, these charges were projected to be reduced by 50% at the beginning of 2025 with the integration of a 300 MW Natural Gas plant that was set to offer 80% of the grids' energy needs at US\$0.5 per kWh, significantly reducing generation costs of US\$85 per barrel of HFO (GPL, 2023b).

Coupled with RE the charges would reduce significantly as less reliance will be on imported HFO. When considering the two chosen energy sources, based on the LCOE results of this study the solar was US\$0.011, US\$0.009, & US\$0.006 per kWh, being the 4MW, 2.5MW and 2MW scenarios respectively, the wind farm's outcome was US\$0.031, US\$0.018 and US\$0.020 per kWh, being 4MW, 2.5MW & 3MW scenarios respectively.

While LCOE is not an end user charge, it represents the minimum charge to breakeven over the life of the plants. According to Nagy et al., (2013) lowered electricity costs contributes to real income rise. Household purchasing power increases which encourages consumer spending. Cost savings creates incentivized investments in other modernized technologies that continues the scaling up of renewable transitions.

5.3. Environmental Impact

In this section, the results reflect responses to the KPIs: environmental trade-offs, biodiversity impacts and CO² abatement.

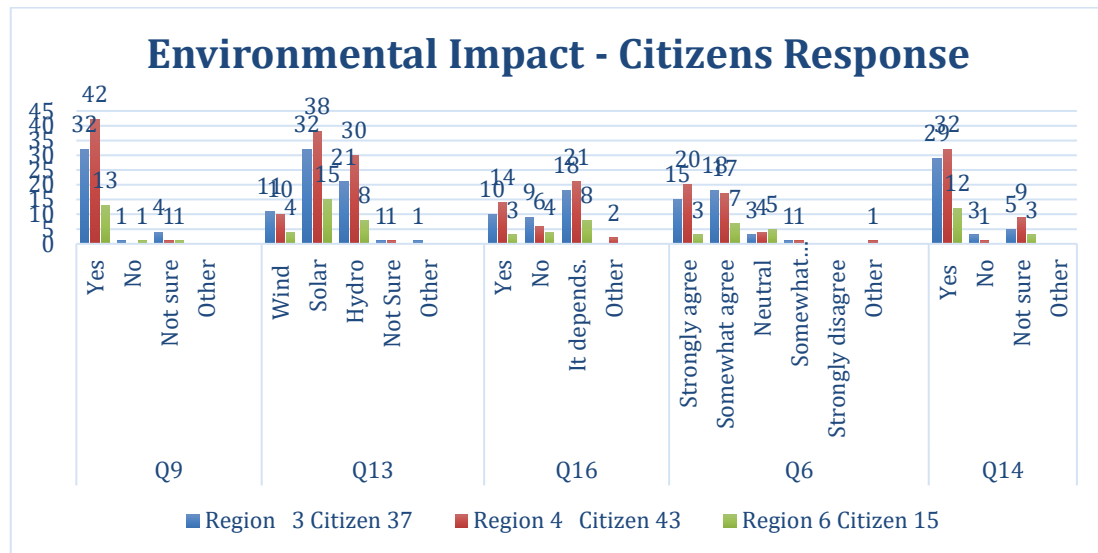


Figure 14 Environmental Impact Results – Citizens

(Source: Created by Author using Microsoft Excel, 2025).

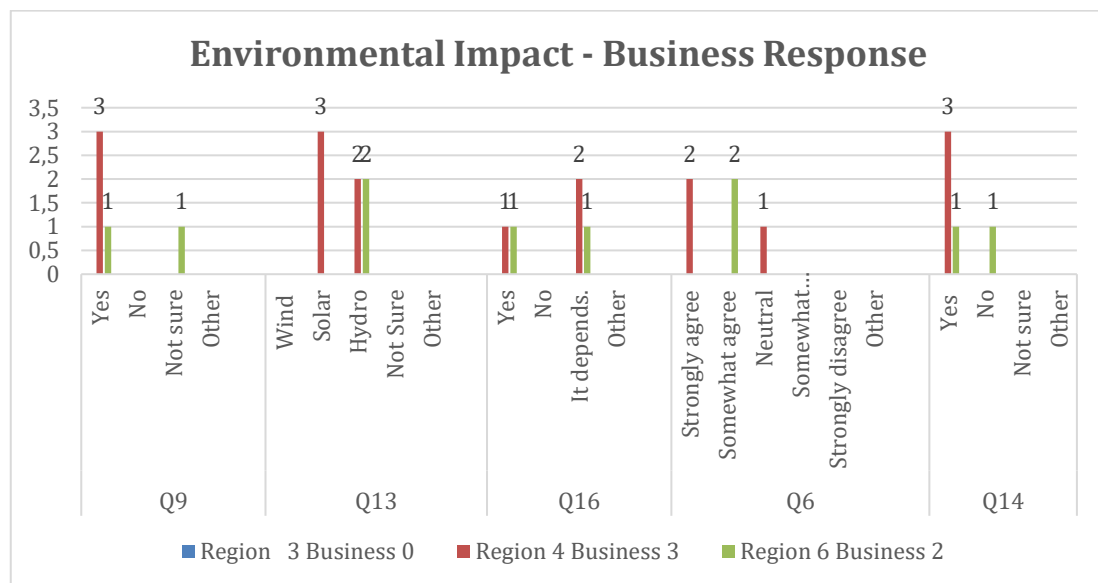


Figure 15 Environmental Impact Results – Businesses

(Source: Created by Author using Microsoft Excel, 2025).

Environmental Trade-offs

Considering solar PV and Wind technologies, these sources will require extensive land mass, a limited resource impacting Sustainable Development Goals such as ecosystem protection and or food production. (Maimó-Far et al., 2024).

According to Anna-Kaisa Kosenius and Markku Ollikainen (2013), RE has varying effects in their social and environmental impacts, therefore, to design an effective RE policy, the trade among the alternative sources must be assessed by societies.

In this context, 32%, 42%, and 13% of citizens from regions 3, 4 and 6 respectively, are positive that transitioning to RE will benefit the environment, 1% from regions 3 and 6 are in the negative while 4%, and 1% from regions 3, 4 & 6 respectively are not sure. 3% and 1% of businesses from regions 4 and 6 are positive about RE transitions while 1 from region 6 is not sure.

While the societal feedback is mostly positive, there are a few cons to consider in this study; the coastal regions in which the RE projects were proposed to be installed are densely populated with 90% of the nation's citizens, therefore, land in those regions is a scarce resource; the region and location of choice for the solar PV farm are farm lands which threatens the livelihood of farmers and by extension the nation's food security; the location of choice for the onshore turbines is the coastline, while this region is not used for farming, it may be an area of recreation for local communities and tourists, restricting recreational activity will not only impact the locals and businesses but by extension, the tourism industry.

Nevertheless, 11% 10% and 4% of citizens from regions 3, 4 & 6 respectively found wind to be the most suitable energy source for Guyana's natural environment. 32%, 38% and 15% from regions 3, 4 and 6 respectively chose solar PV, 21% 30% and 8% from regions 3, 4 and 6 chose hydro. 3% of businesses from region 4 chose solar while

2% from regions 4 and 6 chose hydro. Consideration for wave was not given at the time of the survey's circulation.

The trade-offs require environmental justice in that RE projects like wind or solar can immensely affect certain communities, to ensure the disbursement of equitable benefits and burdens, their engagement and involvement in the decision-making process is vital (Sustainability Directory, 2025).

Marine Biodiversity

Wave energy and offshore wind farms are usually the most threatening RE projects to marine biodiversity, however, for this study, consideration was not given for offshore wind farms, but was given for wave energy, even though it will not be a recommended source of Guyana's energy mix, its environmental impacts are strongly associated with marine biodiversity.

According to Ramírez, (2020.) the oscillating water column (OWC) wave energy converter (WEC) face challenges such as effects on marine life, changes in sediment transport, and the need for durable materials, uncertainty about their environmental impacts-spanning design, construction, operation and decommissioning remains key barriers to broader adaptation, they may also affect coastal ecosystems and generate noise pollution.

WECs are usually situated in unstable and complex environments, it is difficult to conduct reliable ecological research on impacts, numerous species are supported with conservation or commercial value, as studies on WEC effects are scarce, establishing a stronger framework for assessing impact is needed (Harte, 2021).

According to Ascobans, (2016), animal behaviour can change near collection devices (WECs), which may attract or repel them; underwater noise from these devices also

affects species, anthropogenic sound can both endanger animals and help prevent strikes by alerting them to device presence.

WECs alter habitats by disrupting hydrodynamic and ecosystem interactions with collisions posing the greatest risks, though pollution and other effects remain concerns, it is noted that many risks to marine life are not well understood and calls for research on wave energy effects on cetaceans and porpoises throughout the project's life span, robust tracking and monitoring of impacts on habitat and animal population are need (Ascobans, 2016).

Effective monitoring allows for timely mitigation, while modelling helps predict the likelihood of strikes, comprehensive environmental impact assessment and marine spatial planning are essential for balancing ocean energy use with conversion efforts (Ascobans, 2016).

Since the recommended RE projects will only be solar PV and onshore wind, the marine biodiversity of Guyana will not be under threat unless wave is considered later in the government plan, currently it's not part of their LCDS.

CO₂ Abatement

Renewable energy sources are essential for a sustainable energy transition and play a crucial role in addressing climate change, the Paris Agreement (2015) aims to limit global temperatures increases to 1.5°C above preindustrial levels, requiring CO₂ to reach net zero by 2050 (Kateryna Morozovska et al., 2024).

In this context, citizens feedback regarding Guyana's potential reduction of reliance on fossil fuels for energy indicated responses of 15%, 20% and 3% from regions 3, 4 and 6 who strongly agreed. 18%, 17% and 7% from the respective regions somewhat agreed while 3%, 4% and 5% were neutral. 1% from regions 3 and 4 somewhat disagreed. Another citizen from region 4 said if the objective is to reduce Guyana's

national consumption, they agree. However, as Guyana is currently experiencing an oil boom, they do not support reducing mining activities unless an alternative approach that is both safe and economically viable is introduced. 2% and 1% of businesses in region agreed and neutral respectively, while 2% in region 6 somewhat agreed.

Further feedback on if Guyana should implement a policy aimed at phasing out fossil fuel in favour of renewable energy over the next 10-20 years found that 29%, 32% and 12% of citizens in regions 3, 4 and 6 respectively, agreed while 3% and 1% from regions 3 & 4 disagreed and 5%, 9% and 3% in regions 3, 4 and 6 respectively, are not sure. 3% and 1% of businesses from regions 3 and 4 respectively agreed while 1% from region 6 disagreed.

Additionally, the wind and solar energy farms' results recorded potential CO₂ abatement as follow:

Tabel 11 displays the GHG emissions and possible abatement after the integration of RE and natural gas in MWh/Yr Guyana's DBIS and isolated grids.

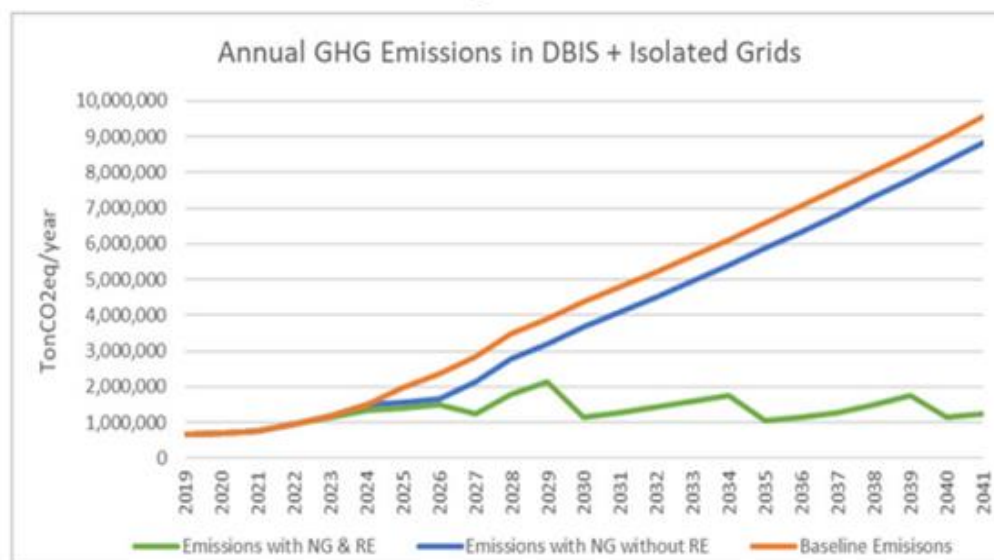


Figure 16: Annual GHG Emissions in DBIS + Isolated Grids

Table 7: CO₂ Abatement Calculations.

Components	Energy Production X Emissions Factor	CO ₂ Abatement Results in MWh/Yr
Wind Production MWh/Yr	8.2M MWh/Yr	
Solar Production MWh/Yr	+ 11.9M MWh/Yr	
Total Production W+S	20.2M MWh/Yr	
Emissions Factor of Solar and Wind Projects/Guyana	X 0.661MWh/Yr	
Results		13.3M tCO ₂ /MWh/Yr

(Source: Created by Author using Microsoft Word, 2025).

The result indicated that without the integration of natural gas and with the use of RE being wind and solar only at 7MW combined capacity, Guyana has the potential of abating CO₂ emissions of 13.3MtCO₂ MWh/Yr, surpassing 2041 levels by 3.3M when compared to the governments projections. Note, this calculation does not include life cycle assessment emissions of the farms which are usually negligible.

5.4. Conclusion

Social – RE is socially accepted by most of the citizens, 72% are likely to install solar PV in their homes to be self-sufficient and improve public service since 58% experience power outages often and very often. 75% find RE transition to be very important for Guyana and 69% are willing to be engaged as stakeholders who will feel very close to the projects. Engagement is important since 40% are somewhat familiar with RE, and 39% are familiar, however in case of displacement 47% are willing to negotiate before moving their homes or businesses.

Economic – of the citizens, 60% expends US\$47-US\$95, 15% US\$100-US\$191, 12% US\$196-US\$287 and 10% US\$24-US\$43, 3% of businesses US\$47-US\$95 and 2% US\$100-US\$191. 86% of the citizens are expecting reductions of these charges, 1% expects no change and 7% expressed it might be possible. While all 5% of businesses are expecting reductions.

According to the literature, the government had announced the reduction of electric utility by half, but this is after the integration of natural gas, not RE. With the integration of RE along side natural gas, further reduction in electricity charges is expected.

Environmental – Most citizens somewhat agreed with less reliance of fossil fuel at 42%, 38% agrees, 12% are neutral and 1% disagrees while 2% of businesses strongly and somewhat agree and 1% is neutral, this is likely because Guyana is still in her transition phase and RE is still a new concept in the nation because 73% of citizens will support a fossil fuel phase out policy over the next 10-20 years 17% is not sure and 4% disagrees. While 4% of businesses agrees and 1% disagrees. CO² abatement potential is 13.3MtCO₂ MWh/Yr, surpassing 2041 levels by 3.3M when compared to the government's projections.

Chapter 6 Conclusion and Recommendations

6.1. Conclusion

Climate change to date remains a major global issue and a topic of priority on most government's agenda. To abate its effects decarbonization strategies were implemented by nations around the world to tackle its root cause and that is excessive CO² atmospheric emissions. This study investigated the nation of Guyana; a Small Island Developing State (SIDS) to discover its decarbonization strategy and its potential of harnessing renewable energy with the possibility of transforming its energy sector from conventional fossil-fuel generation to renewable energy generation.

To conduct the research six key questions were asked; does Guyana have a decarbonization strategy? What is their energy demand? What is the CAPEX, OPEX and Decommissioning costs of solar, wind and wave projects? How will the implantation of the projects impact the social, economic and environment of the nation? What is the required renewable capacity for Guyana? And what is the best energy mix for Guyana?

To answer those questions, a systematic literature review was done to gather secondary empirical data on Guyana's strategy, potential cost of the projects and energy demand which answered questions 1, 2 & 3. To answer questions 4, 5 and 6, energy potential data was downloaded from the Copernicus website to calculate Guyana's energy potential of each project, and two electronic survey was circulated to gather primary data on the social, economic and environmental aspects of the study, but only one survey was answered. The data was processed by way of renewable energy calculations, a cost analysis, a decision analysis and a socioeconomic impact assessment.

The key findings were while the Guyana's decarbonization strategy (LCDS) is not designed to achieve complete carbon neutrality, its main objective is to replace reliance

on heavy fuel oil (HFO), Guyana's primary energy source, with low-carbon alternatives through a phased approach, with full integration projected between 2025 and 2041 with the intent of reducing and keeping CO₂ emissions at 2018 levels, their planned energy mix is solar, wind, hydro, bioenergy and natural gas.

The results indicate that solar energy offers substantial potential for Guyana with a projected production of 11.9K GWh/Yr based on tests conducted; solar has been the first RE source implemented in the nation. Wind energy indicated a potential production of 8.2K GWh/Yr, however, wind projects are yet to be commissioned. Wave energy's production was the lowest at 7.2K GWh/Yr but has the potential to produce more should the plant be stationed further offshore.

The decision analysis had two parts, a scenario analysis and a comparative analysis. The scenario analysis results proved that 6MW of installed capacity of wind and solar only at US\$8.9M inclusive of decommissioning was enough to meet Guyana's energy demands in the most cost-effective way for 2025 to 2030.

The comparative analysis revealed that wind and solar carried the lowest and least production cost per unit respectively at LCOE US\$0.018/kWh and US\$0.009kWh concluding the decision of best sources of RE out of the three to be included in the energy mix which coincided with Guyana's current energy mix.

These outcomes, however, were limited by assumptions made on investment costs, capacity needs and the formulas in the mathematical and accounting models used to analyse the data and therefore does not reflect the most accurate results when compared to published empirical findings. Yet they reflect a likely possibility of Guyana's RE potential in each regard.

To conclude the research, the sustainability of the projects was tested by way of a socioeconomic impact assessment (SEIA) to measure the projects impact on the society, economy and environment.

Socially, the findings proved that the society has a fair understanding of RE and are willing to accept transitional changes yet lack awareness. Most of both citizens and businesses would like to be engaged as stakeholders when plans are being implemented for RE, the sentiments of closeness were expressed.

Economically, the cost of electricity is poised on being cut in half during 2025 with the integration of natural gas, further research indicated that with the integration of RE as well electricity charges will further reduce creating costs savings in businesses and households.

Environmentally, the environmental trade-off dynamic revealed should citizens or businesses face displacement to accommodate RE projects, a fair amount are willing to change location but the majority indicated that they will negotiate, their decision will be based on adequate compensation from the investors, a limitation on the results of this study was land use, water use and materials used per project was not assessed since a life cycle assessment was not done.

6.2. Recommendations

The findings indicate potential sustainability prospects of the projects; Guyana should continue to pursue their plans and implement their strategy within their timelines.

Adequate monitoring of their energy demands should be conducted to accurately gauge and determine their capacity needs to not over and under invest.

Surplus energy can either be stored, resold or reallocated to other critical sectors like Maritime and necessary energy intensive processes, for example:

- Since the power plants were proposed for the coastal cities, the excesses can be sold to ports desirous of going green but are not in the financial position to do so independently.
- Build new port facilities that are green adopting the landlord model.
- Invest in bunkering facilities using wind and solar energy during the electrolysis process to create alternative fuels, becoming a first mover in the region and adding to the global supply chain.
- Supply power to ports at a subsidized cost who will in turn offer OPS services to vessels capable of receiving renewable power.

Further, store the excess in storage devices to ensure there is backup supply of power to cater to deficits since supply of energy from wind, and solar etc are heavily dependent on seasonal variations.

Invest in charging stations that will encourage the uptake of electric vehicles addressing the decarbonisation of the road transport industry.

Draft policies that encourage new home and business owners to design their spaces to facilitate RE.

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Appendices

```
import subprocess
import sys

# -----
# Ensure required libraries are installed
# -----
required = ["numpy", "pandas", "matplotlib", "netCDF4"]
for pkg in required:
    try:
        __import__(pkg)
    except ImportError:
        subprocess.check_call([sys.executable, "-m", "pip", "install", pkg])

import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
from netCDF4 import Dataset, num2date

# =====
# Utility-scale power from uploaded NetCDF datasets (Jan-Dec 2024)
# =====

SITES = {
    "Region3_Wind": {"lat": 6.887, "lon": -58.3098, "capacity_W": 4_000_000},
    "Region4_Solar": {"lat": 6.6112, "lon": -58.058, "capacity_W": 3_000_000},
    "Region6_Wave": {"lat": 6.6, "lon": -57.23, "capacity_W": 4_000_000},
}

# Physics constants
RHO_WATER = 1025
G = 9.81

# Wind turbine parameters
CUT_IN, RATED, CUT_OUT = 3.0, 12.0, 25.0

# Wave farm parameters
CAPTURE_WIDTH_M = 50.0
WAVE EFFICIENCY = 0.35

# -----
# Helper: Load netCDF variable at nearest point (with debug)
# -----
def load_point_from_nc(path, varnames, lat, lon):
    ds = Dataset(path)
    print(f"\n--- Variables in {path} ---")
    print(list(ds.variables.keys()))

    lats = ds.variables['latitude'][:]
    lons = ds.variables['longitude'][:]
    if lons.max() > 180:
        lons = np.where(lons > 180, lons - 360, lons)
    i_lat = np.abs(lats - lat).argmin()
    i_lon = np.abs(lons - lon).argmin()

    # Handle time variable safely
    if 'valid_time' in ds.variables:
        time_var = ds.variables['valid_time']
    elif 'time' in ds.variables:
        time_var = ds.variables['time']
    else:
        raise KeyError("No time coordinate found in dataset")

    time_units = time_var.units
    time_calendar = getattr(time_var, 'calendar', 'standard')
    times = num2date(time_var[:], units=time_units, calendar=time_calendar)
    # Convert CFTIME objects safely to pandas datetime64
    times = pd.to_datetime([pd.Timestamp(t.isoformat()) for t in times])

    data = {}
    for v in varnames:
        if v not in ds.variables:
            print(f"Warning: Variable '{v}' not found in {path}. Skipping.")
            continue
```

(Appendix 1: Code of Wind, Solar and Wave Power & Energy Calculation.)

```

data = {}
for v in varnames:
    if v not in ds.variables:
        print(f"Warning: Variable '{v}' not found in {path}. Skipping.")
        continue
    arr = ds.variables[v][:]
    if arr.ndim == 3:
        data[v] = arr[:, i_lat, i_lon]
    elif arr.ndim == 2:
        data[v] = arr[:, i_lon]
    else:
        data[v] = arr[:]
ds.close()

return pd.DataFrame(data, index=times) if data else None

# -----
# Power calculation functions
# -----
def wind_power(u100, v100, capacity_W):
    v = np.sqrt(u100**2 + v100**2)
    frac = np.where(v < CUT_IN, 0.0,
                    np.where(v >= CUT_OUT, 0.0,
                             np.where(v <= RATED, ((v - CUT_IN)/(RATED - CUT_IN))**3, 1.0)))
    return np.minimum(frac, 1.0) * capacity_W

def solar_power(ssrd_accum, capacity_W):
    inc = np.diff(ssrd_accum, prepend=ssrd_accum[0])
    inc = np.where(inc < 0, ssrd_accum, inc)
    irr = inc / 3600.0
    frac = np.clip(irr / 1000.0, 0.0, 1.0)
    return frac * capacity_W

def wave_power(swh, mwp, capacity_W):
    P_per_m = (RHO_WATER * (G**2) * (swh**2) * mwp) / (32 * 3.142)
    P_available = P_per_m * CAPTURE_WIDTH_M * WAVE EFFICIENCY
    return np.minimum(P_available, capacity_W)

# -----
# 1) Load site-specific data and compute hourly power
# -----
PATH_WIND = "C:/data_stream-oper_stepType-instant.nc"
PATH_SOLAR = "C:/data_stream-oper_stepType-accum.nc"
PATH_WAVE = "C:/data_stream-wave_stepType-instant.nc"

site_hourly = {}

wind_df = load_point_from_nc(PATH_WIND, ["u100", "v100"], SITES["Region3_Wind"]["lat"], SITES["Region3_Wind"]["lon"])
if wind_df is not None:
    site_hourly["Region3_Wind"] = pd.DataFrame({"Power_W": wind_power(wind_df["u100"], wind_df["v100"], SITES["Region3_Wind"]["capacity_W"] )}, index=wind_df.index)

solar_df = load_point_from_nc(PATH_SOLAR, ["ssrd"], SITES["Region4_Solar"]["lat"], SITES["Region4_Solar"]["lon"])
if solar_df is not None:
    site_hourly["Region4_Solar"] = pd.DataFrame({"Power_W": solar_power(solar_df["ssrd"].values, SITES["Region4_Solar"]["capacity_W"] )}, index=solar_df.index)

wave_df = load_point_from_nc(PATH_WAVE, ["swh", "mwp"], SITES["Region6_Wave"]["lat"], SITES["Region6_Wave"]["lon"])
if wave_df is not None:
    site_hourly["Region6_Wave"] = pd.DataFrame({"Power_W": wave_power(wave_df["swh"], wave_df["mwp"], SITES["Region6_Wave"]["capacity_W"] )}, index=wave_df.index)

# -----
# 2) Combine hourly and daily energy
# -----
if site_hourly:
    combined_hourly = pd.concat([v["Power_W"] for k, v in site_hourly.items()], axis=1)
    combined_hourly_kwh = combined_hourly * (3600.0/1000.0)
    daily_energy_kwh = combined_hourly_kwh.resample("D").sum()
    totals_kwh = combined_hourly_kwh.sum(axis=0)

    combined_hourly.to_csv("C:/Users/Admin/OneDrive/Desktop/hourly_power_W.csv", index_label="timestamp")
    daily_energy_kwh.to_csv("C:/Users/Admin/OneDrive/Desktop/daily_energy_kwh.csv", index_label="date")

```

(Appendix 1: Code of Wind, Solar and Wave Power & Energy Calculation.
Continued.)

```

with open("C:/Users/Admin/OneDrive/Desktop/energy_results.txt", "w") as f:
    f.write("=== Available Power & Energy from Aug-Dec 2024 (from uploaded datasets) ===\n")
    for site, total in totals_kwh.items():
        f.write(f"{site}: {total:.2f} kWh\n")
    f.write("\nProject coordinates (Guyana):\n")
    for name, cfg in SITES.items():
        f.write(f"{name}: lat={cfg['lat']}, lon={cfg['lon']}, capacity_W={cfg['capacity_W']}\n")

print("Saved files: 'hourly_power_W.csv', 'daily_energy_kwh.csv', 'energy_results.txt'")

plt.figure(figsize=(16, 10))
sample = slice(combined_hourly.index.min(), combined_hourly.index.min() + pd.Timedelta(days=7))
ax1 = plt.subplot(2, 1, 1)
(combined_hourly.loc[sample] / 1000.0).plot(ax=ax1)
ax1.set_title("Hourly Power (First 7 Days) - kW")
ax1.set_xlabel("")
ax1.set_ylabel("Power (kW)")
ax1.grid(True)

ax2 = plt.subplot(2, 1, 2)
(daily_energy_kwh).plot(ax=ax2)
ax2.set_title("Daily Energy - kWh")
ax2.set_xlabel("Date")
ax2.set_ylabel("Energy (kWh)")
ax2.grid(True)

plt.tight_layout()
plt.savefig('C:/Users/Admin/OneDrive/Desktop/Energy_graph.png', dpi=300)
plt.show()

else:
    print("No site could be processed. Please check variable names printed above.")

```

(Appendix 1: Code of Wind, Solar and Wave Power & Energy Calculation Continued.)

Using equation 1 explained in chapter three of this study the following steps were carried out:

1. Calculate wind speed (v)

The input data of (u_{100}) and (v_{100}) provided the eastward and northward wind components at 100m height.

The total wind speed magnitude was calculated using the Pythagorean theorem: $v = \sqrt{u^2 + v^2}$.

2. Apply turbine power curve (calculate frac) which is the piecewise function that modelled a turbine's real-world behaviour.

Cut-in speed ($\text{Cut_IN} = 3.0 \text{ m/s}$), below this speed there is not enough force to overcome friction and start the turbine, which is defined by: if $v < \text{Cut_IN}$: $\text{frac} = 0.0$

Cut-out speed ($\text{Cut_OUT} = 25.0 \text{ m/s}$), above this speed, the turbine automatically shuts down to prevent damage which is defined by: if $v \geq \text{Cut_OUT}$: $\text{frac} = 0.0$

Rated Power ($\text{Rated} = 12.0 \text{ m/s}$): Between the cut-in and rated speed the power output rapidly increases, this is in proportion to the cube of the wind speed ($P \propto v^3$) this was modelled in the script with a cubic curve normalised between 0 and 1.

Defined by: if $v \leq \text{rated}$: $\text{frac} = ((v - \text{Cut_IN}) / (\text{Rated} - \text{Cut_IN}))^{**} 3$

Rated Power Level: Between the rated speed and the cut-out speed, the turbine's system of control (like blade pitching) maintains a consistent power output to protect the generator which is defined by: else: $\text{frac} = 1.0$.

3. Calculate Electrical power output: the output fraction (frac) is multiplied by the turbine's nameplate (capacity_W) (4,000,000 W) to arrive at the final power in watts for the wind farm in region 3, which was defined by: $\text{Power_W} = \text{frac} * \text{capacity_W}$.

The result was a time series of power output in watts for the wind farm, based on the hourly wind data from Copernicus.

(Appendix 2: Wind Power Calculation)

Using equation 2 explained in chapter three of this study the following steps were carried out:

1. The input data was ssrd (Surface Solar Radiation Downwards) as an accumulated field. This implies that the value of each time step is the total energy (Joules per m²) accumulated from the beginning of the forecast.

To identify energy that arrived in hour prior, the difference was taken from between consecutive steps defined by: `inc = np.diff(ssrd_accum, prepend=ssrd_accum[0])` which converted Joules per metre square (J/m²) to J/m² per hour.

2. Covert to irradiance (irr): irradiance is power per unit area (watts per m²) since 1 watt is = 1 Joule per second, Joules was converted per hour to watts per m² by dividing by the number of seconds in an hour which was defined by: `irr (W/m2) = inc (J/m2) / 3600.0s`

3. Calculate Power Fraction (frac): solar panels gave a ‘Standard Test Condition’ (STC) rating of 1000 W/m² which is the irradiance level at which their nameplate capacity is produced.

The maximized power of the fraction is simply the actual irradiance divided by 1000 W/m² defined by: `np.clip` which is the function in the script that ensures the fraction stays between 0 (night) and 1 (radiant sun at or above STC) defined by: `frac = irr / 1000.0`.

4. Calculate Electric Power output: the output fraction is multiplied by the farm’s capacity (3,000,000 watts) defined by: `Power_W = frac * capacity_W` to arrive at the final power in watts for the solar farm in region 4, based on hourly solar irradiance data from Copernicus.

(Appendix 3: Wind Power Calculation)

Using equation 3 explained in chapter three of this study the following steps were carried out:

1. Calculate Wave Power Fluctuation ($P_{\text{per_m}}$): this is the standard formula used to compute the theoretical power per meter of wave crest for deep-water waves and was derived from $(\rho * g^2 * H^2 * T) / (32\pi)$.

2. Calculate Device Power Capture (Available Power) define by: $P_{\text{available}}$: in reality, a device cannot capture all the power in the waves, at this step estimates are made of how much power the device may capture.

$P_{\text{available}} = P_{\text{per_m}} * \text{Capture_Width} * \text{Efficiency}$ being:

Capture width = 50.0m which is a key concept used in wave energy, it's an effective width that represents how much of the wave front the device can extract energy from, it is swept analogous to the area of a wind turbine rotor.

Wave Efficiency = 0.35 being a reasonable estimate for wave energy converter technology that accounts for conversion losses from mechanical energy to electricity.

3. Cap at device capacity: after arriving at the result being power available ($P_{\text{available}}$) in watts (W) using time series data downloaded from Copernicus, it was capped at 4,000,000W defined by the function: (np. minimum) .

(Appendix 4: Wave Power Calculation)

Using equation 4 found in chapter three the following calculation was made:

1. Convert hourly power to hourly energy: Power in watts (W) * Time (s).

$$\text{Energy (Joules)} = \text{Power_W} * 3600\text{s}$$

Since energy is commonly measured in kWh which is 1,000 watts * 3600s (3,600,000 Joules) the conversion was done directly for each farms output.

$\text{Energy_kWh} = (\text{Power_W} * 3600) / 1000$ or $\text{Power_W} * 3.6$ which was used for the entire data frame defined by: $\text{combine_hourly_kWh} = \text{combined_hourly} * 3.6$.

2. Calculate daily energy:

The `resample("D").sum()` method is an effective pandas operation that grouped the hourly energy data (combined hourly kWh into daily bins from (00:00 to 23:59).

All the hourly energy values are then summed into each daily bin.

The result is then presented as total energy produced each day, in kWh.

With overall result being a daily time series of production in kWh for each site and the combine system as displayed on figure 7.

(Appendix 5: Daily and Hourly Power to Energy Calculation)

Date	Region3_Wind GWh	Region4_Solar GWh	Region6_Wave GWh	Combined Monthly Total 2024 GWh
Jan-24	1,095.39	983.10	991.42	3,069.91
Feb-24	1,388.09	994.06	768.55	3,150.69
Mar-24	1,223.21	1,151.03	842.58	3,216.82
Apr-24	881.44	1,056.02	761.57	2,699.03
May-24	693.96	832.12	528.18	2,054.26
Jun-24	348.89	763.15	328.49	1,440.53
Jul-24	226.00	933.06	315.45	1,474.51
Aug-24	139.36	1,098.44	240.17	1,477.98
Sep-24	454.16	1,128.00	317.10	1,899.26
Oct-24	568.17	1,130.83	542.32	2,241.32
Nov-24	727.21	964.57	784.75	2,476.52
Dec-24	535.68	923.74	800.81	2,260.23
TOTAL	8,281.56	11,958.11	7,221.39	27,461.07

(Appendix 6: Energys Farm Results Case One – 11MW)

Case Two	2.5MW	2.5MW	2MW	7MW
Date	Region3_Wind GWh	Region4_Solar GWh	Region6_Wave GWh	Combined Monthly Total 2024 GWh
Jan-24	684.62	819.25	991.42	2,495.29
Feb-24	867.56	828.38	768.55	2,464.48
Mar-24	764.51	959.19	842.58	2,566.28
Apr-24	550.90	880.02	761.57	2,192.48
May-24	433.72	693.43	528.18	1,655.34
Jun-24	218.05	635.96	328.49	1,182.50
Jul-24	141.25	777.55	315.45	1,234.25
Aug-24	87.10	915.36	240.17	1,242.64
Sep-24	283.85	940.00	317.10	1,540.95
Oct-24	355.11	942.36	542.32	1,839.79
Nov-24	454.50	803.81	784.75	2,043.06
Dec-24	334.80	769.78	800.81	1,905.40
TOTAL	5,175.97	9,965.09	7,221.39	22,362.46

(Appendix 7: Energy Farms Results Case Two – 7MW)

Case Three	3MW	2MW	1MW	6MW
Date	Region3_Wind GWh	Region4_Solar GWh	Region6_Wave GWh	Combined Monthly Total 2024 GWh
Jan-24	821.55	655.40	991.42	2,468.37
Feb-24	1,041.07	662.70	768.55	2,472.32
Mar-24	917.41	767.35	842.58	2,527.34
Apr-24	661.08	704.01	761.57	2,126.66
May-24	520.47	554.75	528.18	1,603.39
Jun-24	261.66	508.77	328.49	1,098.92
Jul-24	169.50	622.04	315.45	1,106.99
Aug-24	104.52	732.29	240.17	1,076.99
Sep-24	340.62	752.00	317.10	1,409.72
Oct-24	426.13	753.89	542.32	1,722.34
Nov-24	545.40	643.04	784.75	1,973.20
Dec-24	401.76	615.83	800.81	1,818.40
TOTAL	6,211.17	7,972.08	7,221.39	21,404.64

(Appendix 8: Energys Farm Results Case Three – 6MW)

LCOE Input Data Case 1 - 11MW			
Costs US\$	Wind	Solar	Wave
CAPEX	6,400,000.00	4,500,000.00	29,200,000.00
OPEX	128,000.00	67,500.00	2,336,000.00
Decommissioning	300,000.00	1,104,000.00	730,000.00
Capacity (nameplate rating)	4MW	3MW	4MW
Project Lifespan	25yr	25yr	25yr
Assumed Discount Rate	8%	8%	8%
MWh/yr 2024 Output	8,281,557.34	11,958,113.46	7,221,394.90
Capacity Factors of RE Farms			
Formula Components	Wind	Solar	Wave
MWh/yr	8,281,557.34	11,958,113.46	7,221,394.90
Days	366	366	366
Hours	24	24	24
Capacity (nameplate rating MW)	4	3	4
x100%	100	100	100
	35,136	26,352	35,136
Capacity Factor MWh/yr %	23,570	45,378	20,553
LCOE			
Formula components	Wind	Solar	Wave
Compute Capital Recovery Factor at 8%			
$r(1+r)^n /$	1.0800	1.0800	1.0800
$(1+r)^n - 1$	6.8485	6.8485	6.8485
	0.5479	0.5479	0.5479
	5.8485	5.8485	5.8485
CRF	0.0937	0.0937	0.0937
Compute Present Value of Decommissioning			
Decom $n /$	300,000.00	1,104,000.00	730,000.00
$(1+r)^n$	6.8485	6.8485	6.8485
PV Decom	43,805.37	161,203.77	106,593.07
Annualized CAPEX + Present Value Decommissioning x CRF			
CAPEX	6,400,000.00	4,500,000.00	29,200,000.00

PV Decom	43,805.37	161,203.77	106,593.07
CAPEX + PV Decom	6,443,805.37	4,661,203.77	29,306,593.07
x CRF	0.09	0.09	0.09
Annualized CAPEX including PV Decom/yr	603,647.82	436,655.88	2,745,405.86
Annualized CAPEX + Decommissioning + OPEX			
Annualized CAPEX + PV Decommissioning/yr	603,647.82	436,655.88	2,745,405.86
+OPEX	128,000.00	67,500.00	2,336,000.00
Total Annual Cost	731,647.82	504,155.88	5,081,405.86
LCOE = Annual Cost/Annual Energy (MWh/yr)			
Annual Cost	731,647.82	504,155.88	5,081,405.86
Capacity Factor MWh/yr 2024	23,570.01	45,378.39	20,552.69
LCOE US\$/MWh	\$ 31.04148	\$ 11.11	\$ 247.24
LCOE US\$/kWh	\$ 0.031	\$ 0.011	\$ 0.247

(Appendix 9: LCOE Calculation Case One – 11MW)

LCOE Input Data Case 2 - 7MW			
Costs US\$	Wind	Solar	Wave
CAPEX	4,000,000.00	3,750,000.00	14,600,000.00
OPEX	80,000.00	56,250.00	1,168,000.00
Decommissioning	300,000.00	920,000.00	730,000.00
Capacity (nameplate rating)	2.5MW	2.5MW	2MW
Project Lifespan	25yr	25yr	25yr
Assumed Discount Rate	7%	7%	7%
MWh/yr 2024 Output	5,175,973.34	9,965,094.55	7,221,394.90
Capacity Factors of RE Farms			
Formula components	Wind	Solar	Wave
MWh/yr	5,175,973.34	9,965,094.55	7,221,394.90
Days	366	366	366
Hours	24	24	24
Capacity (nameplate rating MW)	2.5	2.5	2
x100%	100	100	100
	21,960	21,960	17,568
Capacity Factor MWh/yr	23,570	45,378	41,105
LCOE			
Formula components	Wind	Solar	Wave
Compute Capital Recovery Factor at 6%			
$r(1+r)^n /$	1.0700	1.0700	1.0700
$(1+r)^n - 1$	5.4274	5.4274	5.4274
	0.3799	0.3799	0.3799
	4.4274	4.4274	4.4274
CRF	0.0858	0.0858	0.0858
Compute Present Value of Decommissioning			
Decom $n /$	300,000.00	920,000.00	730,000.00

(1+r) ⁿ	5.4274	5.4274	5.4274
PV Decom	55,274.75	169,509.24	134,501.90
Annualized CAPEX + Present Value Decommissioning			
CAPEX	4,000,000.00	3,750,000.00	14,600,000.00
PV Decom	55,274.75	169,509.24	134,501.90
CAPEX + PV Decom	4,055,274.75	3,919,509.24	14,734,501.90
x CRF	0.0858	0.0858	0.0858
Annualized CAPEX including PV Decom/yr	347,985.22	336,335.12	1,264,375.23
Annualized CAPEX + Decommissioning + OPEX			
Annualized CAPEX + PV Decommissioning/yr	347,985.22	336,335.12	1,264,375.23
OPEX	80,000.00	56,250.00	1,168,000.00
Total Annual Cost	427,985.22	392,585.12	2,432,375.23
LCOE = Annual Cost/Annual Energy (MWh/yr)			
Annual Cost	427,985.22	392,585.12	2,432,375.23
Capacity Factor MWh/yr 2024	23,570.01	45,378.39	41,105.39
LCOE US\$/MWh	\$ 18.16	\$ 8.65	\$ 59.17
LCOE US\$/kWh	\$ 0.018	\$ 0.009	\$ 0.059

(Appendix 10: LCOE Calculation Case Two – 7MW)

LCOE Input Data			
Costs US\$	Wind	Solar	Wave
CAPEX	4,800,000.00	3,000,000.00	7,300,000.00
OPEX	96,000.00	45,000.00	584,000.00
Decommissioning	300,000.00	736,000.00	730,000.00
Capacity (nameplate rating)	3MW	2MW	1MW
Project Lifespan	25yr	25yr	25yr
Assumed Discount Rate	6%	6%	6%
MWh/yr 2024 Output	6,211,168.01	7,972,075.64	7,221,394.90
Capacity Factors of RE Farms			
Formula components	Wind	Solar	Wave
MWh/yr	6,211,168.01	7,972,075.64	7,221,394.90
Days	366	366	366
Hours	24	24	24
Capacity (nameplate rating MW)	3	2	1
x100%	100	100	100
	26,352	17,568	8,784
Capacity Factor MWh/yr	23,570	45,378	82,211
LCOE			
Formula components	Wind	Solar	Wave
Compute Capital Recovery Factor at 6%			
$r(1+r)^n /$	1.0600	1.0600	1.0600
$(1+r)^n - 1$	4.2919	4.2919	4.2919
	0.2575	0.2575	0.2575
	3.2919	3.2919	3.2919
CRF	0.0782	0.0782	0.0782
Compute Present Value of Decommissioning			
Decom $n /$	300,000.00	736,000.00	730,000.00
$(1+r)^n$	4.2919	4.2919	4.2919
PV Decom	69,899.59	171,486.99	170,089.00

Annualized CAPEX + Present Value Decommissioning			
CAPEX	4,800,000.00	3,000,000.00	7,300,000.00
PV Decom	69,899.59	171,486.99	170,089.00
CAPEX + PV Decom	4,869,899.59	3,171,486.99	7,470,089.00
x CRF	0.0782	0.0782	0.0782
Annualized CAPEX including PV Decom/yr	380,956.26	248,095.02	584,360.55
Annualized CAPEX + Decommissioning + OPEX			
Annualized CAPEX + PV Decommissioning/yr	380,956.26	248,095.02	584,360.55
OPEX	96,000.00	45,000.00	584,000.00
Total Annual Cost	476,956.26	293,095.02	1,168,360.55
LCOE = Annual Cost/Annual Energy (MWh/yr)			
Annual Cost	476,956.26	293,095.02	1,168,360.55
Capacity Factor MWh/yr 2024	23,570.01	45,378.39	82,210.78
LCOE US\$/MWh	\$ 20.24	\$ 6.46	\$ 14.21
LCOE US\$/kWh	\$ 0.020	\$ 0.006	\$ 0.014

(Appendix 11: LCOE Calculation Case Three – 6MW)

<https://marvishoppie.aidaform.com/energy-transition-guyana>
(Appendix 12: Link to Electronic Survey Questions).